High Quality Building Generalization by Extending the Morphological Operators

Jonathan Damen Marc van Kreveld Bert Spaan

Department of Information and Computing Sciences
Utrecht University

Abstract

We revisit the morphological operators closure and opening to achieve high quality aggregation of buildings when performing cartographic generalization. We show that *closure followed by opening*, or vice versa, provides an elegant solution that incorporates both small building elimination, detail elimination, and building aggregation, and gives output of high quality. Since some short edges remain, the outcome of the morphological operators can be simplified using standard short edge elimination techniques. We compare the outcome of the usual morphological operators closure and opening with our combined ones, which are in fact closure followed by opening and opening followed by closure. We also study the effects of increasing the size of the square with which the morphological operators are performed, and the effects of short edge elimination.

1 Introduction

Cartographic generalization of spatial data has been a major research topic for many years now. Many issues have been addressed, including algorithms for individual generalization operators, the order of operators, and evaluation of the results. The ultimate goal is to be able to perform fully-automated high-quality map generalization. The AGENT project [7] made a large step in this direction. It provides a framework and a methodology in which evaluation of situations and algorithms for improvement are incorporated. The success of such a global approach still depends on the quality of the individual steps taken. Hence, the interest in the implementation of generalization operators that give high quality results remains.

Building generalization. Cartographic generalization of urban data involves the generalization operators elimination, displacement, aggregation, exaggeration, detail elimination, squaring, and typification (see for instance [12]). Let us consider the situation of a collection of buildings that requires generalization; Figure 1 shows a typical situation. Elimination is needed to remove small buildings like sheds, or small isolated houses. Displacement is needed for buildings that would be too close at the desired map scale, or to move buildings further from a road. Aggregation is the operator that groups buildings into larger units of built-up blocks, if they should not be shown separately. Detail elimination is the removal of short edges from building outlines, and improves the visual quality of the map by making it appear less cluttered. Squaring makes the corners of a building have right angles, providing abstraction and improving the visual quality. Typification is needed to preserve a regular pattern in a larger group of buildings by replacing that group with a smaller group that still exhibits that regular pattern.

Many of the operators needed for building generalization have been studied. We list some of these next. Methods for displacement were given in [1, 9, 10, 17, 20]. Detail elimination and short edge removal was studied in [6, 19, 20]. Typification was done in [2, 13, 14]. Squaring was studied in [11, 15, 18]. Approaches for the aggregation operator are reviewed more extensively next.

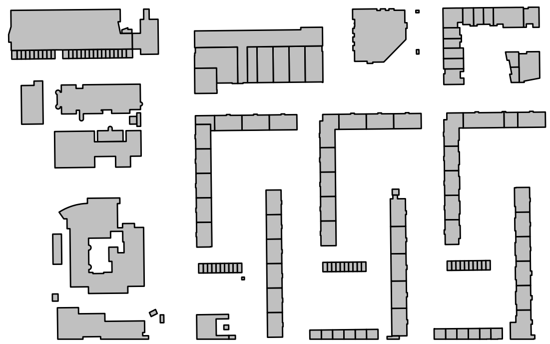

Figure 1: Buildings typical for the input of building generalization (© GVI).

Building aggregation approaches. There are four main approaches for building aggregation: (i) using triangulation, (ii) using the GAP tree, (iii) using morphological operators, and (iv) using a dedicated approach.

The triangulation approach was studied by Ware et al. [26]. Globally, the idea is to triangulate the free space between the buildings and select triangles that can be 'added' to the buildings. If triangles are chosen that lie between two close by buildings, one larger, aggregated building is created.

The GAP tree approach was introduced by van Oosterom [24] for the elimination of regions in general partitions like landuse maps. Its use in urban environments was examined in van Putten and van Oosterom [25].

Morphological operators have been used several times for the generalization of buildings. Li [8], Su et al. [23], and Cámara and López [3] show that for raster data, morphological operators can be used for urban generalization. Mayer [11] extends this to vector data.

A dedicated approach to aggregation was taken by Regnauld and Revell [16]. They suggest a multi-step method that distinguishes various cases, and involves grouping, rotation, replacement, enlargement, simplification, and some other special operations. Their method is designed to produce the geometric situation for Ordnance Survey 1:50,000 maps and achieves high quality.

Considerable research has also been targeted at grouping buildings that should be aggregated. Obviously the road network can assist to provide a partitioning into groups [7, 18]. Grouping based on visual aspects was considered extensively in [27].

Finally, 3-dimensional extensions to building generalization were given in [11, 22], and building generalization for display on mobile devices was studied in [21].

New approach and results. Our contributions to the research on morphological operators for building generalization are twofold. Firstly, we present a simple extension of the morphological operators that avoid possible problems with the standard operators. The closure operator can leave arbitrarily narrow parts in buildings, and the opening operator can leave arbitrarily small holes and narrow passages between buildings. Our extension solves these problems.

Secondly, we experimentally examine the outcome of our approach to building generalization. We combine the new morphological operators with short edge removal and show that the result has high cartographic quality. Although we did not implement other approaches, our results are significantly better than the results of triangulation and GAP tree approaches (the latter were introduced for on-the-fly generalization where computation speed is more important than cartographic quality). In our experiments we report statistics like the resulting area of building blocks, the perimeter, and the number of vertices remaining.

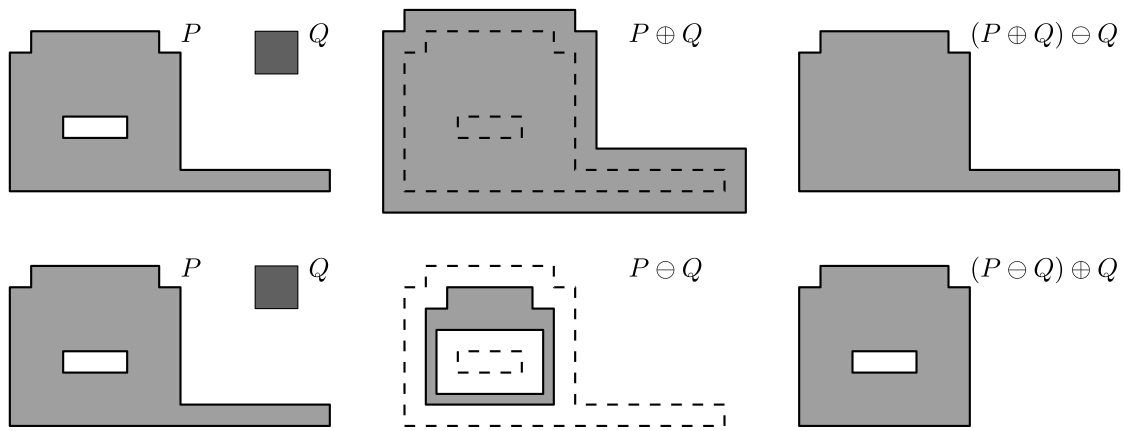

Figure 2: Top row: A building P and a square Q, their Minkowski sum (dilation), and the closure. Bottom row: A building P and a square Q, their Minkwoski subtraction (erosion), and the opening.

2 The morphological operators

In this section we briefly define and discuss the Minkowski sum and Minkowski subtraction, and the morphological operators dilation, erosion, opening, and closure. See Figure 2 for examples.

2.1 Minkowski sum

Given two polygons P and Q (or any subsets of the plane), the Minkowski sum $P \oplus Q$ is defined as

$$P \oplus Q = \{p + q \mid p \in P\,;\ q \in Q\}\,,$$

where p and q are points inside P and Q, but interpreted as vectors for the vector addition $p + q$. Notice that a change of the position of P or Q leads to a change in the position of $P \oplus Q$, but not to the shape of $P \oplus Q$.

We will consider Minkowski sums where Q is a disc or a square centered at the origin, and P represents some building outline. The Minkowski sum $P \oplus Q$ will be a slightly larger and (generally) less detailed version of P. The size of Q is essentially the amount by which P is enlarged. The Minkowski sum of P with a disc or a square is also called the *dilation* of P.

If P is a set of two polygons instead of one, the same definition can be used for $P \oplus Q$. Depending on the distance between the two polygons of P and the size of Q, the Minkowski sum $P \oplus Q$ can consist of one or two polygons. If the result is just one polygon, then the two polygons of P have been aggregated into one.

2.2 Minkowski subtraction

The Minkowski subtraction $P \ominus Q$ is defined as

$$P \ominus Q = \mathit{Complement}(\{p + q \mid p \notin P\,;\ q \in Q\})\,,$$

where p and q are points interpreted as vectors. Intuitively, we grow *the outside area of* P instead of P itself, and what remains of P is $P \ominus Q$. If Q is a disc or a square, then the Minkwoski subtraction $P \ominus Q$ is a slightly smaller and (generally) less detailed version of P. The *erosion* operator is the almost the same as the Minkowski subtraction, except that Q is mirrored in $(0, 0)$ first. Since we are only interested in squares and discs centered at $(0, 0)$, the Minkowski difference and the erosion are the same, and we will use $P \ominus Q$ for the erosion as well. A single polygon P may become disconnected by the erosion operator.

2.3 Opening and closure

The closure of P and Q is defined as $(P \oplus Q) \ominus Q$. The opening of P and Q is defined as $(P \ominus Q) \oplus Q$. It is well-known that

$$P \ominus Q \quad \subseteq \quad (P \ominus Q) \oplus Q \quad \subseteq \quad P \quad \subseteq \quad (P \oplus Q) \ominus Q \quad \subseteq \quad P \oplus Q \, .$$

If the closure is applied to more than one polygon, then they can become connected. Also, holes in a single polygon can be filled up. If the opening is applied to a single polygon, then it can become disconnected. Also, holes in a polygon can be opened and merged with the unbounded exterior of the polygon, or with other holes.

3 New morphological operators and short edge removal for building generalization

In this section we present a simple—almost trivial—extension to the morphological operators closure and opening. We observe in Figure 2 that the closure operator can leave long and narrow parts in buildings, and the opening operator can leave long and narrow holes and inlets. Furthermore, the opening operator can leave long and narrow passages between two buildings, and the closure can do the same with two holes in one building.

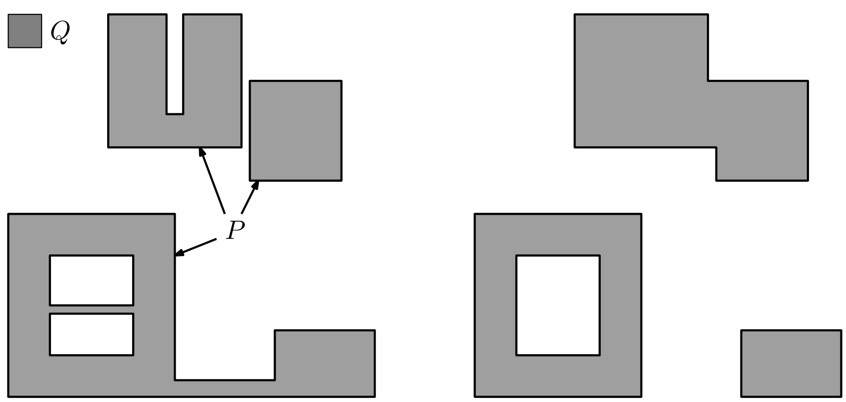

Figure 3: Left, a possible input, and right, the corresponding output after opening and closure in either order.

One way to deal with these problems is to first apply the opening and then the closure, or first the closure and then the opening. The former option is the same as first taking the erosion with a square, then the dilation with a square *of twice the size*, and then the erosion with a square again. The latter option has erosion and dilation exchanged.

If $P^{\oplus} = P \oplus Q$ denotes the dilation of P and $P^{\ominus} = P \ominus Q$ the erosion, then $P^{\oplus\ominus}$ denotes the closure and $P^{\ominus\oplus}$ denotes the opening. The two new operators are $P^{\oplus\ominus\ominus\oplus}$ and $P^{\ominus\oplus\oplus\ominus}$. For any polygon P, we have $P^{\ominus\oplus} \subseteq P^{\oplus\ominus\ominus\oplus} \subseteq P^{\oplus\ominus}$ and $P^{\ominus\oplus} \subseteq P^{\ominus\oplus\oplus\ominus} \subseteq P^{\oplus\ominus}$, but none of P, $P^{\oplus\ominus\ominus\oplus}$, and $P^{\ominus\oplus\oplus\ominus}$ properly contain each other for all P. Examples to show this are given in Figure 4.

The element Q with which the morphological operators are performed is relevant for the result. The seemingly most natural and only orientation-invariant element is the circle, but for man-made structures like buildings, the operators can give circular arcs in the generalized building outlines, so the use of a circle is unsatisfactory. Another natural choice is the square. However, different orientations of the square will give different results in the generalized building outlines. It appears to be best to choose an orientation that corresponds most to the orientations of the edges of the input buildings. For every building, we will determine the major orientation separately using the

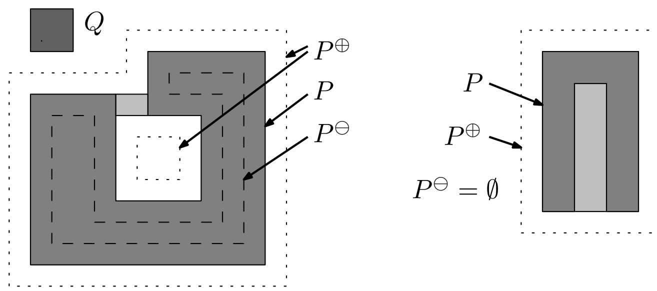

Figure 4: Left, an example where $P^{\oplus\ominus\ominus\oplus} \subset P^{\ominus\oplus\oplus\ominus}$; the light grey rectangle is only in $P^{\ominus\oplus\oplus\ominus}$. Right, an example where $P^{\ominus\oplus\oplus\ominus} \subset P^{\oplus\ominus\ominus\oplus}$; the two grey parts together form $P^{\oplus\ominus\ominus\oplus}$ whereas $P^{\ominus\oplus\oplus\ominus}$ is empty.

smallest minimum bounding rectangle [5], and therefore we may use different orientations of the square for different buildings in the data set.

The new operators do not eliminate all short edges. To get rid of these, we also describe an edge simplification method similar to the least squares adjustment method described by Sester [20].

To eliminate a short edge e_i of a polygon P, we first consider the angle that the edges e_{i-1} and e_{i+1} adjacent to e_i make.

Offset. If the angle between e_{i-1} and e_{i+1} is at most 45 degrees, then we slide edge e_i parallel to itself in one direction or the other, making e_{i-1} and e_{i+1} shorter or longer until some edge disappears.

Corner. If the angle between e_{i-1} and e_{i+1} is more than 45 degrees and less than 135 degrees, then we extend both e_{i-1} and e_{i+1} until they meet in a point and e_i disappears.

Intrusion and extrusion. If the angle between e_{i-1} and e_{i+1} is at least 135 degrees, then we slide edge e_i parallel to itself in the direction that makes e_{i-1} and e_{i+1} shorter, until one of e_{i-1}, e_i, and e_{i+1} disappears.

Some additional tests are needed to make sure that short edge elimination does not give undesirable results like self-intersections. We ignore this issue here, since this paper concentrates on the morphological operators.

4 Experiments and results

In this section we analyze the output of the morphological operators presented in this paper. Firstly, we consider the influence of the shape of the element Q with which the morphological operators are done. Then we study the relation between building generalization and the size of the element Q. Thirdly, we compare the operators opening followed by closure, and closure followed by opening. Fourthly, we consider the outcome of short edge elimination as described in the previous section.

We have performed more tests than we can show here. The figures in this paper show typical examples, but our observations come from a larger collection of tests.

The implementation was done in C^{++} and makes use of the CGAL library [4]. This library offers an implementation of the Minkowski sum of any two polygons. The Minkowski subtraction was implemented by computing a bounding box of the polygon P, and generating a new polygon with the bounding box as outer boundary and P as a hole. The Minkowski sum of this polygon with Q provided the required Minkowski subtraction as the hole (or holes) of the new polygon. The implementation is not efficient enough to be used in interactive situations. Possibly, a new, dedicated implementation can perform well enough for interactive situations, but our main objective was the visual quality of the output.

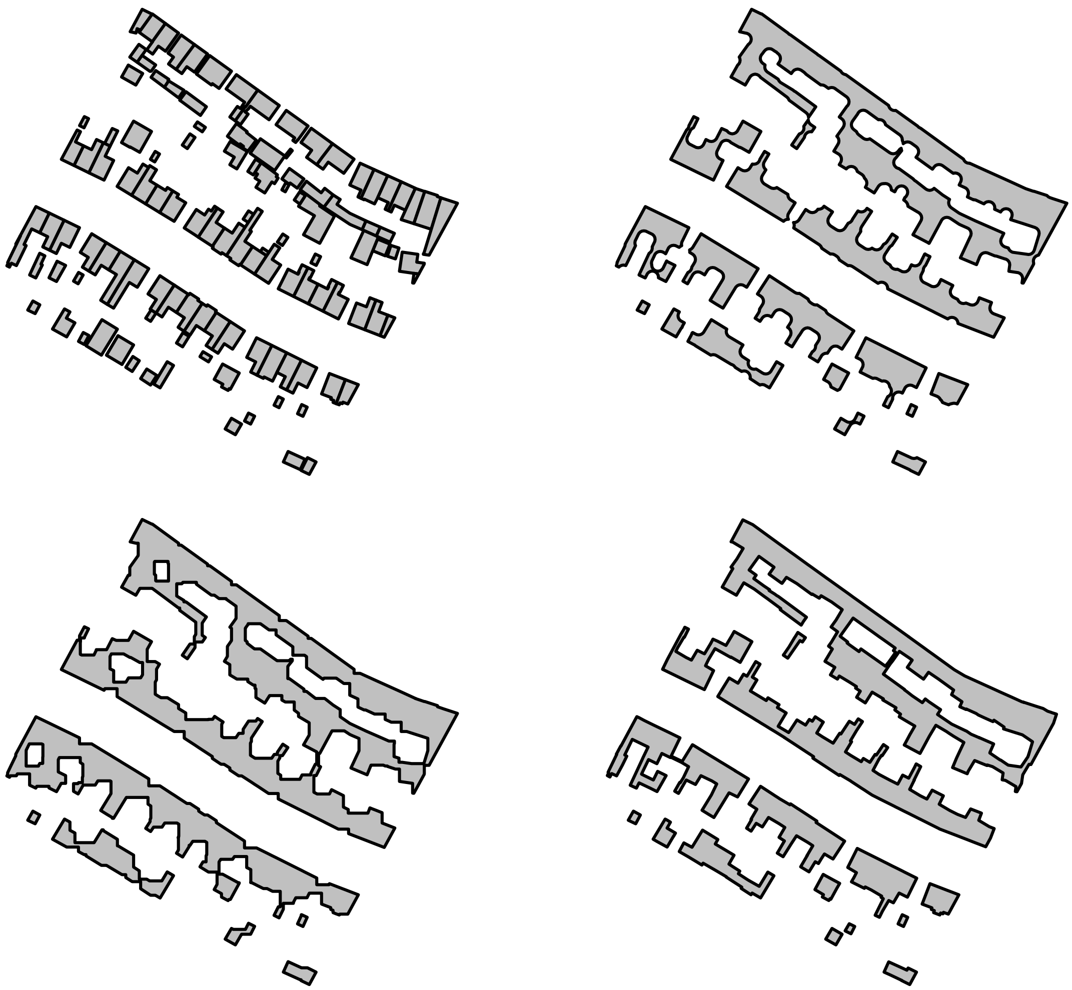

Figure 5: Original block (© GVI), closure with disc, closure with coordinate axis-aligned square, and closure with building-aligned square.

Shape of the element. As to be expected, morphological operators on buildings with a circular element Q give artifacts. Also, if the square is not aligned with the buildings to be aggregated, artifacts occur as well. This is shown visually in Figure 5.

Size of the element. It appears that the size of the element influences the amount of generalization that is done: The larger the element, the more generalization. But it is not true that more and more details are removed, because some short edges remain present in the buildings even if the morphological operator is applied with a very large element. Figure 6 shows the effect of changing the size of the element Q for a block of data from the Ordnance Survey. Figures 8 and 9 show more examples and meta-information based on GVI data. For this block and two others we tested, the area of the buildings after closure followed by opening was always the same or larger than the area of the buildings after the opening followed by closure. For an element size of 6 and up the difference is significant. For the number of vertices and the perimeter, there is no consistent difference.

It appears that if the element size is large, then the opening followed by the closure loses many buildings, possibly all of them. For elements of small size, the difference between the two operators is much less clear.

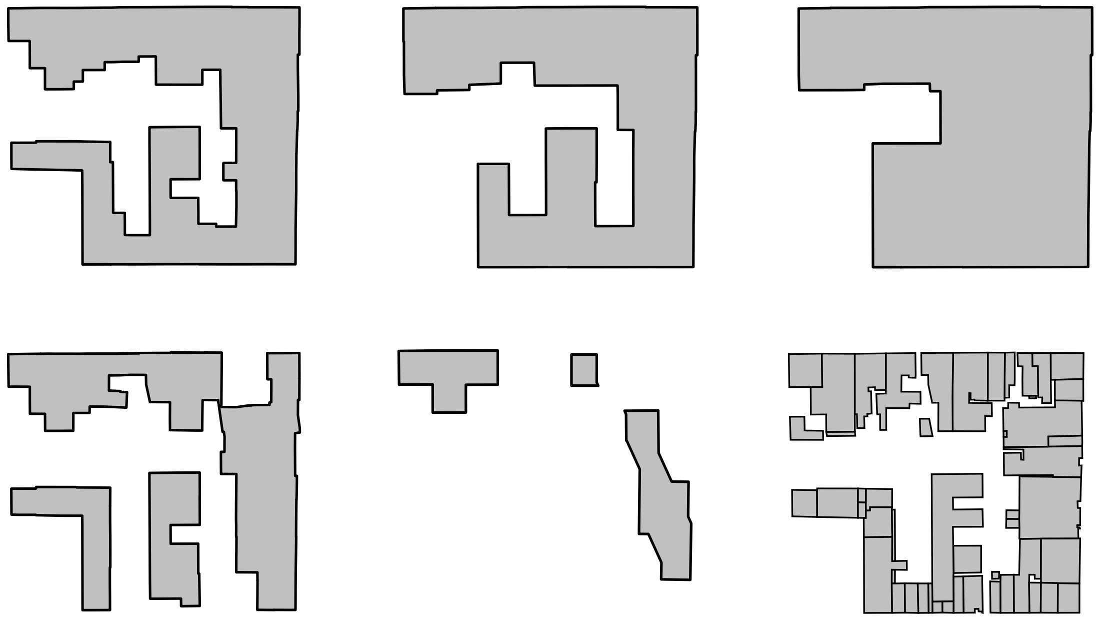

Figure 6: Morphological operators on block of houses. Top row: closure followed by opening (element sizes 6, 12 and 18). Bottom row: opening followed by closure (element sizes 6 and 12; element size 18 removes all buildings), and the original block (Ordnance Survey © Crown Copyright, all rights reserved).

Opening, closure, and the combinations. Figure 6 also shows some differences between applying the closure first and then the opening, and applying the opening first and then the closure. More examples are given in Figure 7, where the topmost four figures show the opening, the closure, the opening followed by the closure, and the closure followed by the opening, applied to the data shown in Figure 1.

We observe that the closure keeps small buildings that are removed with the other three operators. We also observe that the two combinations of opening and closure provide more generalization than only the opening or the closure. The differences between opening followed by closure, and closure followed by opening are small.

Short edge elimination. Our last set of figures shows the effect of simplification by short edge removal, as described in Section 3. The bottommost four figures in Figure 7 show short edge elimination with two different threshold values, applied to the result of closure followed by opening and to the result of opening followed by closure. It is clear that short edge removal does its task well, and several more details are removed which the opening and closure did not remove, without introducing artifacts or influencing the global picture. Other experiments (not reported here) show that the short edge elimination after closure and opening reduce the number of vertices of the output drastically, making it suitable for applications where data transmission speed is a factor.

We have also tried short edge elimination before closure and opening. Generally the output consists of significantly less building area than when eliminating short edges at the end. The reason is that short edge elimination on the input data usually makes buildings smaller, or even eliminates several of them. The potential of the closure operator to cover the areas in between buildings is therefore reduced. This is especially true for short edge elimination with higher threshold values.

5 Conclusions

It was already known that the morphological operator closure works well for building generalization by providing both aggregation and simplification. We showed that applying the closure and then the opening, or the opening and then the closure, works even better. If the operator is performed with a large (square) element, it appears that performing the closure first is the better order. If we post-process the outcome by an incremental short edge removal step, then we obtain high-quality generalized maps of built-up areas.

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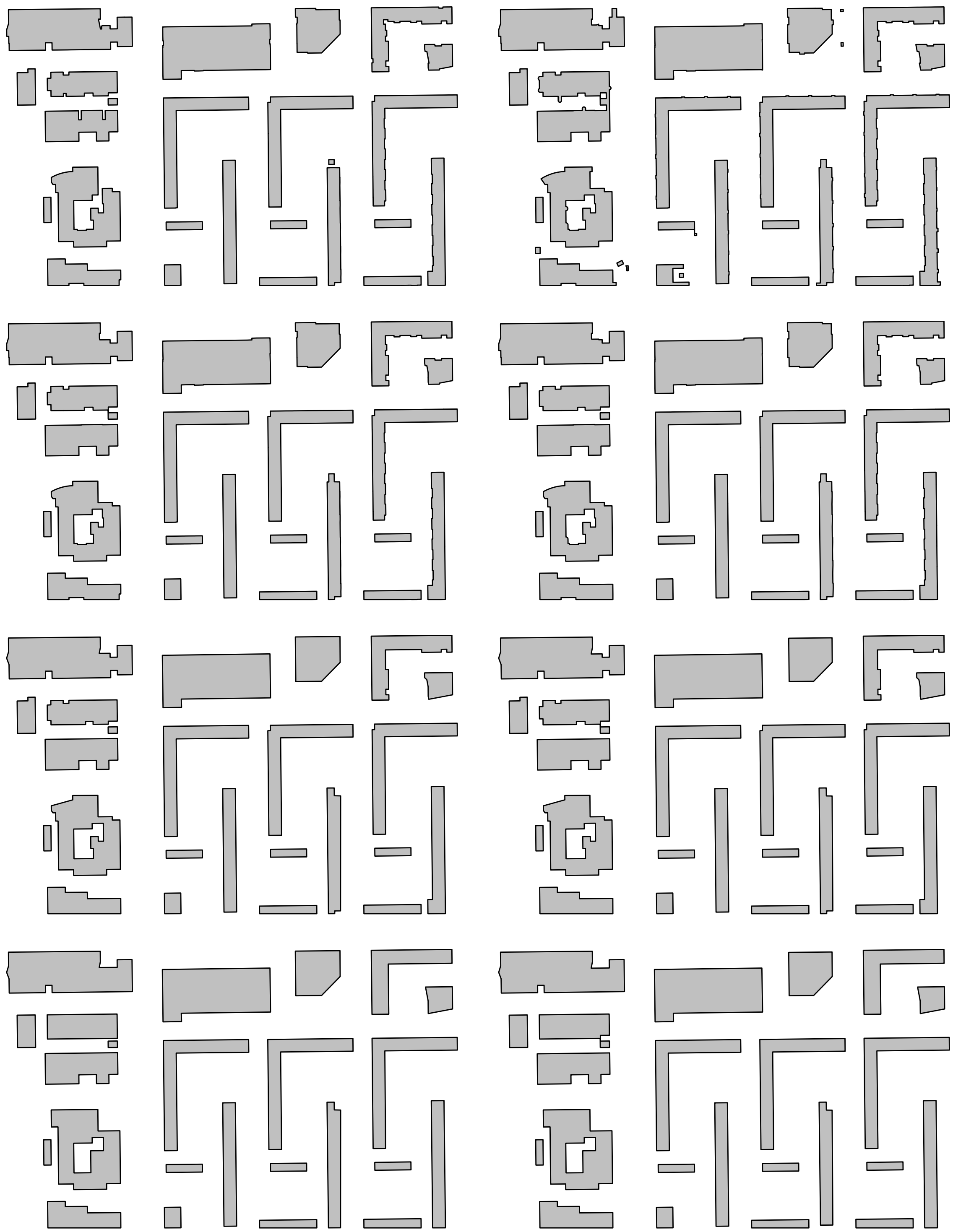

Figure 7: Generalization of the data of Figure 1. Top left: Opening. Top right: Closure. Second row left: Opening followed by closure. Second row right: Closure followed by opening. Third row: As second row, but with short edge elimination with distance 2. Fourth row: As second row, but with short edge elimination with distance 4.

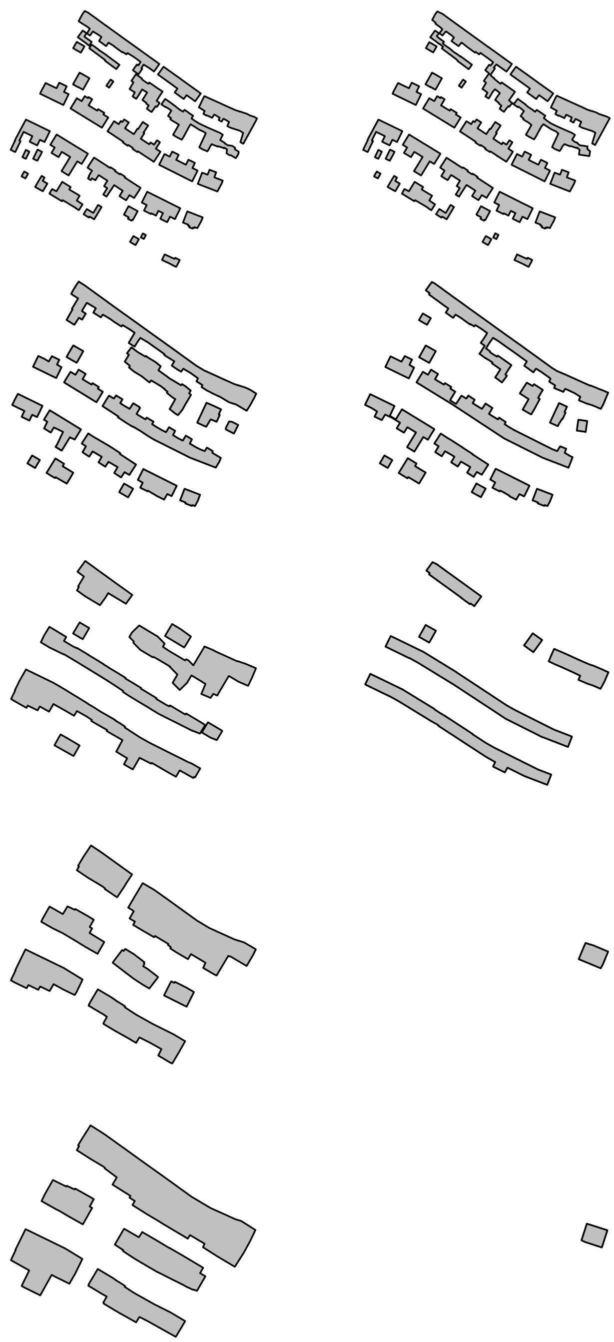

Figure 8: Different element sizes for a block. Left column: closure followed by opening. Right column: opening followed by closure. Element sizes 2, 4, 6, 8, and 10 from top to bottom.

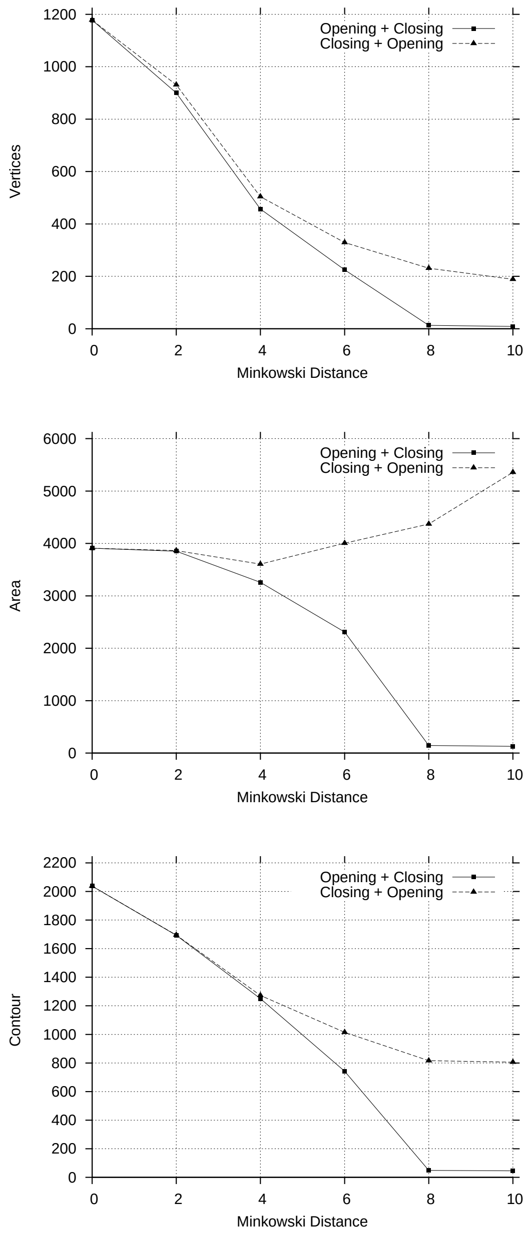

Figure 9: The number of vertices, the total area of the buildings, and the total contour length corresponding to Figure 8.