A Stroke-based Approach to Detect Patterns of Discrete Buildings for Generalization Purposes

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Abstract: Generalization is the prerequisite to derive multiple representation and requires high efforts in case of manual map production. For the buildings in the OpenStreetMap (OSM) data, there can be found no intermediate generalization results between the neighboring zoom levels, which may lead to lower legibility at the smaller scales. In this paper, a stroke-based approach is proposed to detect patterns of discrete buildings for the generalization purposes, which aims at meeting this problem. The strokes are structured based on the proximity graph of building. After pruning the strokes by the given rules, five patterns of building are detected based on the related isolated stroke or strokes. Therefore different generalization units are formed on basis of the patterns. Following that, different generalization strategies are developed and applied aiming at preserving the original characteristics of each unit. By this way, generalized buildings satisfy the legibility constraints and the original distribution structures of buildings are also preserved. The advantages and limitations of the proposed approach are discussed based on the experimental results.

Keywords: Building generalization, Building patterns, Stroke, OSM data

1. Introduction

Building serves as the center place of human activities in cities, which has significant meaning in politics, economy, culture and so on. Therefore building is one of the most important artificial objects on the map, which also occupies very high map load. Generalization is a necessary work in map production when the scale changes. In the process of map multiple representation, map generalization is required to keep the legibility in different scales. Therefore the issues of building generalization have attracted many research attentions in the field of automated cartographic generalization. Meanwhile, the quality of building generalization directly affects the use value of maps. A well generalized legible map can also bring good aesthetics feeling to map users.

OpenStreetMap (OSM) is a widely used map site nowadays. However by inspecting different zoom levels of OSM, buildings are presented only with zooming in and out rather than generalization, which may lead it less legible when the scale decreasing. As shown in Figure 1, buildings are shown legibly in zoom level 17, however with the level zooming out to 16 and 15, buildings on the map become more crowded and difficult to distinguish. When it zooms out to level 14 which is the smallest display level of building in OSM, buildings become extremely tiny so that it is impossible to distinguish buildings. Hence with the zoom level decreasing, it is necessary to implement the generalization work in order to achieve a more legible building presentation.

The objective of this paper is to provide an integrated methodology to detect building patterns and then generalize the buildings within the patterns. The task only considers the partition function to the buildings of the contextual road network. The proposed method can be subdivided into three parts, whereby the stroke techniques is utilized. Firstly, constructing strokes on the basis of the refined proximity graph of buildings, secondly classifying the strokes and forming the different generalization units of buildings. Finally, specific generalization strategies and operators are designed and implemented to different generalization units.

The paper provides a short review about methods of building patterns detection and generalization in section 2. The methodology of stroke-based building pattern detection is described in section 3 and the generalization of different building units are discussed in section 4. Experimental results are presented and discussed in section 5 and the conclusions are given in section 6.

(a) Level 17 (b) Level 16 (c) Level 15 (d) Level 14

Fig. 1. Presentations of buildings in different OSM zoom levels

2. Related research work

According to Li et al. (2004), the generalization process of buildings can be decomposed into two steps, firstly the patterns or groups of buildings are detected, and then appropriate generalization operators are selected and applied to the different detected building groups. In these two steps, the detection of building patterns is the basic and essential task, which affects the following generalization work profoundly. In general, the detection quality of building patterns determines the quality of generalization directly. Hence, it is critical to detect building patterns and to preserve the original patterns so that map users can have the similar visual perception which is quite important in communicating the geographic information. Accordingly, the detection of building patterns has attracted many research attentions.

In summary, the detection methods of building patterns or building groups can be categorized into two primary strategies, one is based on urban morphology and Gestalt theory, and another one is Graph-based. For the former, Li et al. (2004) uses Gestalt principles which includes proximity, similarity, closure, continuity and common fate, to form the local constraints and provide the criteria for grouping. The similar grouping idea can be also found in the work of Yan et al. (2008), Qi and Li (2008) and Liqiang et al. (2013). There are also algorithms and methods based on graph. Regnauld (1996) uses Miminal Spanning Tree (MST) to represent the neighborhood relationships of buildings so as to detect the patterns. Anders and Sester (2000) put forward a parameter-free graph-based clustering approach. Zhang et al. (2010) present two graph-theoretic algorithms to detect align-along-road alignment and unstructured clusters of building patterns. Zhang et al. (2013) also propose a framework and several algorithms to recognize collinear and curvilinear building patterns. Centinkaya et al. (2015) make a comparison of four graph-based grouping algorithms in urban block. In addition, some other ideas are also presented aiming at solving specific problems. Christophe and Ruas (2002) use projection idea to detect the straight line alignments. Lüscher et al. (2009) adopt integrating ontological model and Bayesian inference to recognize the pattern of terraced house. The researches mentioned above provide contributions to solve the detection problems of building patterns, however, by analyzing these approaches, we find that there are still some aspects to be further studied and improved. The detection of building patterns is concentrated more on the regular patterns (e.g. linear patterns, grid patterns etc.), while the rest irregular patterns are neglected. The irregular patterns of buildings also occupy a considerable percentage on map, how to decide which buildings should be generalized together is still a problem. And the generalization of the detected building patterns also need to be discussed detailedly.

Normally, the building patterns are typed into linear alignments and nonlinear clusters (Zhang, Ai, & Stoter, 2010). For the linear alignments, they present regularly and the representative patterns are collinear, curvilinear and align-along-road. Nevertheless except the grid like cluster, the nonlinear clusters present unstructured or irregular pattern in general. To summarize, the reviewed researches focus more on the detection of linear alignments and there are also methods to recognize the grid like cluster. However for the irregular unstructured clusters, there are less detecting methods. This kind of pattern is an obbligato part of the building, which is also the component to the whole generalization process. Therefore how to detect unstructured clusters groups should be also received attentions. Moreover, the current detection algorithms mostly aim at detecting one specific pattern, it is still lack of a systematic detection method which can solve different patterns at one time. In the light of the above arguments, this paper introduces stroke idea to recognize building patterns. The stroke-based method can simultaneously detect linear alignment as well as unstructured clusters by pruning stroke on account of some designed rules. After the detection of different building patterns, different generalization strategies are provided by using appropriate generalization operators.

3. Detection of building patterns based on stroke

The term "stroke" was firstly proposed by Thomson and Richardson (1999). The concept of stroke is based on the principle of 'Good Continuation' in the theories of Gestalt psychology. In the network constituting by lines, a stroke is a chain of several segments which appear to follow in the same direction tend. The idea of stroke was camp up with the idea of a curvilinear segment that can be drawn in one smooth movement and without a dramatic change in style. And this kind of good continuation principle can serve as the basis for partitioning a road network into a set of linear elements. The idea of stroke is widely used in the generalization of road network, which can be found in references (R C Thomson & Brooks, 2000) (Chaudhry & Mackaness, 2005) (Chen, Hu, Li, Zhao, & Meng, 2009) (Weiss & Weibel, 2014). Linear pattern is one of the common buidling patterns, and this is the inspiration why the stroke idea is considered to detect building patterns. In this paper, the stroke-based detection method is consist of three main steps: stroke construction, stroke pruning and stroke classification. The followings are the detailed introduction of these three steps.

3.1 Stroke construction

The construction of strokes is based on the proximity graph of buildings which is derived mostly by Constrained Delaunay Triangulation Network (CDTN). In the proximity graph, buildings are regarded as vertices and any two buildings which share at least one same triangle are regarded as proximal, and an edge (shown as the blue lines in Figure 2a) is formed between the centroids of these two buildings. The methods follows the detailed description of proximity graph from Zhang (2010, 2013).

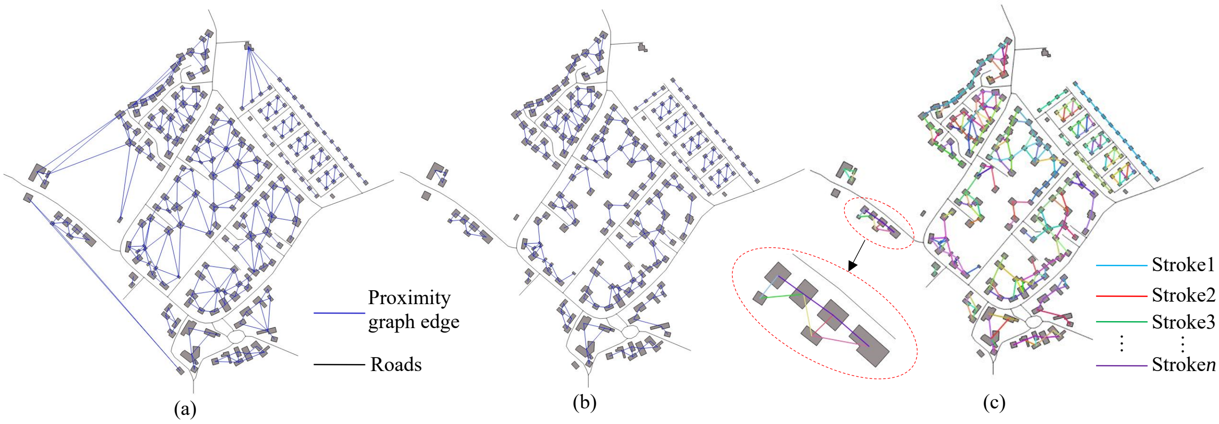

Fig. 2. Stroke construction of building proximity graph: (**a**) proximity graph of the original building data (**b**) refined proximity graph by distance (**c**) stroke construction of refined proximity graph

Proximity graph only reflects the topological proximity of buildings, for this reason, even two distant buildings may have the proximal relationship, and this is helpless to the further detection task. Therefore the original proximity graph should be refined. There are many different methods for the refinement of proximity graph. Anders (2003) summarizes several frequently-used methods, such as Nearest Neighbor Graph (NNG), Minimum Spanning Tree (MST) and Relative Neighborhood Graph (RNG). Here we only use the distance index to refine the original proximity graph, which means that if the distance between two proximal buildings is larger than the specified threshold, the edge that presents the proximity relationship should be deleted (Figure 2b). The value of the distance threshold is set experientially, which should also meet the demands that the obvious long edges must be deleted and the edges between two relative close buildings should be preserved.

The refined proximity graph can be regarded as a network, thus the common stroke technology in the road network generalization is used to help detecting building patterns. Road network have a natural perceptual grouping characteristic, and "Good Continuation" is the dominant principle when judging the stroke. By adopting this idea, the edges in the network generated by the refined proximity graph can be also structured into strokes. Only those edges which satisfy the "Good Continuation" principle can be structured into the same stroke. In Figure 2c, each stroke is presented by one kind of color. As we can see that the nodes of strokes are the centroids of buildings so that the relationships between strokes and buildings are formed, which means that the building patterns can be reflected on the strokes so that the detection of building patterns can be conducted by handling the strokes.

3.2 Stroke pruning

Firstly defining the term of "short stroke". Referring the definition of stroke in road network, a stroke is normally the set of several or many road short segments, therefore here a short stroke denotes that a stroke only relates two buildings. By comparison, a stroke which relates at least three buildings is regarded as a normal stroke. The following two rules are designed to prune strokes.

Rule 1: Deleting the short strokes which are connected only by normal strokes.

Rule 2: Deleting the strokes related three-building which connect with strokes that relate more than four buildings.

Figure 3a shows an example of the pruning process, by executing Rule 1, nine short strokes are deleted except short stroke *A* and *B* which do not connect with normal strokes. And based on rule 2, the two three-building related strokes are deleted as both of them are connected with the strokes relates four or more buildings. Figure 3b exhibits the final stroke pruning result of Figure 2c.

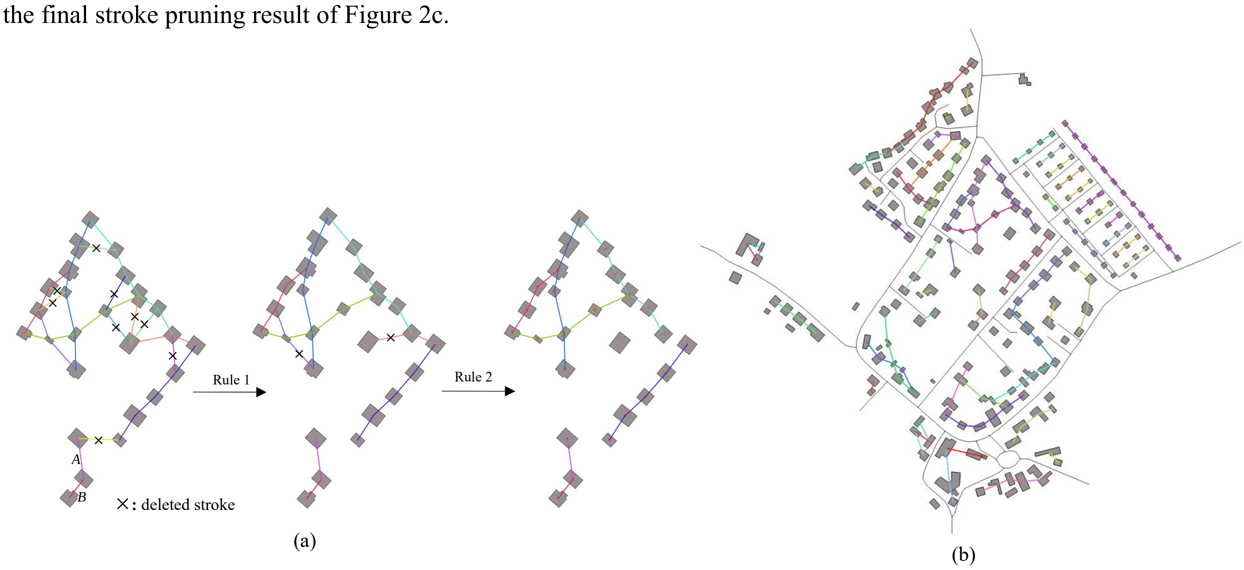

Fig. 3. **(a)** Stroke pruning rules and **(b)** pruned strokes

3.3 Stroke classification and building patterns detection

After pruning, it can be found that some strokes are presented isolated while some others are intersected with each other. The foundation of stroke classification are caring about whether it is isolated or intersected and it is a short stroke or a normal stroke. Four categories of stroke are given as followings:

- **Isolated stroke**: here the stroke refers to a normal stroke, namely it relates at least three buildings. Isolated stroke denotes that a single stroke that there are no other strokes intersecting with it.
- **Stroke group**: stroke group denotes that there are at least two normal strokes intersecting with each other. Stroke group can be regarded as a tiny network.
- **Isolated short stroke**: isolated short stroke denotes that there is only one short stroke, it does not intersect with any other normal or short strokes.
- **Short stroke group**: short stroke group denotes in this stroke group at least two short strokes are intersect.

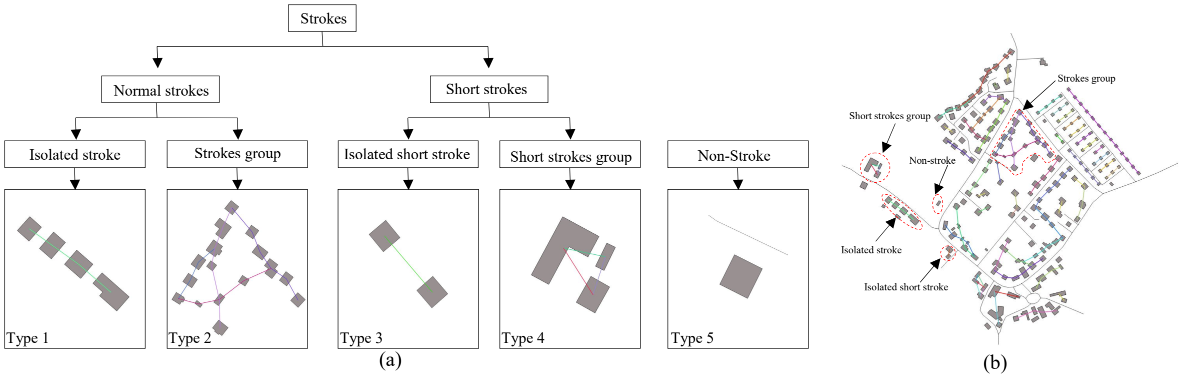

Fig. 4. Classification of stroke and detected building patterns

Figure 4 shows the classification of strokes. Hereto it can be found that building patterns are detected. Five different patterns are detected as followings:

Building pattern Type 1: the buildings related by an isolated stroke are detected as the linear pattern;

Building pattern Type 2: the buildings related by a strokes group, in some degree it can also be regarded as a special unstructured cluster, in this cluster, it may also contain some partial linear patterns;

Building pattern Type 3: the buildings related by an isolated short stroke can be also regarded as unstructured cluster, but only two buildings are in this type;

Building pattern Type 4: the buildings related by a short stroke group are detected as the unstructured cluster;

Building pattern Type 5: the rest buildings which are not related by strokes are single buildings, strictly speaking, they are not patterns, in order to keep the consistency of terminology, here also using pattern.

By pruning the stroke, different building patterns can be detected simultaneously, and each detected building pattern forms a generalization unit. By analyzing the characteristic of each building pattern, different strategies and operators are designed and used to implement the generalization to the units.

4 Generalization of different building patterns

4.1 Generalization of Type 1 building pattern

Buildings in pattern Type 1 present like linear pattern. The typification operator is adopted to implement on this type. Currently there are some typification algorithms (Sester & Brenner, 2000) (Burghardt & Cecconi, 2007) can be used. Figure 5 shows the generalization process of this situation.

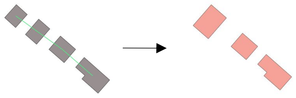

Fig. 5. Typification of Type 1 building pattern

4.2 Generalization of Type 2 building pattern

This is the most complex situation comparing with other types. The buildings in pattern Type 2 can be classified into three categories: intersected buildings, intermediate buildings and hanging buildings, which are shown in Figure 6b. Intersected buildings refer to the buildings which locate at the intersection point of strokes. Intermediate buildings refer to the buildings which locate between two intersected buildings, and the intermediate buildings are connected by the same one stroke. Hanging buildings refer to the buildings which are not belong to the former two categories, and they locate at the end part of the related stroke.

The generalization process of this pattern is divided into the following three steps:

Step 1: for the intersected buildings, all of them should be retained, because they are located at the intersecting point which means that they play an important role of the structure, therefore their preservation can keep the main structure of the buildings groups.

Step 2: for each single part of the intermediate buildings related by one stroke, if the number is two or more, they should be aggregated or typified, shown like A_1, A_2 in Figure 6b. If the number is only one, and if the size or distance comparing or computing with its corresponding intersecting building are smaller than the thresholds, it should be deleted, shown like A_4 (too small), A_5 (too distant) in Figure 6b. Otherwise it should be retained, shown like A_3 (large enough), A_6 (distant enough) in Figure 6b.

Step 3: for each single part of the hanging buildings related by one stroke, the generalization rule is similar like intermediate building. If the number is two or more, it should be aggregated or typified, shown like B_2 in Figure 6b. If the number is only one, and if the size or distance comparing or computing with its corresponding intersecting building are smaller than the thresholds, it should be deleted. Otherwise it should be retained, shown like B_1 (large enough) in Figure 6b.

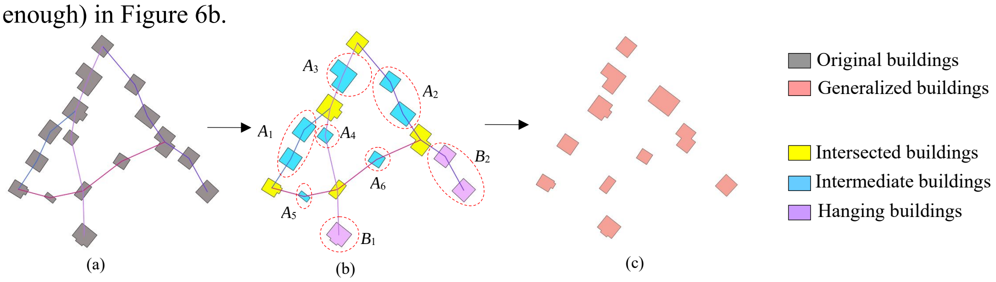

Fig. 6. Generalization of stroke group related buildings

4.3 Generalization of Type 3 building pattern

An isolated short stroke only relates two buildings. The generalization of these two buildings should be discussed in different situations.

Situation 1: if these two buildings have extremely high similarity, not only the size but also the shape, the best solution is to select typification as the operator (Figure 7a).

Situation 2: if the size difference of these two buildings is larger than threshold while their distance is satisfied with the threshold, aggregation is chosen as the generalization operator (Figure 7b).

Situation 3: if the distance between these two buildings is larger than threshold, the solution is to delete the smaller one and retain the larger one (Figure 7c).

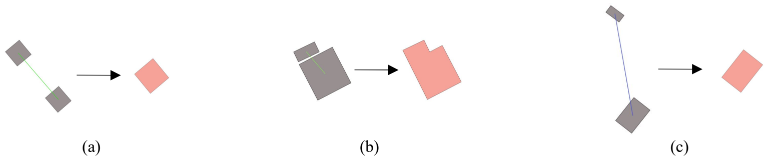

Fig. 7. Generalization of buildings related isolated short stroke

4.4 Generalization of Type 4 building pattern

The buildings related by short strokes group are presented as building cluster, the generalization process should also be considered in different situations.

Situation 1: if the buildings are close to each other and all the distances are smaller than the threshold, the buildings should be aggregated as a new one (Figure 8a).

Situation 2: if some of the buildings are distant from others, the aggregation should implement separately. Only the buildings whose distances are smaller than the threshold should be aggregated (Figure 8b).

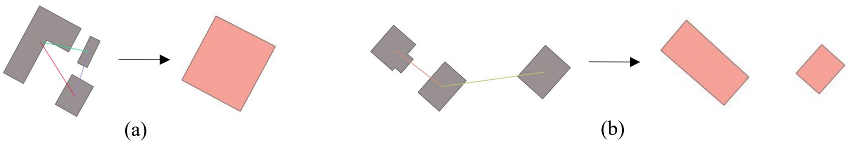

Fig. 8. Generalization of short stroke group related buildings

4.5 Generalization of Type 5 building pattern

After pruning the stroke, not all the buildings are related by strokes. For a non-stroke related building whose size is smaller than the threshold, if it is located in region where has less building density, even though its size is smaller than the threshold, it should also be retained, otherwise it should be deleted. For example, in Figure 9, the size of building *B*, *C*, *D* are smaller than the threshold, but building *D* locates in a less buiding density region, hence building *D* is retained.

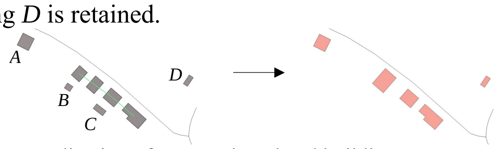

Fig. 9. Generalization of non-stroke related buildings

5. Experiment and discussion

The proposed approach is implemented using the software QGIS 2.18 with Python programming language. WebGen services provided by the ICA Commission on Generalization and Multiple Representation is chosen to implement the specific generalization operations (e.g. typification). From OSM data, Rockau, which is a small village around Dresden is selected as the test area.

5.1 Experimental results

Figure 10 shows the generalized results by the proposed stroke-based approach. Figure 11 are the results with the symbolization of OSM style in different zoom levels. Table 1 provides the statistical results regarding the amount of each building pattern type and the total number of the buildings in the corresponding type before and after generalization.

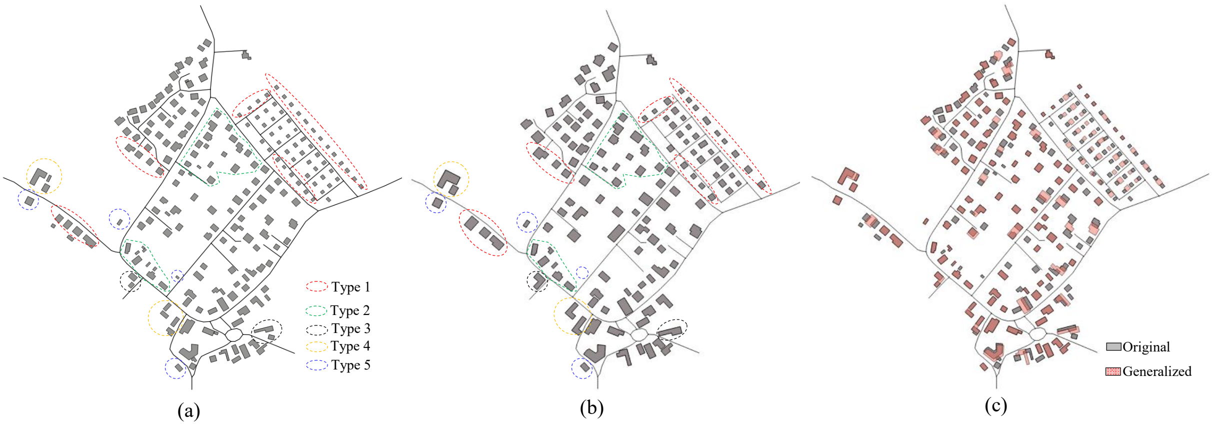

Fig. 10. Generalization results of the proposed method (**a**) original (**b**) generalized (**c**) overlap of original and generalized data

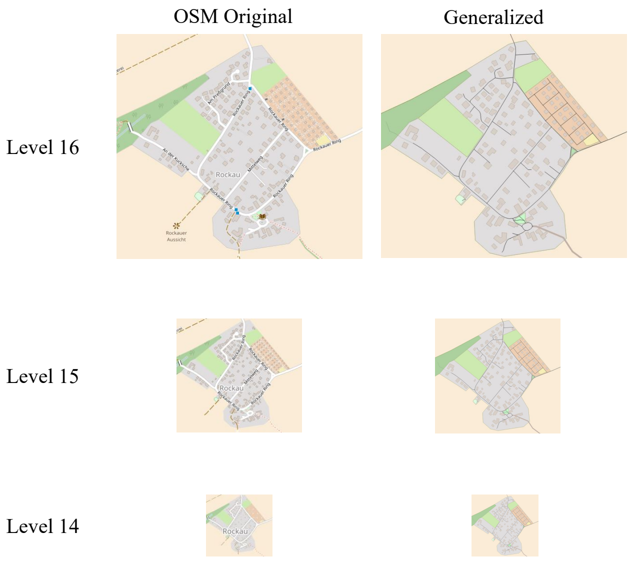

Fig. 11. Comparison of original and generalized on different zoom levels with symbolization

Tab. 1. Amount of building patterns and buildings before and after generalization

Building pattern	Type 1	Type 2	Type 3	Type 4	Type 5	Sum
Total number of generalization units	18	7	11	3	-	-
Total number of buildings	76	84	22	10	25	217
Total number of generalized building	50	65	11	6	8	140

5.2 Discussion

From Figure 10, it can be found that in each generalization unit, the original patterns are well kept. For example, the obvious linear patterns (shown in red dashed circles in Figure 10) are also presented linearly. All the five different building patterns are presented like before. Thus the generalized results preserve the characteristics of the original distribution, which satisfied the requirements of similarity before and after generalization.

From the statistical data in Table 1, it can be seen that the generalized results decrease the number of buildings, which is good for reliving the legible problem of the original display. From the generalized results with symbolization (Figure 11), comparing with the original one, on zoom level 16, the generalized one seems less crowded, and especially on zoom level 15 and 14, the generalized one reliefs the problems that the buildings are hard to distinguish.

Advantage of the proposed approach is that by adopting stroke technique in the process of building pattern detection, not only the linear building patterns are recognized, but also the unstructured clusters can be detected simultaneously. The entire region of building data are divided into different generalization units, by analyzing the characteristic of each generalization units, different generalization strategies are designed for them, which can preserve the original presents or structures of the building.

There are also some limitations: the proposed approach aims at the data of suburb region where the buildings are discrete. In the region where has large commercial and industrial buildings, it can be foreseen that the existence of large area buildings will bring new problems to the stroke-based approach. Therefore how to modify the method to extend the range of application is still to be studied.

6. Conclusions

This paper proposes a stroke-based approach to detect building patterns for the generalization purposes. With the help of strokes, different building patterns are detected simultaneously and generate the generalization units. Different generalization strategies and operators are designed and used to the units by analyzing characteristic. The experimental results indicate that with the generalization of buildings, the legible problems of OSM are relieved when the zoom level decreasing so that better visual feeling is brought to the map users. Currently, the generalization results are evaluated only by the visual perception, which is subjective and non-precisely, hence the future work should focus on the evaluation. Another outlook is that the proposed approach should also consider the effects caused by the generalization of road network.

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