Preparing Simplified 3D Scenes of Multiple LODs of Buildings in Urban Areas Based on a Raster Approach and Information Theory

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Abstract We have developed a method for the simplification of the footprints of 2D buildings based on a rasterisation process. The rasterisation is processed within quarters and the urban area is subdivided into quarters based on natural contours such as roads and water objects and not on straight geometric lines (the common subdivision approach to orthogonal tiles). Quarters were organised into a hierarchical model, according to the gaps between the quarters and the stages of the clustering process, using Kohonen's self-organising maps. Each degree of simplification (generalisation) corresponds to some level of hierarchy. Information theory was used to estimate the amount of the 2D generalisation of building footprints. Simplified building footprints were extruded for the compilation of a 3D urban perspective from multiple levels of detail (LODs) The entropies of 3D scenes for each quarter of the hierarchy and each LOD were compared in order to define the level of detail to be used in the final 3D scene.

1 Introduction

The prevalence of computer devices (especially smartphones and tablet computers) and the latest achievements in software, enable us to use 3D maps almost everywhere. The two most common problems to arise in any discipline are that: (1) huge computer resources are required for drawing 3D models based on the original, non-simplified models, and (2) 3D models based on the original non-simplified objects are very detailed and often appear unreadable and overly complex. Some method for the simplification of models has to be applied to resolve both problems. The simplification of urban area maps is an extremely complex topic, mainly because of the variety and complexity of building models. The main

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types of objects in a 3D city model are buildings, and so this chapter focuses on the simplification of buildings. There are two different tasks in the building simplification process: (1) simplification of a single building, and (2) generalisation of groups of buildings. “Simplification of a single building” has been widely researched as a subject, and we can describe several different approaches to generalisation, all of them valid. In contrast, “generalisation of a group of buildings” has been treated, so far, only on a very limited level. There are several very similar approaches, mainly based on the Delaunay Triangulation (DT) (e.g., Li et al. (2004) and Xie et al. (2012)). We propose, in concept, another approach which enables the simplification of buildings and groups of buildings in one holistic process. The approach is based on rasterisation and vectorisation operations, which are carried out by sub-dividing the urban neighbourhood into quarters. Initial results for this approach were presented by the authors in Noskov and Doytsher (2013a). In this chapter, we suggest the use of information theory to estimate the quality of the simplification of 2D building footprints. Information theory is also used to define the optimal levels of detail (LOD) of the buildings in each city quarter depicted in the final 3D scene. This chapter is structured as follows: related work is considered in Section Two, the algorithms of raw quarter calculations and building quarter hierarchy are presented in Section Three, the raster-based algorithms for generalising a group of buildings is considered in Section Four, evaluation of the generalisation results are presented in Section Five, and the new information-based content analysis approach to compiling 3D scenes is presented in Section Six, while concluding results are presented in Section Seven.

2 Related Work

The holistic approach to the 3D generalisation of buildings was described in Xie et al. (2012). The main idea supposes that, within a threshold (distance from a viewpoint), we will generate objects which contain the results of the simplification of single buildings, whereas outside the threshold we will generate objects containing the results of groupings of buildings and their simplification as a single building. An approach to “converting 3D generalisation tasks into 2D issues via buildings' footprints” was described in He et al. (2012).

The generalisation of 3D building data approach (Forberg 2007), based on scale-space theory from image analysis, allows the simplification of all orthogonal building structures in one single process. Another approach (Thiemann 2002) considers buildings in terms of constructive solid geometry (CSG). In Xie et al. (2012) an approach was proposed which realised 3D single building simplification in five consecutive steps: building footprint correction, special structure removal, roof simplification, oblique facade rectification and facade shifting. A very interesting approach was proposed in Kada (2002). In this approach, geometric simplification was realised by remodelling the object by means of a process similar to half-space modelling. Approximating planes were determined from the polygonal faces of the original model, which were then used as space-dividing primitives to create facade and roof structures of simpler shapes.

The second aspect of the 3D generalisation of an urban environment is the generalisation of groups of buildings. 3D generalisation of groups of buildings is mentioned in several publications (e.g. Glander and Döllner (2009), Guercke et al. (2011), He et al. (2012), and Trapp et al. (2008)). These papers describe different approaches to 3D grouping and group generalisation: the grouping of building models (using the infrastructure network) and replacing them with cell blocks, while preserving local landmarks (Glander and Döllner 2009); “express[ing] different aspects of the aggregation of building models in the form of Mixed Integer Programming problems” (Guercke et al. 2011); and, the grouping of building models “with a minor height difference and the other with a major height difference” (He et al. 2012).

In spite of the large number of publications and developing projects, we can identify a very important shortcoming in almost all 3D city maps (or screenshots). There are usually only two ways of displaying large cities: depicting only the buildings nearest to the viewpoint (where all the other buildings are not displayed and the area is depicted as a plain map), or displaying all the 3D building models (which usually involves a lengthy processing time and heavy computer and internet traffic resources, and furthermore, causes distant parts of the city to be presented as a very dense and an unreadable 3D view). As mentioned above, there are a large number of publications on generating and using the LODs of single buildings, while there are only a very limited number of approaches to creating LODs of group of buildings in order to solve the problem described above.

There are also related links in studies used to calculate the entropy of simplified layers and 3D scenes. The ‘entropy’ is the main measure used to estimate the quality of simplification. As noted by Shannon (1948), ‘entropy’ is a quantitative measure of information content. Sukhov (1970) implemented a quantitative measure of the information content of a map for the first time. Neumann (1994) measured the topological information of a contour map. The effectiveness of map design and the information content of maps were considered in Knopfli (1983) and Bjorke (1996). To estimate the quality of a map and the compiled 3D scene, we used three measures: coordinate digit density (CDD) function (Battersby and Keith 2003, and Clarke et al. 2001), entropy of Voronoi regions, and entropy of Voronoi neighbours (Li and Huang 2002); for more details see Section Five.

3 Calculation of Raw Quarters and Quarter Hierarchy

Finding a practical method of simplification is a very important issue in generalisation. One of the more common problems occurs when buildings are joined through obstacles such as wide roads or rivers. In this case, buildings must not be joined to each other, and those 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 generalisation itself.

To calculate the quarters, we decided to use the slope of the terrain, water objects and roads. For implementing and testing our approach, geodata for the city of Trento, Italy was used. The buildings (with individual heights), water objects and roads were extracted from the landuse map of Trento. The landuse map and land relief (DEM) were downloaded from the website of Trento Municipality, Italy. It was found that buildings were positioned only in areas with a slope of less than 30 degrees. Areas of the terrain with slopes greater than 30 degrees were thus excluded. We also used roads and water objects for defining the quarters. These objects are polygons extracted from the landuse map. All 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 generalisation). All pixels of the merged objects were given the value "1"; an empty space on the raster map was given a "0" value. Each group of pixels with value "1" was expanded by adding one pixel (1 meter). In the next step, the values of pixels were inverted ("1" to "Nil" and vice versa), resulting in many pixel areas with the value "1" which were split by "Nil" pixels. The final raw quarter map was prepared by vectorisation of the inverted raster map. Fig. 17.1 illustrates the process of preparing quarters.

In the initial phase of the research we prepared raw quarters. We could not use the raw quarters for a high level of generalisation, as raw quarters would be too small for large generalised buildings. To overcome this limitation, a new, flexible hierarchical approach of subdividing the urban area into variable quarters, was developed. The raw quarters were placed on the lowest level of the hierarchy; on the highest level, the whole area of the city was defined as one large quarter. A special approach to developing the quarter generalisation (or quarters merging) enabled this hierarchy, where the size and content of the quarters are correlated with the level of the 3D generalisation, and this, in turn, was related to the distances from the viewpoint when compiling the 3D urban scene. Each level of the hierarchical tree of quarters had some level of quarter generalisation. The hierarchy was based on buffer operations. We widened the quarters with a buffer; thus, adjacent quarters were merged into one object, while other objects only changed their geometry (the outer boundary of quarters were simplified; some small inner elements, such as holes and dead-end roads, were filled). We then decreased the quarter by a buffer of the same size. If the width of the gap of merged quarters was smaller than the buffer width, the objects remained as a merged polygon; otherwise the polygon was split back into separate objects differing from the original objects due to their simplified geometry.

The first step of quarter generalisation was calculating the attributes for each quarter. These calculated multiple attributes (area, compactness, perimeter, fractal dimension of building objects and quarter areas, etc.) were used for the classification of the quarters. We decided to use Kohonen's Self-Organising Map approach to classify quarters. The number of clusters was defined for all levels in the hierarchy of the quarters to perform classification. There are several techniques to automatically define the numbers of clusters (e.g., a gap statistic approach, an information theoretic approach, etc.). At this time, we focused on a manual definition of the number of classes. An initial manual analysis of a series of maps based on quarter attribute visualisation was carried out. For more information about the described classification method see Noskov and Doytsher (2013b).

Fig. 17.1 A) Shaded landuse map of Trento and buildings; B) Non-nil pixel groups which split the city space into quarters (inverting pixel map); C) Final map of raw quarters (defining quarter areas having unique values)

As described above, adding a weighted buffer to the quarters has been suggested in order to take the quarter classes into account (thus differentiating between quarters of the same class and quarters of different classes), aiming to merge neighbouring quarters. To avoid vector artefact and topology problems, data was converted to raster, and buffering operations were executed in a raster environment. We used the raster resolution as the base width of the buffer. Not only does the buffering phase provide the possibility of merging quarters, this operation also helps to fill holes and dead-end roads in polygons, and to eliminate small elements of quarter boundaries. It should be noted that converting vectors to raster can also work as a generalisation operation. Generally speaking, this phase in the research, which was based on vector to raster and raster to vector operations, as well as region growing and buffer implementations on the one hand, and on the quarters' attributes on the other hand, enables us to generalise the quarters and lets us move up or down in the hierarchical level of the quarter subdivision. Quarters of the same class were merged faster than quarters of different classes. This was achieved by putting quarters of the same class into isolated sub-environments (temporal layers) and using different widths of buffers (see result in Fig. 17.2).

This suggested approach allows quarter generalisation based on buffering operations, while taking into account quarter classes. Using this method builds a hierarchical tree of quarters (in the current sample of Trento, from the raw source of 2679 small quarters up to a single huge quarter). We performed the generalisation of quarters starting from a buffer width of 1 meter and increasing it by increments of 0.2 meters, until the buffer width reached 2.6 meters. It was decided to start quarter generalisation from 1 meter because this is the resolution used to generate the raw quarters; and set the upper limit at 2.6 meters because a higher buffer width generates oversized quarters.

We decided to use 8 degrees of building generalisation based on rasterisation processes with resolutions of 10, 15, 20, 25, 30, 40, 50 and 60 meters (resolutions that correspond to degrees of generalisation). A graph of the varying number of quarters and the size of a maximal quarter was used to define which levels of hierarchy could be used for further processing. In addition, the original vector map of buildings was converted to raster maps with different resolutions (10, 15, 20, 25, 30, 40, 50 and 60 meters). These raster maps, overlaid with the generalised quarter maps, were used to estimate which resolution of buildings generalisation should be used with each generalised quarter map. Finally we decided to use a scheme of correspondence between buffer sizes used to calculate quarter levels and pixel sizes used for generalisation (buffer size – raster resolutions) as follows: 0.0 (raw quarters) – 10 and 15, 1.0 - 20 and 25, 1.2 – 30, 1.4 - 40, 1.6 – 50, 1.8 - 60 .

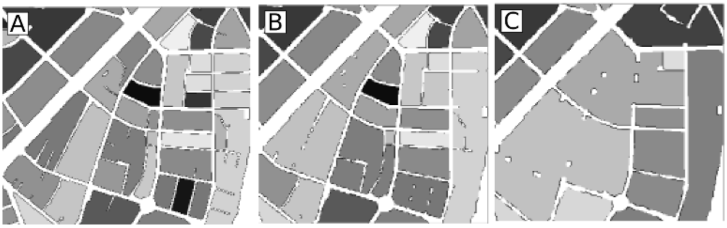

Fig. 17.2 Quarter buffering generalisation (buffer width): A) Original raw quarters; B) 1.4 meters; C) 1.8 meters

4 Simplification of Buildings

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

Fig. 17.3 The Generalisation process of buildings in a quarter: A) Original buildings; B) Rotated quarter and the generalised 10 meter rasterised buildings in red; C) Final result

Within each quarter, the azimuths of all the building's 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 were rotated by 90 degrees (clockwise) again and again; and the rotated azimuths (and their lengths) were put into 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 adjacent building side azimuths was found to give satisfactory results. A weighted average of the azimuths of the longest lengths of all the buildings within a quarter was used to define the general orientation of all the buildings of the quarter.

In order to significantly reduce the number of vertices of the generalised building, and achieve a more realistic appearance of these simplified objects, rasterisation should be carried out in the spatial orientation of the buildings. A rasterisation which is spatially oriented parallel to the grid axes will define 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 counterclockwise at the angle of their general orientation to all the buildings of the quarter. The rotated buildings were then rasterised using a specific pixel size resolution (as explained in the next section). Each pixel with more than half its area covered by the original buildings was given the value “1”; otherwise, it was given the value “Nil”. Figure 17.3 shows the results of this stage.

The level of generalisation is a function of the pixel size rasterisation process - the greater the pixel size, the greater the degree of generalisation. Accordingly, each quarter was generalised at several levels of rasterisation, resulting in several layers of different levels (level-of-detail) of generalised buildings for each quarter. Based on the original data from 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 in the continuous and consecutive appearance of the level-of-detail of the generalised buildings. Generalised buildings were stored in separate layers; the identifiers of these layers contained the resolution of the building generalisation and the number of the level in the quarter hierarchy (or actually, the buffer width).

5 Evaluation of Quality of 2D Footprints Simplification

Eight LODs of buildings were calculated for the city area. The important issue is the evaluation of the results of simplification. The solution to the problem can be found by using information theory. Our attention concentrated on three ways of calculating the entropy of maps: (1) coordinate digit density (CDD) function, (2) entropy of Voronoi regions and (3) Voronoi neighbours. Entropy is a measure of the uncertainty of information content of a map.

The CDD method of calculating the entropy of map was described in Battersby and Keith (2003) and Clarke et al. (2001). The main idea is based on the calculation of the probability of digits in coordinate values of objects. The approach can be expressed with four equations:

$$P(d_n) = \frac{1}{Sn} \;(1);\quad D_n = O(d_n) - P(d_n) \;(2);\quad H(n) = \sum_{1}^{s} \left| D_n(s) \right| \;(3);\quad I = \sum_{0}^{n} H(n) \;(4);$$

In Eq. 1 *P(d_n)* is the probability of an individual character *d* in digit place *n, Sn* in a number of possible states. In Eq. 2 *D* is the overall variation of digit n. *O(d_n)* is the probability of a digit for all points, *P(d_n)* is the common probability of *d* in a considered numerical system. For a standard decimal numerical system, *P(d_n)* is equal to 0.1. *H(n)* (Eq. 3) is the measure of information potential and *I* is total information content (entropy) in a geographic dataset. The entropy of digits in place number 3, 4, 5 from X coordinates 66**445**6, 66**422**3, and 66**440**3 of 3 random centroids of simplified buildings could be calculated as follows:

Digit place #3: D(j)= 0/3-0.1=0.1, where j is 0-3,5-9; D(4)= 3/3-0.1=0.9; H(4,4,4) = 0.9 + 9*0.1=1.8

Digit place #4: D(j)= 0/3-0.1=0.1, where j is 0-3,5-9; D(2)= 1/3-0.1=0.23; D(4)=2/3-0.1=0.57; H(4,2,4)=1.6

Digit place #5: D(j)= 0/3-0.1=0.1, where j is 1,3,4,6-9; D(i)=1/3-0.1=0.23, where i is 0,2,5; H(5,2,0)= 1.4

I= 4.8

Another method involves calculating entropy using Voronoi polygons, reported in Li and Huang (2002). The entropy of Voronoi polygons could be calculated using the areas of polygons and the number of neighbours. The entropy of Voronoi regions is calculated as follows:

$$H = -\sum_{1}^{n} \frac{Si}{S} (\ln Si - \ln S) \qquad (5);$$

Si is the area of individual polygons, S is the whole area, n is the number of polygons. The number of polygons affects this measure; thus final entropy could be normalised:

$$H_N = \frac{H(M)}{\log_2 n} \qquad (6);$$

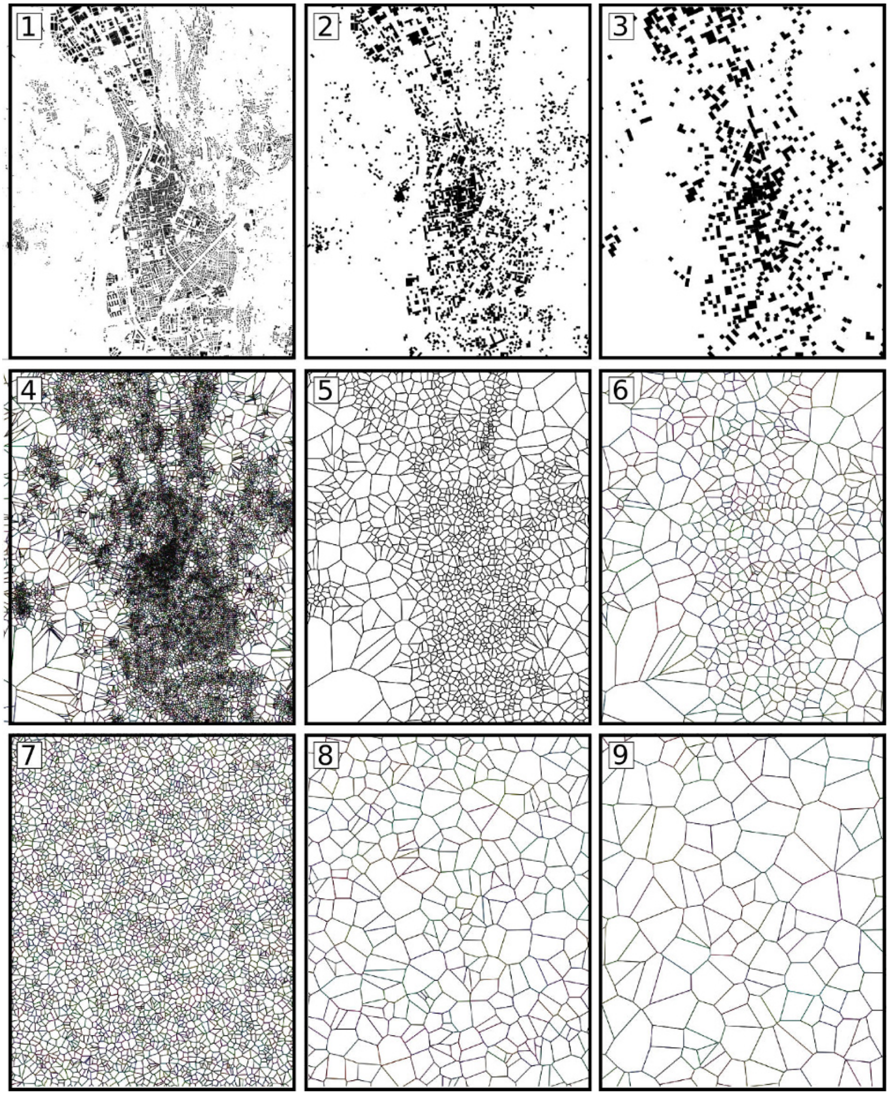

Fig. 17.4 Building layers and Voronoi polygon maps: 1-3) building maps (left-to right: original buildings, generalised by 30m pixel buildings and generalised by 60m pixel buildings); 4-6) Voronoi polygon maps based on points derived from centroids of polygons of the upper building map; 7-9) Voronoi polygon maps based on pseudo-random points, number of points equal to the number of centroids of the upper building map's polygons

To calculate entropy of Voronoi neighbours, the centroids of polygons are connected by Delaunay triangulation, and then the number of neighbours can be easily calculated for each centroid. The entropy is calculated as follows:

$$H = \sum_{j=1}^{Mj} \frac{n_j}{N_j} \ln\left(\frac{n_j}{N_j}\right) \qquad (7);$$

It was found that Voronoi polygons based on pseudo-random point maps could be used as a basic sample, which can be used to evaluate the results of generalisation. A pseudo-random generator from C standard library was used to calculate point coordinates. Two types of random maps were prepared for each level of generalisation and original building layer. Voronoi polygon maps were based on pseudo-random centroids, where the number of polygons is equal to the number of polygons of a correspondent building map. Point maps are where the number of points is equal to the number of vertices of the polygon boundaries of a correspondent map of buildings. The first type was used to evaluate the generalisation through entropy of the Voronoi polygon method. The second type was used to evaluate generalisation through the CDD function method. Figure 17.4 presents comparisons of pseudo-random Voronoi maps and generalised buildings layers' Voronoi maps. It is clear that the pictures with different degrees of generalisation are similar. Figure 17.4 proves this assumption. The bar plots of the information content (entropy) calculated using different methods are presented in Figure 17.5. We can see that the changes in generalised building map entropy are very close to pseudo-random map entropy changes. This means that the model of generalisation described maintains the geographical correctness and characteristics of the urban area.

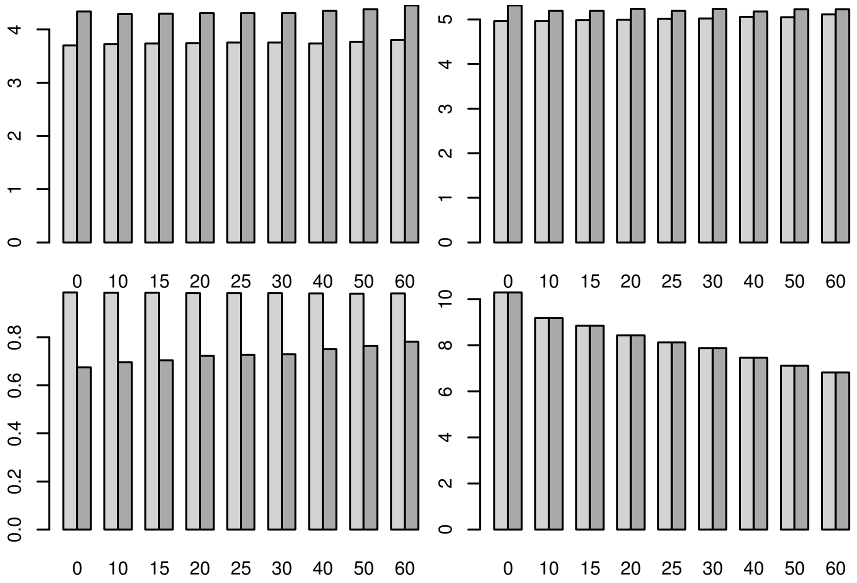

Fig. 17.5 Information content (entropy) of buildings layers (dark grey bars) and random Voronoi maps (light grey bars). The vertical axis is entropy, horizontal degree of generalisation (0-original buildings): the top left and top right) information content of the maps calculated using the CDD method using Eq. 4 for easting and northing coordinates, correspondingly; bottom left) normalised by number of polygons entropy of Voronoi regions (Eq. 6); bottom right) entropy of Voronoi neighbours

6 Compiling of 3D Scene

Noskov and Doytsher (2013b) presented an algorithm for compiling a 3D scene based on buffer zones. Buffer zones around the viewpoint were calculated, then quarters were selected from the hierarchy by zones, and spatial conflicts were resolved. This algorithm requires artificially defining buffer zone sizes and the correspondence between buffer zones and LODs. Our new approach is totally automatic and does not use distance from viewpoint to define the level of generalisation for some quarters. The approach is based on the information content of 3D scenes saved to raster file.

At this time, a database of the hierarchy of quarters and multiple building layers generalised in frames of the quarters was developed. The first (original) level of quarter hierarchy contains original buildings, generalised by pixel sizes of 10 and 15 meters; the second level corresponds to a 20 and 25 meters degree of generalisation; level 3 to 30 m, level 4 to 40m, level 5 to 50 and level 6 to 60m.

To reduce the number of quarters for processing, only those visible on 3D scene quarters were selected. We used a simple method which is demonstrated in Figure 17.6. The raster of a 3D scene was generated with relief, and then a raster with the relief overlaid by the spot of a quarter was calculated. If the two binary pictures were not same, a quarter was marked for further processing; otherwise, the quarter was excluded.

Each visible quarter on the 3D scene was processed to define the optimal level of generalisation. Quarters were ordered by distance from viewpoint; the nearest quarter was processed first. For each quarter, all levels of generalisation were considered. For each level of generalisation (including original buildings) a 3D scene's raster was calculated with resolution x,y containing only correspondent generalised buildings in the frame of the current quarter, and a 3D scene's raster with resolution x,y multiplied by k containing original buildings in the frame of the current quarter. We chose 650,340 for x,y and 5 for k; this was defined with respect to computer configuration. We then converted the raster scene to vector data; all pixels grouped with the same value formed vector polygons (Fig. 17.7). Analysis of 20 different quarters with respect to all degrees of generalisation was performed. Different ways of calculating entropy were tested. The measure which enabled us to define the optimal level of generalisation was found to be:

$$E = \left| \frac{Hg\_c - Horig\_c}{Hg\_0 - Horig\_0} \right| \text{, until } E \le 7 \qquad (8);$$

All H^* parameters were calculated using Eq. 5; instead of Voronoi regions, areas of vectorised pixel groups were used. In the formula, *g* means the generalised buildings and normal 3D scene's raster resolution, *orig* means original buildings and high 3D scene's raster resolution, *c* means current region's frame, *0* means 0 degree of generalisation or original buildings. The expression $Hg\_0 - Horig\_0$ enables us to normalise entropy by eliminating the effect of pixel resolution differences. We use different resolutions of raster files because distant objects in a 3D scene can be depicted as 1 pixel objects (in which case it is impossible to calculate the real entropy of a sample raster); to calculate the entropy of a sample raster with original buildings we therefore needed to enlarge resolution. According to the equation presented above, a level with a maximum degree of generalisation with $E \le 7$ is appropriate for inclusion in the final generalised 3D scene. Value 7 was derived empirically. The *E* parameter could act as the coefficient of degree of the generalisation of a 3D scene.

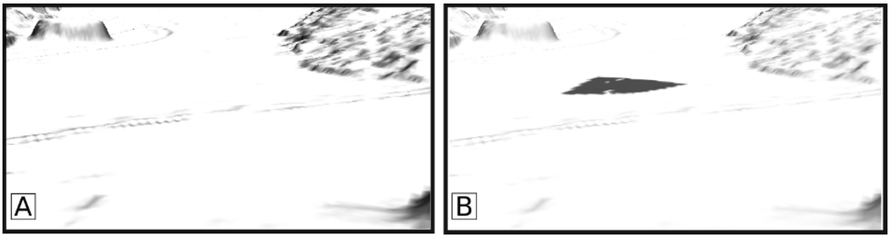

Fig. 17.6 Testing a quarter for visibility in a 3D scene: A) Empty scene with relief only; B) Scene with relief overlaid by the spot of a quarter

Fig. 17.7 Entropy of rasterised 3D scene: A) High resolution raster of original buildings; B) Normal resolution raster with generalised buildings; C) Vector polygon map of visible buildings' faces derived from B

The algorithm can be presented in pseudo code as follows:

```
hierarchy_of_ quarters
buildings          #Contains original buildings separated by quarters (horizontally) and by
resolution (vertically)
dem                #Digital Elevation Model
quarters_of_1level=get_quarters(hierarchy_of_ quarters, level =1)
quarters_of_1level_of_scene=[]
for cur_quart  in quarters_of_1level{
```

```
      if draw_3D_as_PNG(dem, as.raster(cur_quart)) != draw_3D_as_PNG(dem){
         append_to_list(quarters_of_1level_of_scene, cur_quart)       }   }
function e(raster1,raster2){
      areas1=get_polygon_areas(rast_to_vector(rast1))
   areas2=get_polygon_areas(rast_to_vector(rast2))
   return abs(entropy(areas1)- entropy(areas(2)))   }
final_list=[]
for quart in quarters_of_1level_of_scene{
    zero_E=null
    selected_buildings_layer=null
    for resolution in [0,10,15,20,25,30,40,50,60]{
        hyerarchy_level=get_hlevel_by_resolution(resolution)
        cur_quart =  get_quarters(hierarchy_of_ quarters,  level=hierarchy_level, select_by_map=
quart)
        if cur_quart NotIntersectsWith final_list{
             generalised_buildings=get_buildings(resolution=resolution, select_by_map=cur_quart)
             original_buildings=get_buildings(resolution=0, select_by_map=cur_quart)
             out_ras_resolution=650,340
             rast_gen=draw_3D_as_PNG(generalised _buildings, resolution=out_ras_resolution)
             rast_orig=draw_3D_as_PNG(original_buildings, resolution=out_ras_resolution*5)
             E= e(rast_gen, rast_orig)
             if resolution == 0 { zero_E =E}
             if ( E<=7 ) { selected_buildings_layer= rast_gen }
             else { break }            }     }
    appent(final_list, selected_buildings_layer)
 }
final_raster=draw_3D_as_PNG(dem, final_list)
original_buildings=get_buildings(resolution=0, select_by_map=cur_quart)
             out_ras_resolution=650,340
             rast_gen=draw_3D_as_PNG(generalised _buildings, resolution=out_ras_resolution)
             rast_orig=draw_3D_as_PNG(original_buildings, resolution=out_ras_resolution*5)
             E= e(rast_gen, rast_orig)
             if resolution == 0 { zero_E =E}
             if ( E<=7 ) { selected_buildings_layer= rast_gen }
             else { break }            }     }
    appent(final_list, selected_buildings_layer)  }
final_raster=draw_3D_as_PNG(dem, final_list)
```

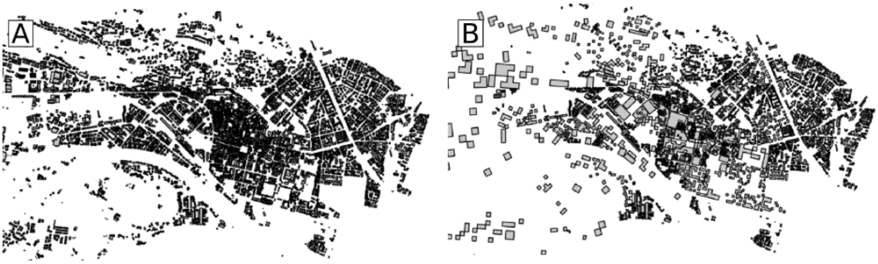

Fig. 17.8 2D footprints depicted on final 3D scene: original buildings (left); generalised buildings (right). View direction – from right to left side of the picture

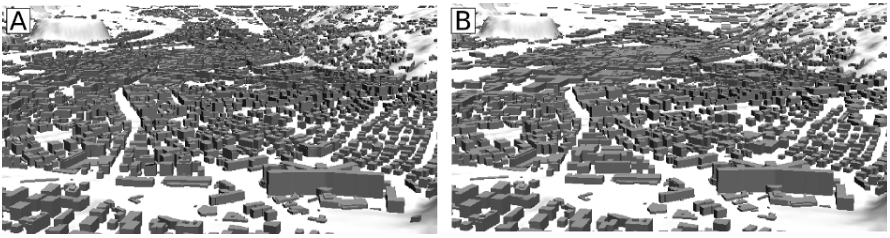

Fig. 17.9 Final 3D scenes: original scene (left); generalised scene (right)

7 Concluding Results

In Figure 17.8, the 2D footprints of the buildings depicted in the final 3D scenes are presented (see Figure 17.9). In contrast to approaches using distance to the object from a viewpoint as the main parameter for defining LODs, the information theory based method is more flexible; this method does not require defining the correspondence between distances from a viewpoint and LODs. According to Table 17.1, the number of nodes and the number of polygons decreased almost three times due to the generalisation, thus the speed of the rendering also decreased almost three times. In addition, the size of the final raster file in PNG format is decreased.

A raster-based cartographic generalisation approach was presented here. It is based on standard tools of rasterisation, vectorisation, region growing, classifying, and overlaying. The main advantages are: (1) the ability to simplistically and efficiently generalise buildings at different levels; (2) achieving variable and continuous level-of-detail of the buildings; (3) the generalised 3D model does not contain unreadable and overly detailed data of separate buildings; (4) the model maintains the geographical correctness and characteristics of the urban area; (5) the developed method helps to reduce computing time, and the computer resources required. The results of generalisation of buildings' footprints were evaluated. The proposed method of compiling 3D scene enables us to define the optimal LODs of objects automatically, and takes into account the information content of a 3D scene.

The method and the process were 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, Debian GNU/Linux 7 operating system, GRASS GIS 7, Bash and R programming languages were used. Calculation of raw quarters, a quarter's hierarchy and multiple LODs for the city area takes several hours. A parallel computing approach for Graphic Cards (OpenCL application) could significantly reduce the required time. Defining optimal LODs for one viewpoint requires approximately 10-15% of the time required for the raw quarter calculations. The time could again be reduced by simultaneously calculating 3D scene parameters for several viewpoints and using them in artificial neural networks for fast optimally defined LODs.

Table 17.1 Comparison of numerical parameters describing the advantages of implemented generalisation

	Number of nodes	Number of polygons	Speed of 3D scene generating, seconds	Size of generated PNG raster file, kilobytes
Original building layer	114,197	12,527	10.2	120
Generalised building layer used for 3D	38,343	4,552	3.4	99

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