AN APPROACH TO BUILDING GROUPING BASED ON HIERARCHICAL CONSTRAINTS

H. B. Qi *, Z. L. Li

Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, CHINA - (Lsgi.hbqi, lszlli)@polyu.edu.hk

Commission II, WG II/3

KEY WORDS: Building generalization, building grouping, hierarchical constraints, Gestalt factors, minimum spanning tree

ABSTRACT:

Building generalization is one of the difficult operations in automated map generalization. It usually consists of two consecutive steps, i.e. dividing buildings into groups (also called building grouping) and performing generalization operations on building groups (also called generalization execution). This paper mainly focuses on the first step, which aims at proposing an approach to identify building groups for generalization. The proposed approach is based on the analysis of manual building grouping process, which leads to the basis of this approach that constraints are used hierarchically in building grouping process. In the approach, contextual features, such as road networks and river networks, and Gestalt factors, i.e. proximity, common orientation and similarity, are identified as constraints and they are used for building grouping in the same hierarchical way as manual grouping process: first, contextual features are used to partition buildings on the whole map into different regions; then, for each region, minimum spanning tree is employed to represent proximity relationships among buildings and three Gestalt factors are sequentially used as weights to segment a region into different groups.

1. INTRODUCTION

Automated map generalization has been an issue in the cartography and GIS communities for many years. In the past few years, much attention has been paid to the generalization of different types of map features, such as building ~~(Ruas, 1998; Regnauld, 2001; Christophe and Ruas, 2002; Duchêne et al., 2003; Li et al. 2004; 2005; Ai and Zhang, 2007; Li, 2007; Yan et al., 2008)~~, road network ~~(Mackaness, 1995; Thomson and Richardson, 1995; Morisset and Ruas, 1997; Thomson and Richardson, 1999; 2003; Jiang and Harrie, 2003; Zhang, 2005)~~, river network ~~(Richardson, 1993; Wu, 1997; Wolf, 1998; Thomson and Brooks, 2000; Ai et al., 2006), etc.~~ However, due to the complexity of the spatial distribution of buildings and for reasons of spatial recognition, building generalization has always been one of the difficult operations in automated map generalization (Li et al., 2004). According to observations on manual generalization, building generalization implicitly consists of two consecutive steps, i.e. dividing buildings into groups (also called building grouping) and performing different generalization operations on different building groups (also called generalization execution) (Li et al., 2004; Yan et al., 2008). ~~Automated building generalization is the simulation of these two steps. For the second step, as mentioned above, many researchers have devoted to this area in the past two decades and, as a result, a subset of generalization operators (e.g. aggregation,, displacement, elimination, simplification and typification) for building generalization have been identified and a lot of algorithms have been developed.~~ Thus, this paper will not discuss this step. Instead, the focus is put on the first step of building generalization, namely building grouping.

Building grouping is a process to separate buildings into different groups based on some criteria (also called 'constraints' in some literature). During the last decades, several researchers have proposed different methods for building grouping based on different criteria. Regnauld (2001) proposed a method to separate buildings into groups by using minimum spanning trees, size and orientation homogeneity, and other perception criteria. Steinhauer et al. (2001) designed a method for recognition of so-called abstract regions in cartographic maps. They used the adjacency of buildings in the Voronoi diagram, the distance between buildings, and their cardinality as criteria to form building groups. Christophe and Ruas (2002) presented an approach to detect buildings aligned in rows. In their approach, straight-line templates are first used to detect building alignments. The identified alignments are then characterized by a set of parameters such as proximity and similarity, and only those perceptually regular buildings are retained. Li et al. (2004) developed a building grouping approach based on urban morphology and Gestalt theory. In the approach, the neighbourhood model in urban morphology provides global constraints for guiding the global partitioning of building sets on the whole map and the local constraints from Gestalt principles provide criteria for further grouping. Allouche and Moulin (2005) explored how Kohonen-type neural networks can be used to identify high-density regions on maps which include cartographic elements of the same type. Yan et al. (2008) presented a multi-parameter approach to automated building grouping and generalization. In the approach, three principles of Gestalt theories (i.e. proximity, similarity and common directions) are employed as guidelines (criteria) and six parameters (i.e. minimum distance, area of visible scope, area ratio, edge number ratio, minimum bounding rectangle and directional Voronoi diagram) are selected to describe spatial patterns, distributions and relations of buildings.

Obviously, these methods try to simulate the manual process that cartographers group buildings together by using a number

* Corresponding author. Tel.: +852 2766 5977; fax: +852 2330 2994; E-mail address: Lsgi.hbqi@polyu.edu.hk.

of well-defined theories/techniques, such as graph theory, Delaunay triangulation network, the Voronoi diagram, Kohonen's Self Organizing Maps (SOM), urban morphology, clustering analysis and Gestalt theory, and by defining a lot of parameters to describe some grouping criteria. But they neglect a fact that the use of these criteria in the manual process of building grouping may have an order of priority, namely hierarchical relationship. Therefore, the objective of this paper is to describe the possible hierarchical relationship among constraints (criteria) for building grouping and propose an approach to building grouping based on these hierarchical constraints.

The remainder of this paper is organized as follows: Section 2 discusses constraints and their hierarchy for building grouping. Then, methods for quantification of these constraints are described (Section 3). The building grouping process based on hierarchical constraints is addressed in Section 4. Finally, some conclusions are drawn (Section 5).

2. HIERARCHY OF CONSTRAINTS FOR BUILDING GROUPING

As mentioned previously, building grouping is based on some constraints (criteria). In this section, constraints for building grouping will be identified and their relationship in the process of building grouping will be described.

2.1 Constraints for building grouping

When generalizing a map in an automated way, constraints are needed to control the process. Here, a constraint is referred to as a design specification to which the solutions to a generalization problem should adhere (Weibel and Dutton, 1998). Over the past few years, several researchers have proposed different sets of constraints for map generalization from different aspects. To govern the whole map generalization process, Weibel and Dutton (1998) defined five different types of constraints: graphic constraints, topologic constraints, structural constraints, gestalt constraints and process constraints. For specific building generalization, Regnauld (2001) identified four main kinds of constraints, namely legibility (i.e., perception, separation and maximum density), visual identity (i.e., shape, size and color), spatial organization (e.g., gestalt factors proximity, similarity and continuity) and homogeneity. Based on geometric, topologic and semantic analysis of spatial objects, Ai and Zhang (2007) proposed five types of constraints for building generalization, i.e., the maintenance of position accuracy, the avoidance of short gap distance, the balance of whole area, the retainment of Gestalt nature and the retainment of square shape. For building grouping in building generalization, Li *et al*. (2004) distinguished two types of constraints: global constraints based on urban morphology and local constraints based on Gestalt principles.

Among these different sets of constraints for map generalization, the Li *et al*.'s classification of constraints is identified specifically for building grouping, which is the focus of this paper. Therefore, they will be followed in this study. That is to say, in this study, two categories of constraints will be employed to guide the process of building grouping. They are contextual features and Gestalt factors. For the former category, among the many contextual features, roads and rivers are often used to partition buildings into groups due to their network structures and their relationships with buildings. The latter category, namely Gestalt factors, is from Gestalt theory, which is the study of the factors influencing grouping perception. This kind of constraints is usually used to govern the spatial organization of features in the building grouping process. From literature, it can be seen that Gestalt factors have been applied for the recognition of spatial distribution patterns for many years in both digital and manual generalization. Up to now, at least eight Gestalt factors have been employed in automated map generalization to form groups of cartographic objects. They are: proximity, similarity, common orientation, continuity, connectedness, closure, common fate and common region. Detailed description of these Gestalt factors can be found in Li et al. (2004) and Yan et al. (2008). Among these eight Gestalt factors, the first three are relevant to the spatial distribution of buildings. Therefore, for local constraints, this paper mainly focuses on these three Gestalt factors.

2.2 Hierarchy of constraints

As discussed previously, two categories of constraints guide the process of building grouping. In practice, these constraints do not work independently. They usually influence the grouping results in a combinatorial way. However, through an observation on manual building grouping process, it can be found that the use of these constraints conforms to the human's custom on spatial cognition: information are arranged hierarchically and hierarchical methods are used for reasoning (Hirtle and Jonides, 1985); 'Hierarchization' is one of the major conceptual mechanisms to model the world (Timpf, 1999). That is to say, in the building grouping process, the use of constraints is hierarchical: first, roads and rivers are used to partition buildings on the whole map into different region; then for each region, Gestalt factors are employed to further partition buildings into different groups. Figure 1 lists the constraints for building grouping and their hierarchical relationship. They will be discussed in the following paragraphs.

Constraints
- Global constraints (Contextual features)
  - Road networks - - - -Level1
  - River networks - - - -Level1
- Local constraints (Gestalt factors)
  - Proximity - - - - - - - - - - - -Level 2
  - Common orientation - - - Level 3
  - Similarity - - - - - - - - - - - -Level 4

Figure 1. Constraints for building grouping and their hierarchical relationship.

The first category of constraints, roads and rivers, are also arranged hierarchically on topographic maps. For example, roads between cities (or towns) may be ranked as national highway, provincial highway, prefectural highway and country road. Roads within a city can be classified as major traffic roads, distributor roads and cul-de-sacs. Likewise, rivers can be distinguished as main rivers and different levels of tributaries. Figure 2 illustrates a hierarchical structure of a road network. In the building grouping process, according to target map scale, roads and rivers with corresponding levels of detail are selected to initially partition buildings on the whole map into different regions.

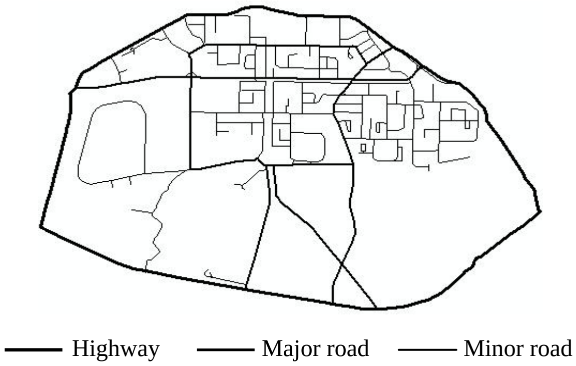
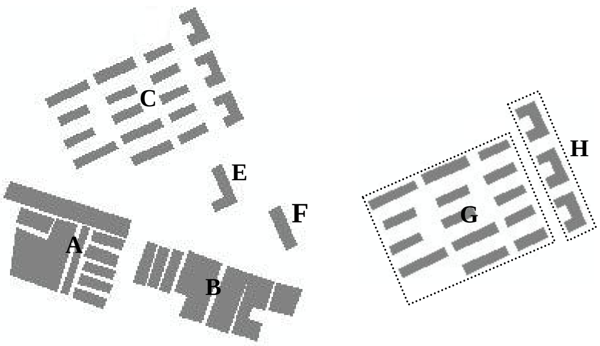


Figure 2. Hierarchical structures of road network.

With regard to the second category of constraints, the use of them (i.e. proximity, similarity, common orientation) for building grouping is also hierarchical. Let's explain this with buildings in Figure 3(a) (they are in the same region partitioned by roads and rivers) as an example. The manual grouping of these buildings may follow such a process. First, according to degree of proximity between buildings, five building groups marked A, B, C, D and E (Figure 3(a)) can be identified. For groups A and B, they will not be divided anymore because the degree of proximity between buildings is "very close". For groups E and F, each of them is considered as a group separately since they are "very far" from the other buildings. Second, for those groups in which the degree of proximity between buildings is "medium", such as group C in Figure 3(a), difference of orientation between buildings is then used to divide the group into different subgroups, such as groups G and H in Figure 3(b). Third, for those subgroups in which the difference of orientation between buildings is "small" (if the difference of orientation of a building is "large" from all the other buildings, it will be considered as a subgroup independently), degree of similarity (combination of shape, size and orientation) is finally used to further partition the subgroup in the same way.



(a) (b)

Figure 3. An illustration of manual process of building grouping. (a) initial grouping according to proximity, (b) further grouping according to orientation and similarity.

According to the above-analyzed process of building grouping, it can be found that proximity, orientation and similarity are hierarchically used to partition buildings into different groups. Figure 4 illustrates the hierarchical relationship of these three constraints. They will be used to guide the proposed method for automated building grouping in this paper.

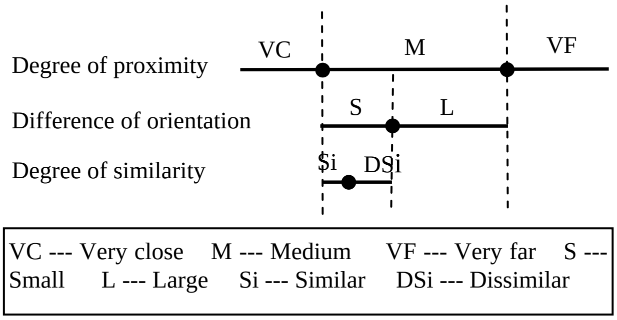


Figure 4. Hierarchical relationships of three local constraints for building grouping.

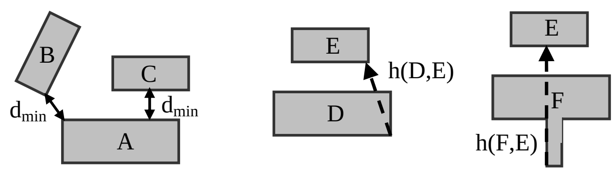
3. QUANTIFICATION OF CONSTRAINTS

In the previous section, constraints for building grouping have been identified and their relationships in the manual grouping process have been analyzed. This section will discuss quantification of these constraints for automated building grouping. For the first category of constraints, namely roads and rives, it's no need to quantify. Therefore, this section mainly focuses on the quantification of the three local constraints.

3.1 Proximity

Proximity is an important influential factor for building grouping. Its quantification means to measure the degree of proximity between neighbouring buildings. Usually distance measures are used for such purpose. Among the many distance measures, the minimum distance, the maximum distance and the centroid distance are three most commonly used ones. However, these distance measures only consider a single point from each object but have nothing to do with the position, shape, orientation, and spatial extent of each object at all. In other words, they are incapable of measuring the distance relations of the objects adequately (Deng et al., 2007). As a result, they are not able to completely describe the degree of proximity between buildings. For example, Figure 5(a) illustrates two pairs of buildings (A-B and A-C) which have the same minimum distance but different degree of proximity.

Hausdorff distance is anther frequently used distance measure which is defined as "maximum distance of a set to the nearest point in the other set" (Rote, 1991). Although it captures the subtleties ignored by the above-mentioned three distance measures, it also has its own weakness, namely very sensitive to noise. That is to say, a single outlier can easily change the distance value. Figure 5(b) and Figure 5(c) illustrate this weakness.



(a) (b) (c)

Figure 5. Illustrations of drawbacks of minimum distance (a) and Hausdorff distance ((b) and (c)) for describing degree of proximity.

To overcome the drawback of the Hausdorff distance, a modified Hausdorff distance is employed to describe the degree of proximity for building grouping in this paper. Compared to the Hausdorff distance, the modified Hausdorff distance considers not only the boundary of the objects but also the interior of the objects. The computation of this distance needs to divide objects into raster units first (see Figure 6). Then, like the Hausdorff distance, the modified Hausdorff distance from A to B (or B to A)) are defined as follows:

$$mh(A,B) = \frac{\sum_{a \in A} \{\min_{b \in B}\{d(a,b)\}\}}{m} \quad (1)$$

$$mh(B,A) = \frac{\sum_{b \in B} \{\min_{a \in A}\{d(b,a)\}\}}{n} \quad (2)$$

The modified Hausdorff distance between A to B is defined as:

$$MH(A,B) = \frac{1}{2}\left(mh(A,B) + mh(B,A)\right) \quad (3)$$

Where a and b are raster units of sets A and B respectively, d(a, b) is Euclidean distance between units a and b, m is the unit number within polygon A and n is the unit number within polygon B.

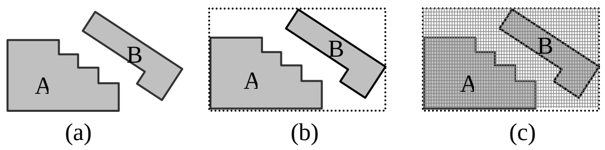


Figure 6. Rasterization of buildings for computation of the modified Hausdorff distance. (a) original buildings, (b) creating minimum bounding rectangle, (c) rasterization.

3.2 Orientation

Orientation is another important influential factor for building grouping in building generalization. It is usually used to describe the spatial extent of an individual building. To date, five measures have been developed to calculate orientation of a building (Duchêne et al. 2003). They are: longest edge, weighted bisector, wall average, statistical weighting, and minimum bounding rectangle (MBR). Through experiments, Duchêne et al. (2003) concluded that the MBR is the most appropriate one. Therefore, in this study, the MBR will be employed to describe orientation of an individual building and difference of orientations between two buildings is used to judge whether two neighboring buildings are in common orientation. According to this computation method, orientation of an individual building is a value between 0 and 180 while difference of orientations between two buildings range from 0 to 90.

3.3 Similarity

Similarity is the third local constraints used for building grouping in this study. It can be evaluated from three aspects, namely shape, size and orientation. In the existing building grouping methods mentioned previously, these three aspects are usually described respectively by different parameters. However, sometimes cartographers consider these three aspects as a whole when they conduct certain generalization operation, such as typification. Therefore, a similarity measure with consideration of these three aspects is needed.

It is noted that when two buildings are equal they must be completely similar in shape, size and orientation. Based on this common sense, a computation method for assessing degree of similarity between two buildings is developed in this study. The method needs to first find their centers of gravity of two compared buildings (Figure 7(a)), and then to superimpose them based on their centers of gravity (Figure 7(b)). After that, the degree of similarity, DS, between two buildings is defined as:

$$DS(A,B) = \frac{S(A \cap B)}{S(A \cup B)} \quad (4)$$

Where $S(A \cap B)$ is the area of the intersection set of polygons A and B, $S(A \cup B)$ is the area of the union set of polygons A and B.

Accordingly, degree of dissimilarity, DD, between two buildings is defined as:

$$DD(A,B) = 1 - \frac{S(A \cap B)}{S(A \cup B)} \quad (5)$$

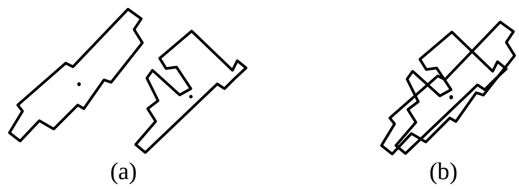


Figure 7. Computation of similarity between two buildings. (a) location of centers of gravity of two compared buildings, (b) Superimposition of buildings based on their centers of gravity.

According to the above-mentioned computation method, degree of similarity between two buildings is a value between 0 and 1 that represents a linear estimation of similarity: high value indicates similar and low value dissimilar.

4. BUILDING GROUPING BASED ON HIERARCHICAL CONSTRAINTS

In the previous sections, constraints and their hierarchy for building grouping are explored and quantifications of these constraints are also discussed. In this section, the building grouping process based on above-discussed hierarchical constraints will be described.

4.1 A line of thought for building grouping

As mentioned earlier in this paper, automated method is the simulation of manual operations. Therefore, the proposed approach is based on the previous analysis on manual process of building grouping. In the approach, the whole building grouping process is considered as a partitioning process: first, contextual features are used to partition buildings on the whole

map into different regions; then Gestalt factors, i.e. proximity, common orientation and similarity are sequentially used to partition a region into different groups.
For the latter part of the partitioning process, minimum spanning tree (MST) is used to capture the adjacency relations between buildings and degree of proximity, difference of orientations and degree of similarity between buildings are separately used as weights to segment the MST. They can be subdivided into three steps:

(1) According to degree of proximity between buildings, a region is partitioned into different groups. For groups in which degree of proximity between buildings is "very close" or "very far", they will not be partitioned anymore. While for groups in which degree of proximity between buildings is "medium", they need to be further partitioned by orientation.

(2) Difference of orientations between buildings is then used to partition the above-mentioned groups into different subgroups. For subgroups in which degree of proximity between buildings is difference of orientations is "small", they need to be further partitioned by similarity.

(3) Degree of similarity between buildings is finally used to partition the above-mentioned subgroups into different super subgroups.

4.2 Building grouping process

Based on the above-mentioned line of thought for building grouping, for a region partitioned by road networks or river networks, building grouping process can be divided into following steps:

1) Construct constrained Delaunay triangulation network: To preserve the integrity of buildings, when constructing Delaunay triangulations, all the building boundaries are forced to serve as edges of triangles. This step is to detect adjacency relationships among buildings (Figure 8(b)).

2) Create connectivity graph: For each building in the network, locate its centroid. Then connect two centroids whose buildings are connected with triangles (Figure 8(c)). This step transforms adjacency relationship among area objects to adjacency relationship among point objects, which is much easier to represent.

3) Quantify constraints for building grouping: According to the above-discussed methods, calculate degree of proximity, difference of orientations and degree of dissimilarity for each pair of connected buildings in the connectivity graph. The values are attached to the edges of the connectivity graph for later use.

4) Identify building groups by proximity: Weight the edges between linked buildings in the connectivity graph with degree of proximity and create minimum spanning tree (Figure 8(d)). The degree of proximity is distinguished as very close, medium and very far in this step (their values is variable according to different target map scales). Then break the minimum spanning tree according to the lower bound value of 'very far' and initial groups can be obtained (Figure 8(e)). In Figure 8(e), buildings located very close are connected by thicker edges and medium by thinner edges.

5) Identify subgroups by orientation: For group in which the degree of proximity between buildings is medium, orientation is used to further identify subgroups. The process is similar to the first four steps (Figure 8(f)-(i)). The difference is that difference of orientation between buildings is used as weight to create and segment minimum spanning tree and the difference of orientation is distinguished as small and large.

6) Identify subgroups by orientation: For subgroup in which the difference of orientation between buildings is small, similarity is used to further identify subgroups. The process is similar to the first four steps. In this step, degree of similarity between buildings is used as weight to create and segment minimum spanning tree and degree of similarity is separated as similar and dissimilar.

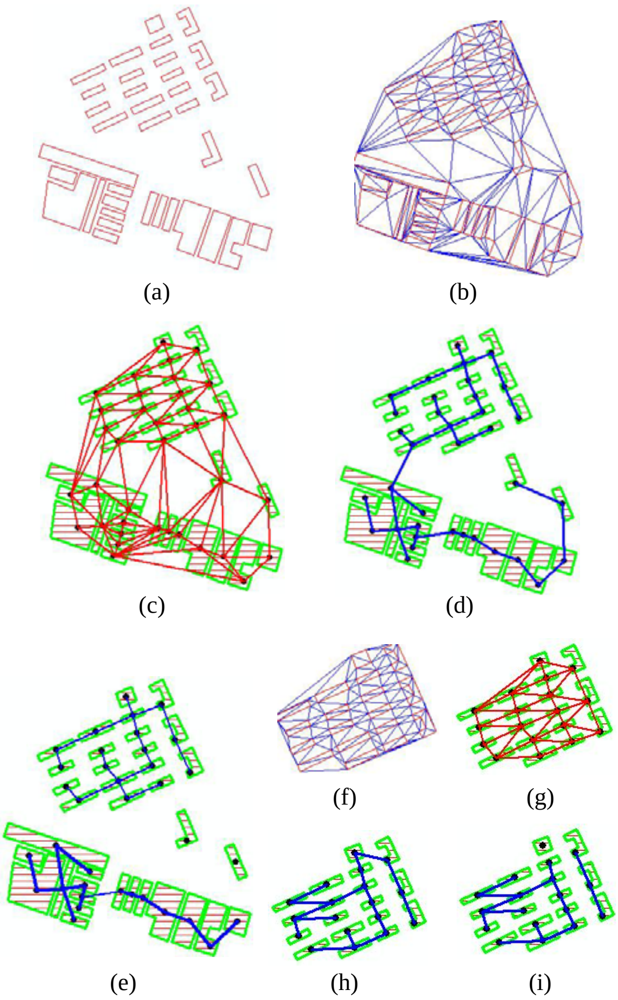


Figure 8. Illustration of building grouping process.

5. CONCLUSION

This paper has presented an approach to identification of building groups. The approach is based on the analysis of manual building grouping process, which leads to the basis of this approach that constraints are used hierarchically in building grouping process. In the approach, contextual features, such as road networks and river networks, are used to partition buildings on the whole map into different regions in the first instance. Then, for each region, minimum spanning tree is employed to represent proximity relationships among buildings and Gestalt factors, i.e. proximity, common orientation and similarity, are sequentially used as weights to segment a region into different groups. Methods for quantification of the three Gestalt factors are also described in this paper.

Future research will focus on all kinds of visual perception tests for building grouping, which will provide benchmarks for the proposed approach.

ACKNOWLEDGEMENTS

This work was substantially supported by State 973 Program of China (no. 2006CB701304) and a studentship (RGLT) of the Hong Kong Polytechnic University.

REFERENCES

Ai T.H., Liu Y.L. and Chen J., 2006. The hierarchical watershed partitioning and data simplification of river network. Proceedings of the 12th International Symposium on Spatial Data Handling, 10-12th July, University of Vienna, Austria.

Ai T.H. and Zhang X., 2007. The aggregation of urban building clusters based on the skeleton partitioning of gap space, *Lecture Notes in Geoinformation and Cartography*, Part 4, pp. 153-170.

Allouche M.K. and Moulin B., 2005. Amalgamation in cartographic generalization using Kohonen's feature nets. *International Journal of Geographical Information Science*, 19(8-9), pp. 899-914.

Christophe S. and Ruas A., 2002. Detecting building alignments for generalisation purposes. in Richardson D.E. and van Oosterom P. (Eds.), Advances in Spatial Data Handling (The 10th International Symposium on Spatial Data Handling), Berlin Heidelberg New York: Springer pp, 419–432.

Deng M., Li Z.L. and Chen X.Y., 2007. Extended Hausdorff distance for spatial objects in GIS. *International Journal of Geographical Information Science*, 21(4), pp. 459-475.

Duchêne C., Bard S., and Barillot X., 2003. Quantitative and qualitative description of building orientation. The 5th ICA workshop on progress in automated map generalization, Paris, France.

Hirtle S.C. and Jonides J., 1985. Evidence of hierarchies in cognitive maps. *Memory & and Cognition*, 13(3), pp. 208-217.

Jiang B. and Harrie L., 2003. Selection of streets from a network using self-organizing maps. *Transactions in GIS*, 8(3), pp. 335-350.

Li Z.L., 2007, *Algorithmic Foundation of Multi-Scale Spatial Representation*, CRC Press, Taylor & Francis Group.

Li Z.L., Yan H.W., and Ai T.H., 2004. Automated building generalization based on urban morphology and gestalt theory. *International Journal of Geographical Information Science*, 18(5), pp. 513–534.

Mackaness W.A., 1995. Analysis of urban road networks to support cartographic generalization. *Cartography and Geographic Information Systems*, 22, pp. 306－316.

Morisset B. and Ruas A., 1997. Simulation and agent modeling for road selection in generalization. Proceedings of the 18th International Cartographic Conference, pp. 1376-1380.

Regnauld N., 2001. Contextual building typification in automated map generalization. *Algorithmica*, 30 (2), pp. 312–333.

Richardson D.E., 1993. Automatic spatial and thematic generalization using a context transformation model. PhD Thesis, Wageningen Agricultural University.

Rote G., 1991. Computing the minimum Hausdorff distance between two point sets on a line under translation. *Information Processing Letters*, 38, pp. 123-127.

Ruas A., 1998. A method for building displacement in automated map generalization. *International Journal of Geographical Information Science*, 12(8), pp. 789–803.

Steinhauer J.H., Wiese T., Freksa C., and Barkowsky T., 2001. Recognition of abstract regions in cartographic maps. In Montello D.R. (Eds.), *Spatial Information Theory*, Berlin Heidelberg New York: Springer, pp. 306–321.

Thomson R.C. and Brooks R., 2000. Efficient generalization and abstraction of network data using perceptual grouping. Proceedings of the 5th International Conference on Geo-Computation.

Thomson R.C. and Richardson D.E., 1995. A graph theory approach to road network generalisation. Proceedings of the 17th International Cartographic Conference, pp 1871－1880.

Thomson R.C. and Richardson D.E., 1999. The 'good continuation' principle of perceptual organization applied to the generalization of road networks. Proceedings of the 19th International Cartographic Conference, Ottawa, pp. 1215－1223.

Timpf S., 1999. Abstraction, levels of detail, and hierarchies in map series. *Lecture Notes in Computer Sciences*, Vol. 1661, pp. 125-140.

Weibel R. and Dutton G.H., 1998. Constraint-based automated map generalization. Proceedings of the 8th International Symposium on Spatial Data Handling, Vancouver, Canada, pp. 214-224.

Wolf G.W., 1998. Weighted surface networks and their application to cartographic generalization. In: Barth W. (Eds.), *Visualization Technology and Algorithm*, Springer-Verlag, Berlin, pp 199－212.

Wu H.H., 1997. Structured approach to implementing automatic cartographic generalization. Proceedings of the 18th International Cartographic Conference, Stockholm, Sweden, pp 349-356.

Yan H.W., Weibel R. and Yang B.S., 2008. A multi-parameter approach to automated building grouping and generalization. *Geoinformatica*, 12(1), pp.73-89.

Zhang Q.N., 2004. Road Network Generalization Based on Connection Analysis. Proceedings of the 11th International Symposium on Spatial Data Handling, 23-25 August, University of Leicester, UK.