Developing a Line-of-Sight Based Algorithm for Urban Street Network Generalization

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Abstract

This paper presents a generalization algorithm focusing specifically on urban street networks that utilizes the accompanying drawing of urban blocks and the concept of convex space, medial axis, and line-of-sight.

This algorithm is going to be implemented as an automatic solution in GRASS GIS for the analysis of spatial configures of built environment.

Outline

1. Representations of urban street network
2. Generation of urban street network representations
3. Developing the generalization algorithm
4. Verification of the algorithm
5. Summary of findings

1. Introduction

1.1 Visual representations of urban street network

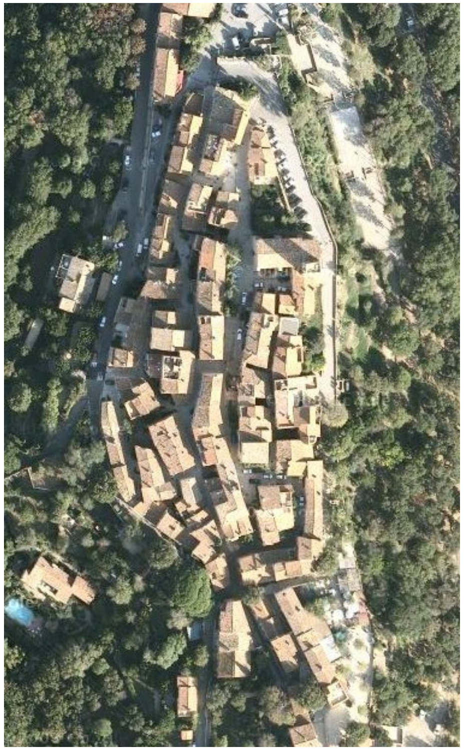
1.2 Abstract representations of urban street network

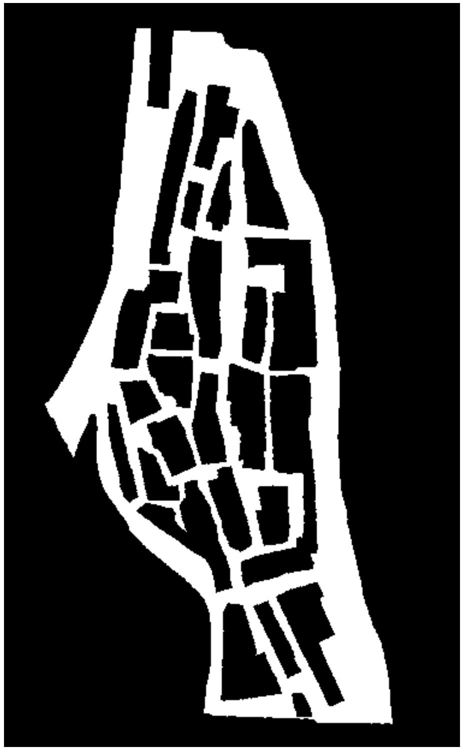
1. Introduction

- > ½ of the world's population is now living in urban areas, meaning the importance of urban settlement escalates.
- One dominant feature of an urban settlement is the extensive street network, thus representations (and analyses) of urban street networks matter.
- These representations can be visual or abstract.

1.1 Visual representations of urban street network

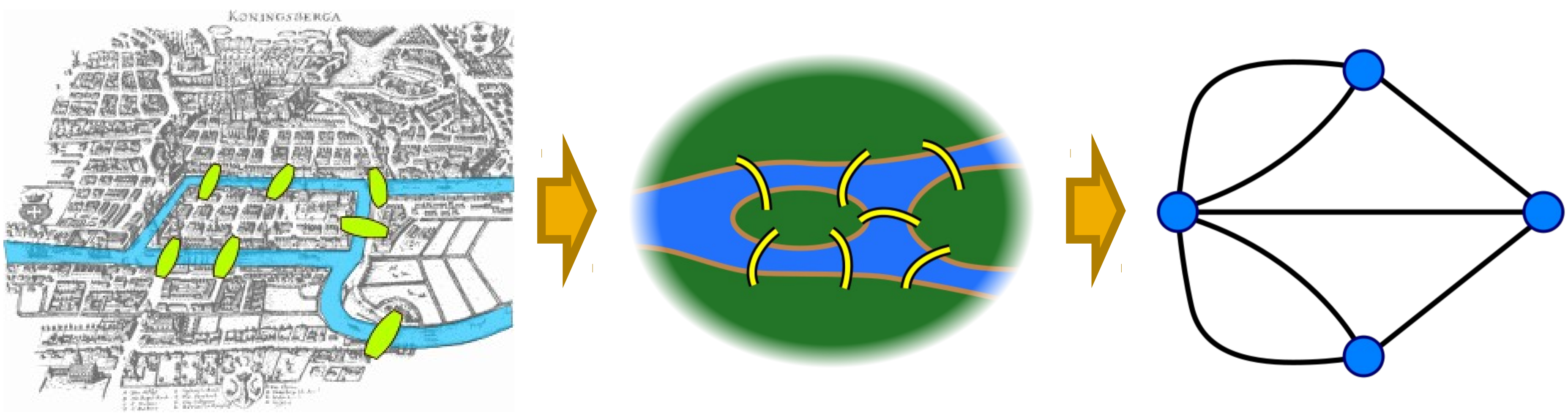
- Two types of visual representation of urban street networks:
  1. Street map: emphasizes the circulation system of the settlement
  2. Figure-ground drawing: emphasizes the open-space system of the settlement





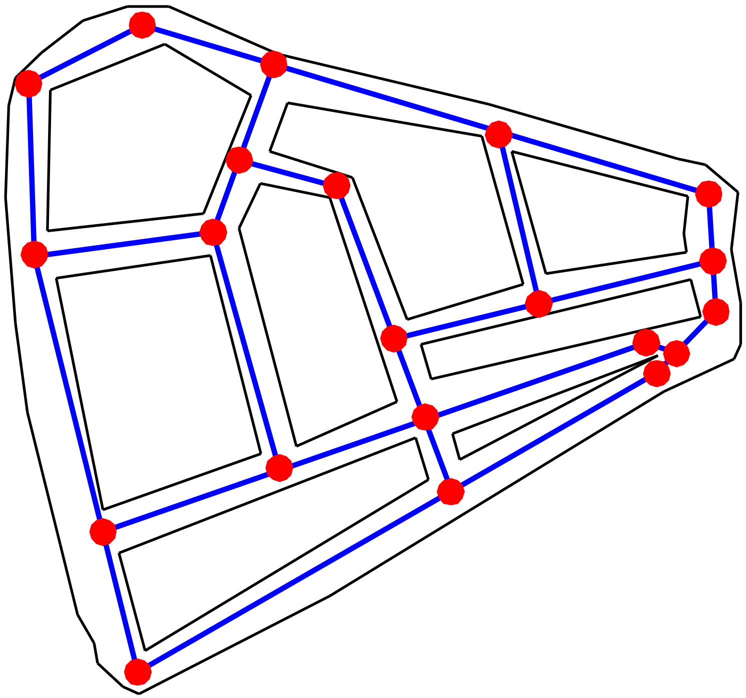
1.2 Abstract representations of urban street network

- Issues of visual representations:
  1. They require human interpretation and thus their usefulness varies among different persons.
  2. They are often too complicated, in that they usually includes much more information than necessary.
- A mathematical graph is the most popular way to abstractly representing urban street networks.

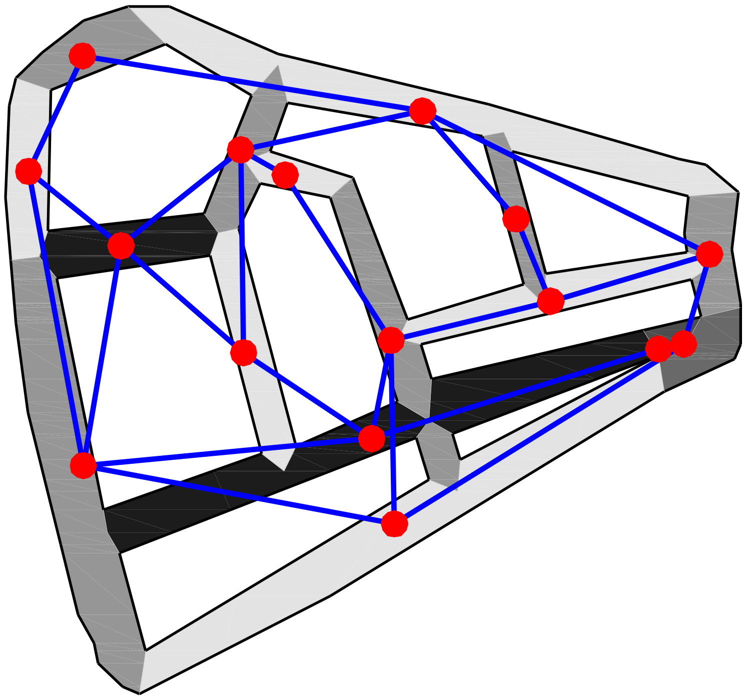


1.2 Abstract representations of urban street network *(continued)*

- Two approaches to abstract representation of urban street networks:
  1. Primal approach: more intuitive and popular
  2. Dual approach: could exhibits the favorable scale-free and small-world properties of a network



A primal graph



A dual graph

2. Generation of urban street network representations

2.1 Medial Axis

2.2 Axial Line

2. Generation of urban street network representations

- Generation of visual representations of urban street network requires a detailed land survey map.
- Automated generalization of visual representations of urban street networks will not be covered.

Historical detailed UK Ordnance Survey

Imagery Layer of modern UK Ordnance Survey MasterMap

Topography Layer of modern UK Ordnance Survey MasterMap

2.1 Medial Axis

- Roads in modern days starts with the delineation of horizontal road alignment.
- Retrieving road centerlines is the most straightforward method of generating a primal representation.
- Alternatively, using shape boundaries of street map to generate medial axes.

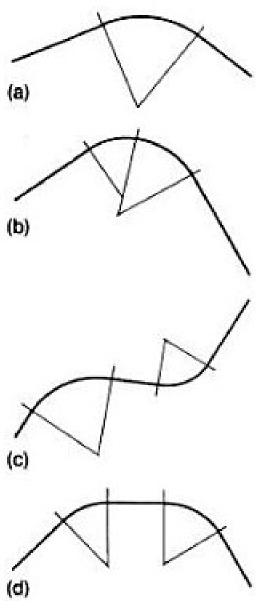


Figure 15.2. Types of horizontal curves. (a) Simple curve with a single radius. (b) Compound curve. (c) Reverse curve. (d) Broken-back curve.

Topography Layer of modern UK Ordnance Survey MasterMap

Transport Layer of modern UK Ordnance Survey MasterMap

2.1 Medial Axis *(continued)*

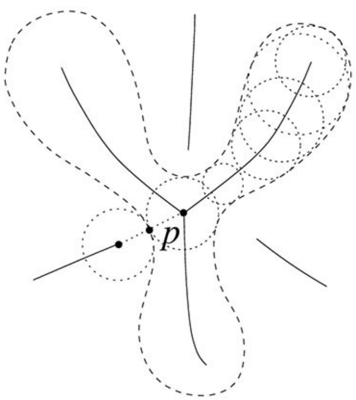


Figure 1: A curve and its medial axis in 2D.

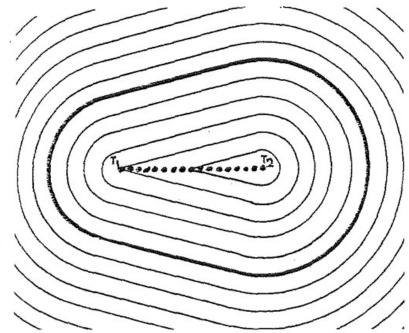


Fig. 3. Generation of new contour description (medial axis function) centered on enclosed space. (t_1 is appearance of corner, t_2 is disappearance. The locus of points and their times are required.)

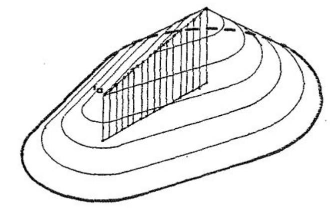
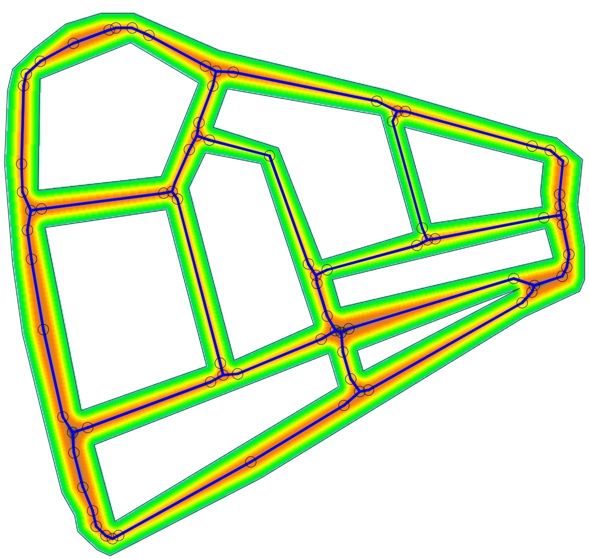


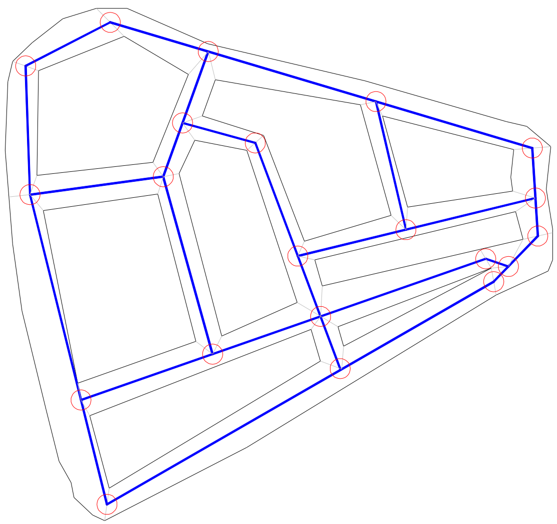
Fig. 4. A three-dimensional static alternative to the two-dimensional kinetic view of the process. (The MAF is the ridge formed where the union of cones on the input contour intersect each other.)

- Blum (1967) uses “medial axis” to refer to the symmetric axis or the topological skeleton of an arbitrary shape.
- Medial Axis Computation (Foskey et al 2003):
  1. Thinning Algorithms
  2. Distance Field Computations
  3. Algebraic Methods
  4. Surface Sampling Approaches

2.1 Medial Axis *(continued)*

- Medial axis is very sensitivity to the object's shape — a minor perturbation in the boundary may cause spurious deviation on the path of the medial axis.
- Other issues of medial axes turned primal graph:
  1. Initial primal graph will be fragmented
  2. The number of links incident upon a node of almost all nodes will still fall between 3 and 6
- Thus generalization and dual approach may be necessary.





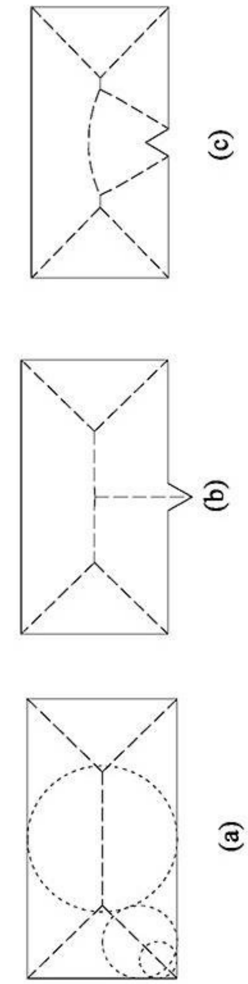


Figure 1: Illustration of Blum's medial axes and their sensitivity

2.2 Axial Line

- Turning medial axes into axial lines and graph.

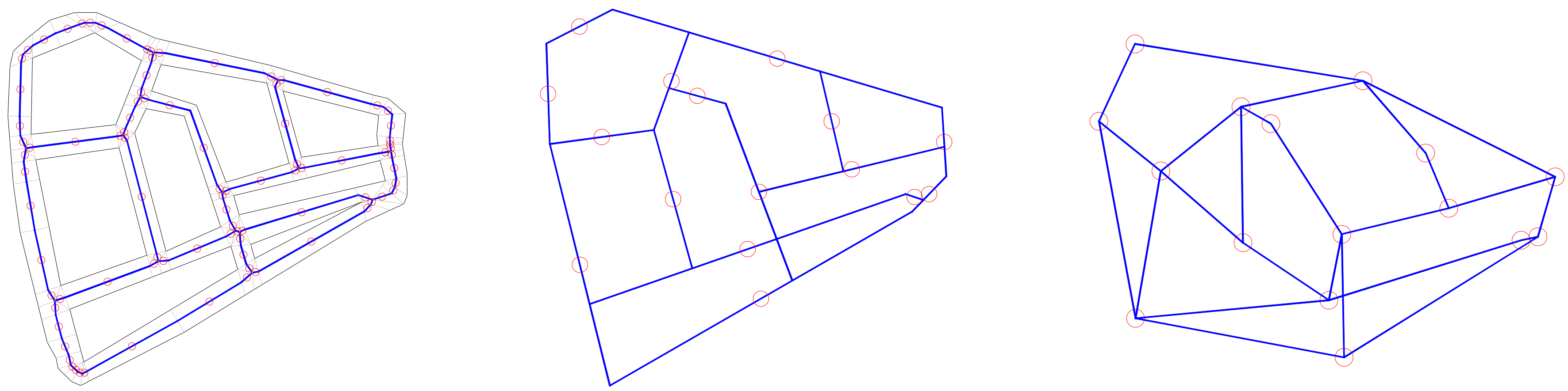
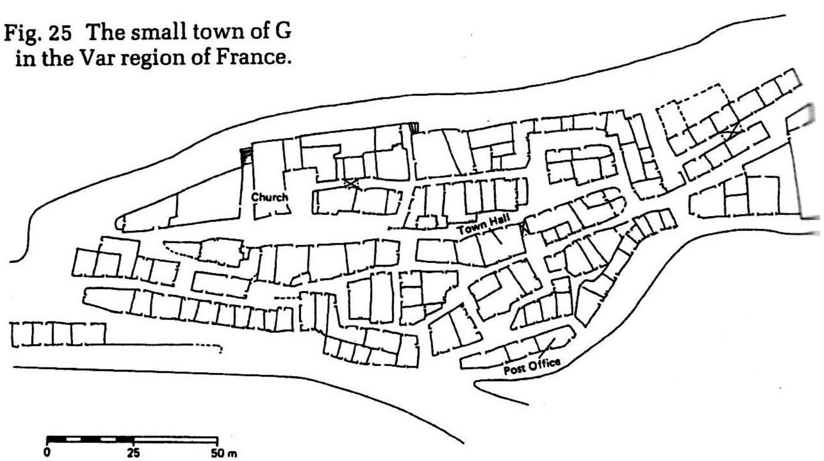
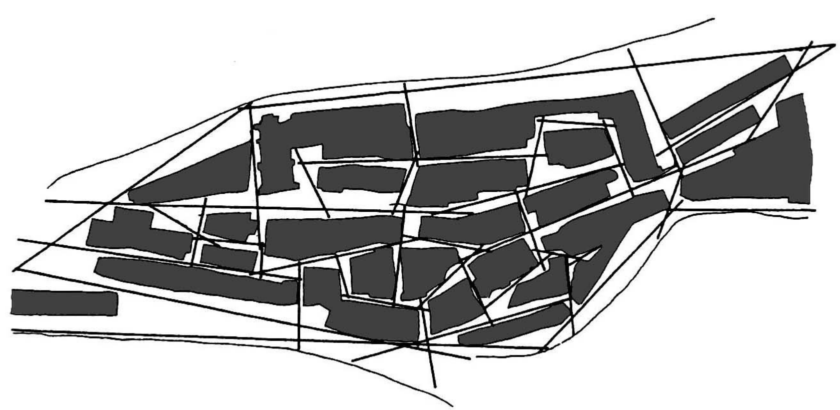


Fig. 25 The small town of G
in the Var region of France.





2.2 Axial Line *(continued)*

- An axial map is “the least set of such straight lines which passes through each convex space and makes all axial links” (Hillier & Hanson 1984, p 92).
- The procedure to generate an axial map is: “first finding the longest straight line that can be drawn ..., then the second longest, and so on until all convex spaces are crossed and all axial lines that can be linked to other axial lines without repetition are so linked” (ibid, p 99).

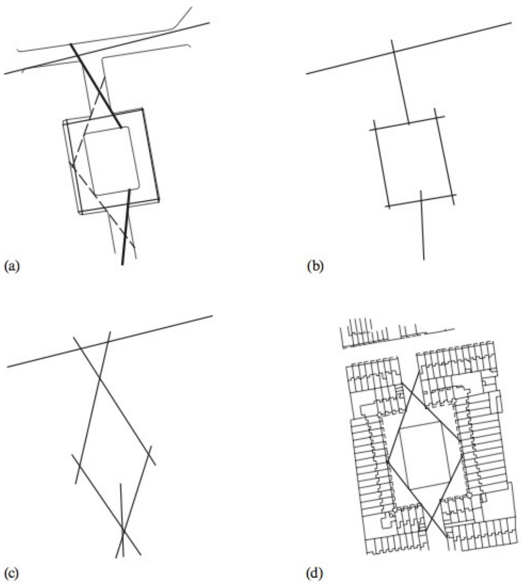


Figure 14. (a) Detail of the subset-elimination axial map of Barnsbury. Notice how the dotted lines minimise the depth between the lines drawn in bold. (b) Detail of the map as drawn by Hillier and Hanson (1984, page 125, figure 63). (c) Detail of the map as drawn by Hillier (1999, page 113, figure 5). (d) Detail of contemporary Ordnance Survey land-line data, © Crown Copyright, used with kind permission. The route to the left may be completed if front gardens (shown with dotted lines) are excluded. The route to the right is not completable.

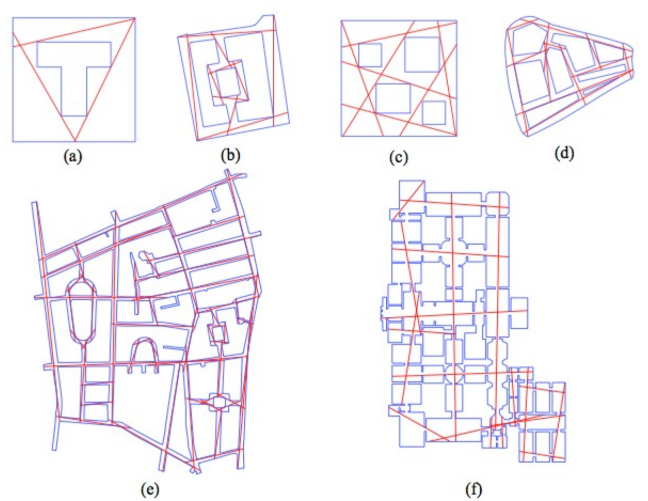


Figure 5: (Color online) The first group of experiments of urban environments taken from the space syntax literature: (a) T-shape, (b) Three-block case, (c) Four-block case, (d) Eight-block case, (e) Barnsbury, and (f) National Gallery London (rotated by 90 degrees)

3. A generalization algorithm that transforms medial axes into axial lines

3.1 Urban open spaces as a system of beady strings
3.2 An overview of the algorithm

3.1 Urban open spaces as a system of beady strings

- Space syntax analogizes the continuous open space to a beady ring system: “convex” spaces are beads; axial lines are strings.
- The mathematical nature of convex space is in which all points can see all others.
- Without grouping through axial lines, the convex map alone can only be applied to the analysis of well separated convex spaces, e.g. rooms inside a building.

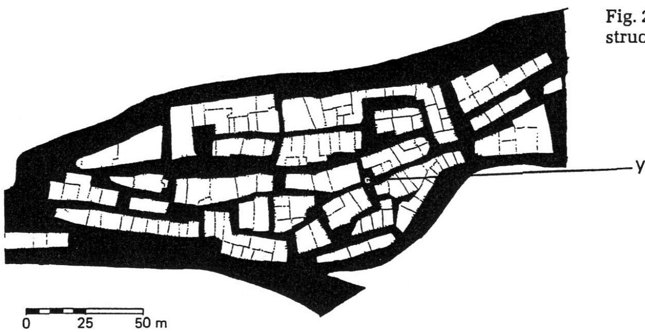
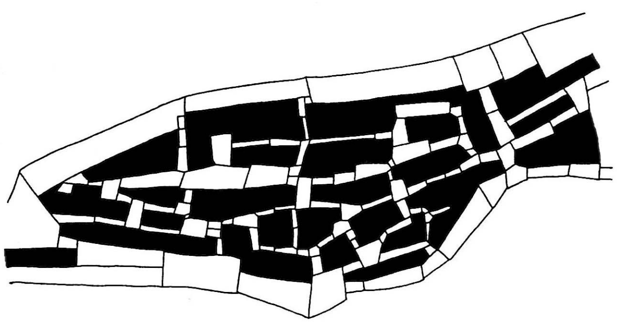


Fig. 26 The open space structure of G.



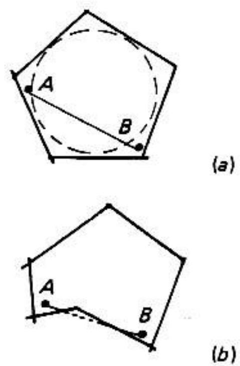


Fig. 39 (a) Convex space: no line drawn between any two points in the space goes outside the space.
(b) Concave space: a line drawn from A to B goes outside the space.

Fig. 88

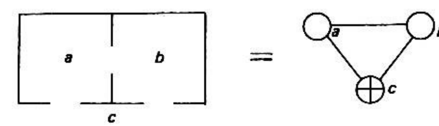


Fig. 89

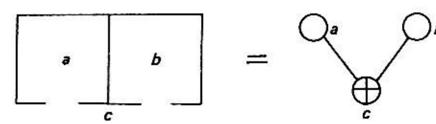


Fig. 90

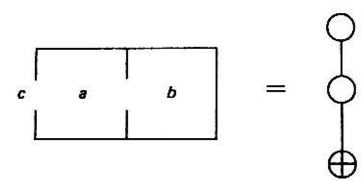
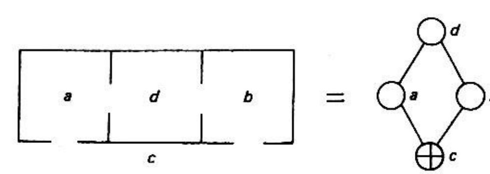


Fig. 91



3.1 Urban open spaces as a system of beady strings *(continued)*

- A convex map is: "the least set of fattest spaces that covers the system" (Hillier & Hanson1984, p 92).
- An algorithm for manually constructing such a convex map: "[s]imply find the largest convex space and draw it in, then the next largest, and so on until all the space is accounted for" (ibid, p 98).

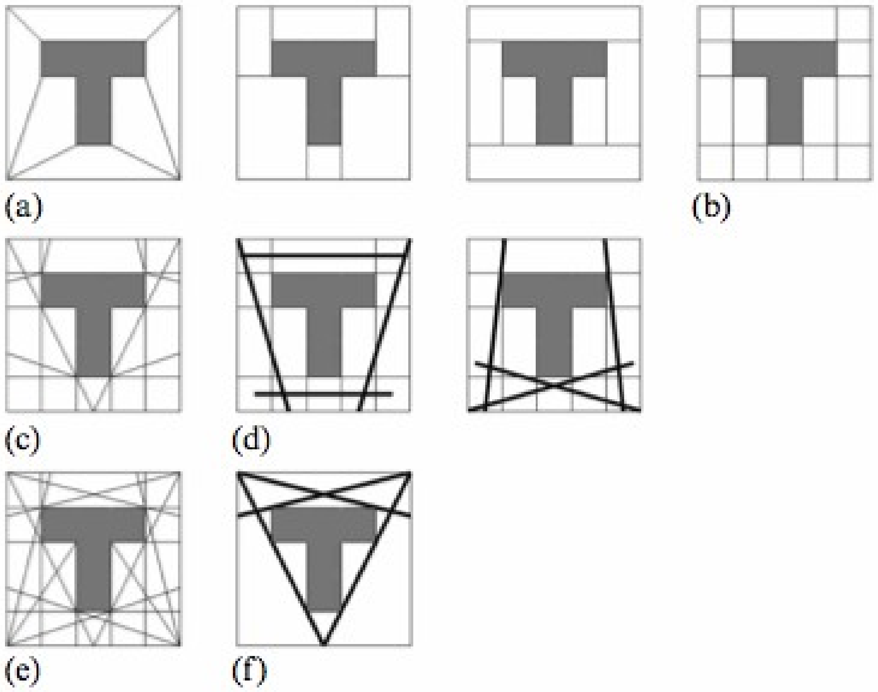
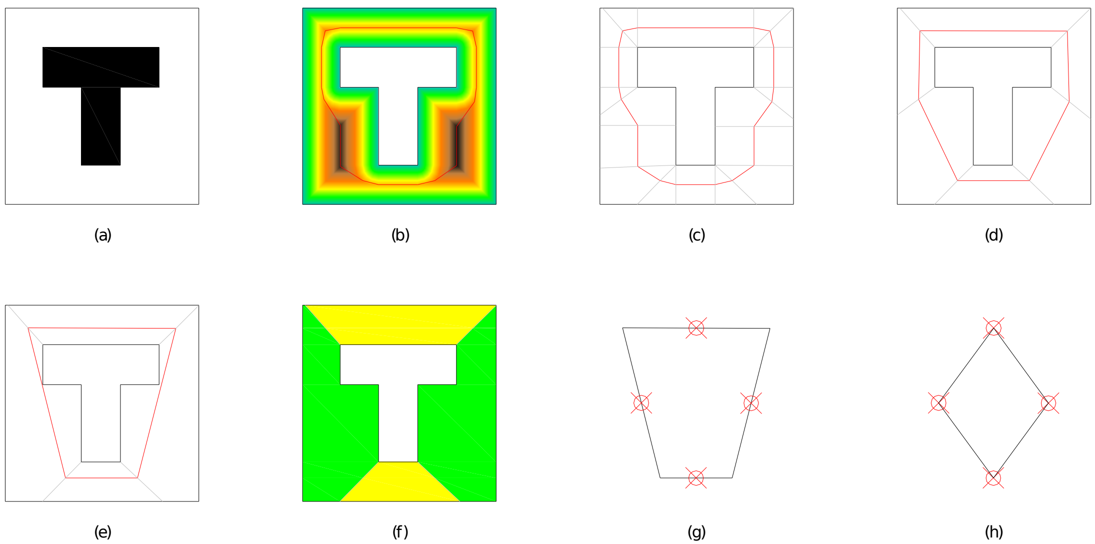
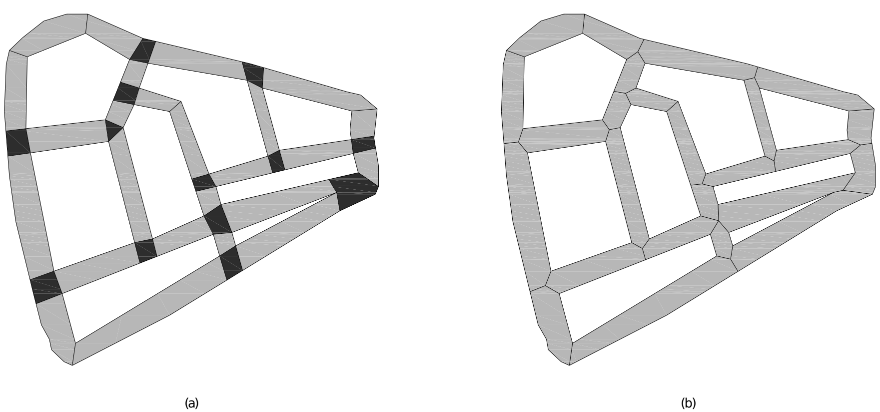


Figure 1. Convex sets, partitions, and axial lines for the basic T-shape.

3.2 An overview of the algorithm

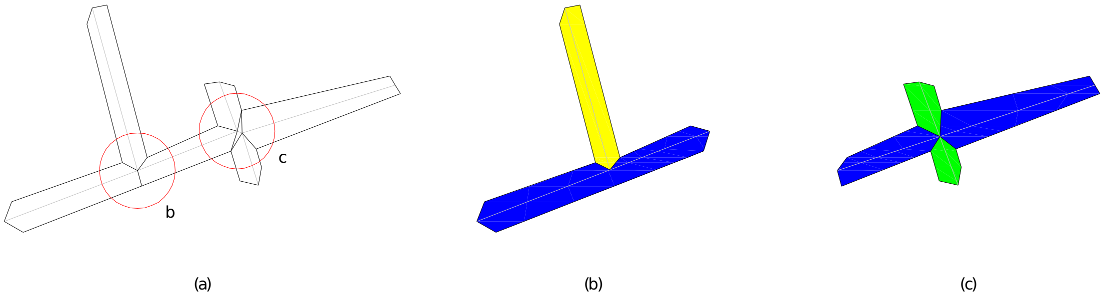


(a) The figure-ground drawing.
(b) The traced medial axis on top of the distance field map using shades of color to indicate the distance from boundaries.
(c) The initially partitioned convex subspaces.
(d) The merged convex spaces.
(e) The final set of generalized medial axes, that is, axial lines on top of associated convex-space sets.
(f) Convex-space sets colored to differentiate.
(g) The axial lines with their midpoints.
(h) The final dual graph.

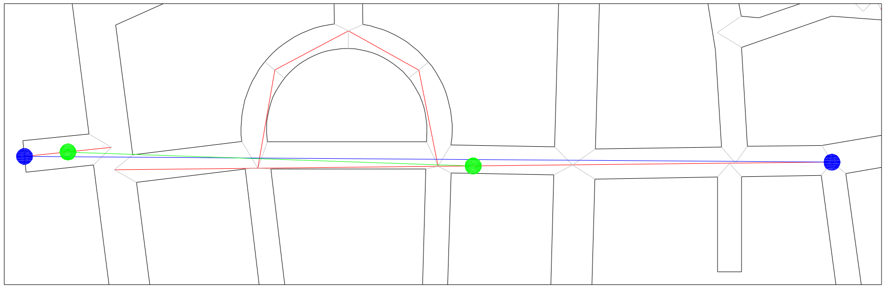


(a) An instance of the link-and-joint convex space partition.
(b) An instance of the all-link convex space partition.

3.2 An overview of the algorithm (continued)



(a) "Join with" situation: three-way (left circle) and four-way (right circle).
(b) "Touch upon" situation.
(c) "Cross over" situation.



The blue line connecting the two endpoints of the red (generalized) medial axes is completely within the boundaries of the streets, while the green line connecting the two midpoints of the red (generalized) medial axes cuts through an almost invisible portion of the corner.

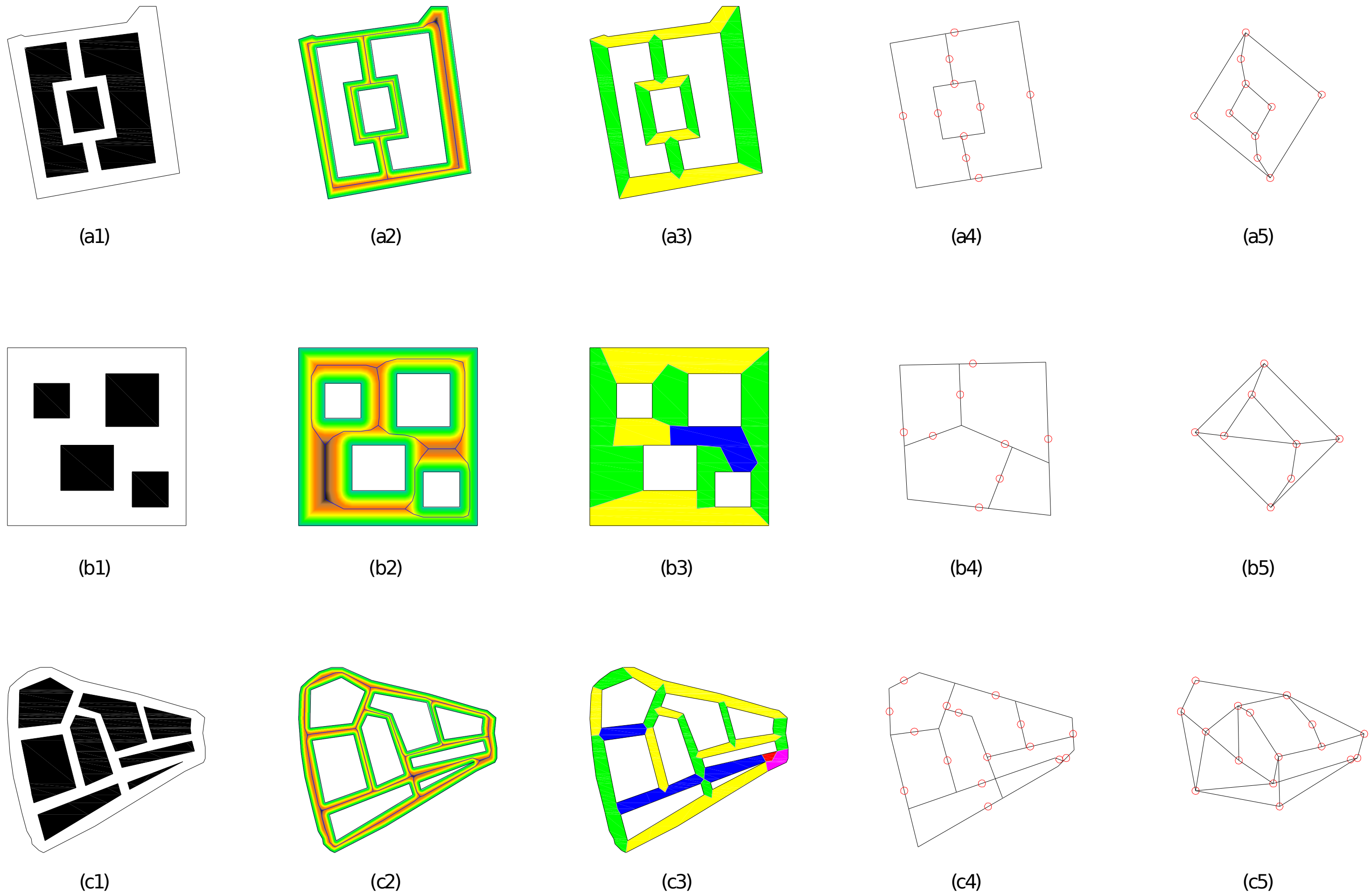
This figure also shows how a curved street section should be subdivided to create generalized linear medial-axis segments.

4. Verification of the algorithm

4.1 Experiments with a set of urban environments

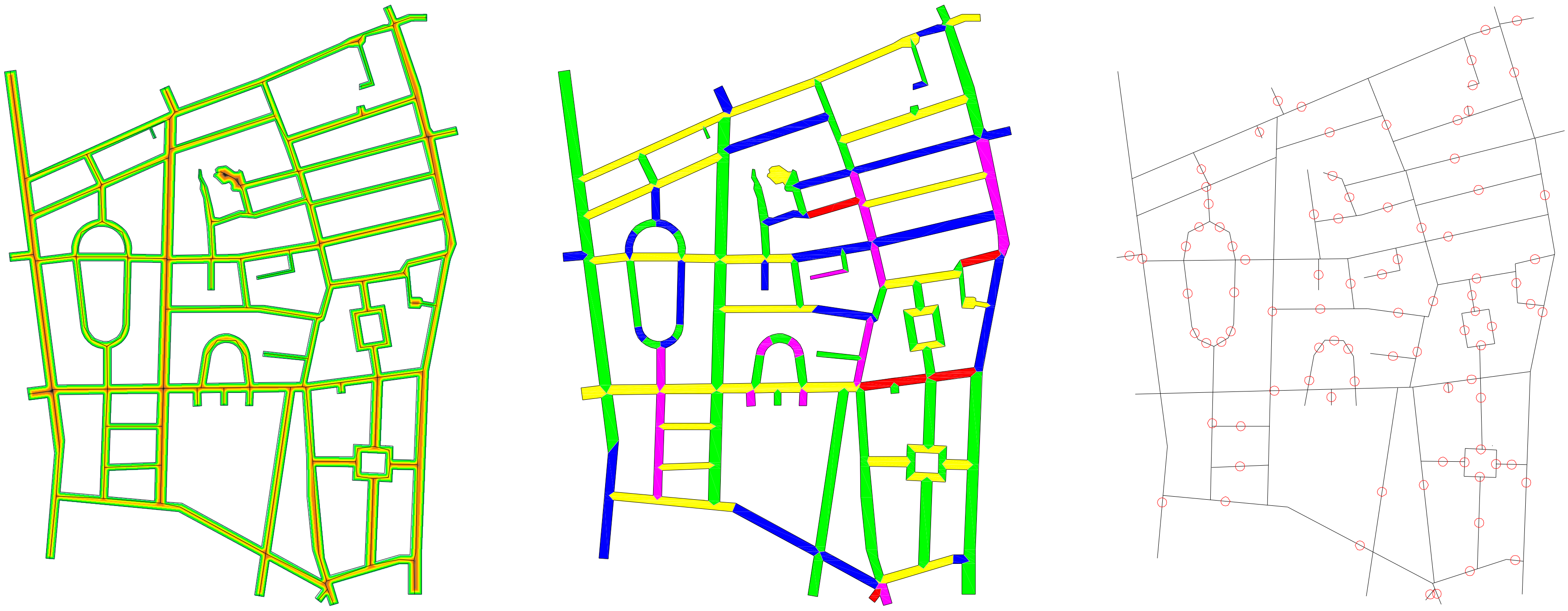
4.2 Thoughts on implementation

4.1 Experiments with a set of urban environments



- Row (a), (b), and (c): the result of the three-, four-, and eight-block tests.
- Column (1): figure-ground drawings.
- Column (2): traced medial axes on top of the distance field map.
- Column (3): the final convex-space sets colored to differentiate.
- Column (4): the final axial lines with their midpoints; column (5) shows the final dual graph.

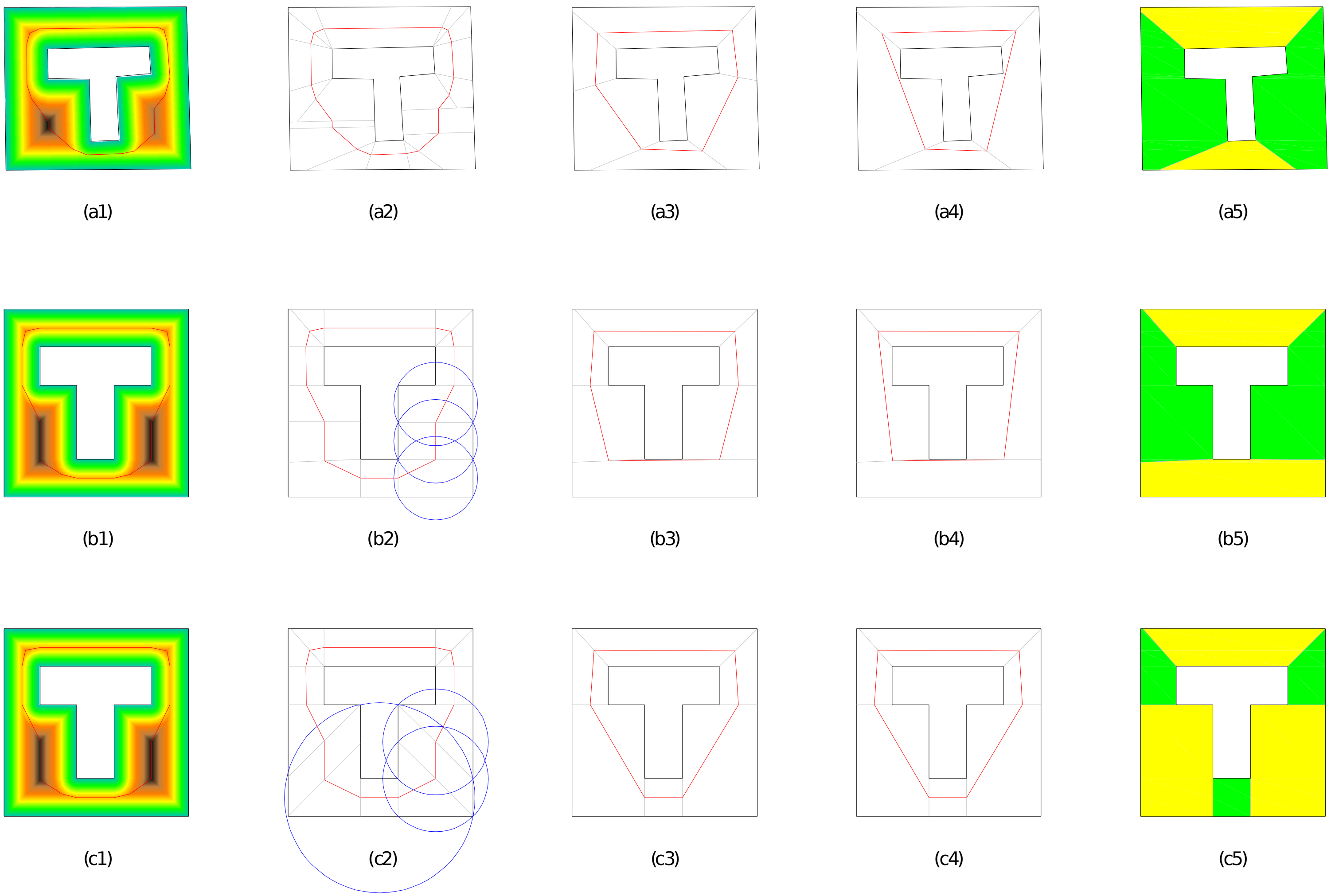
4.1 Experiments with a set of urban environments *(continued)*



(a) (b) (c)

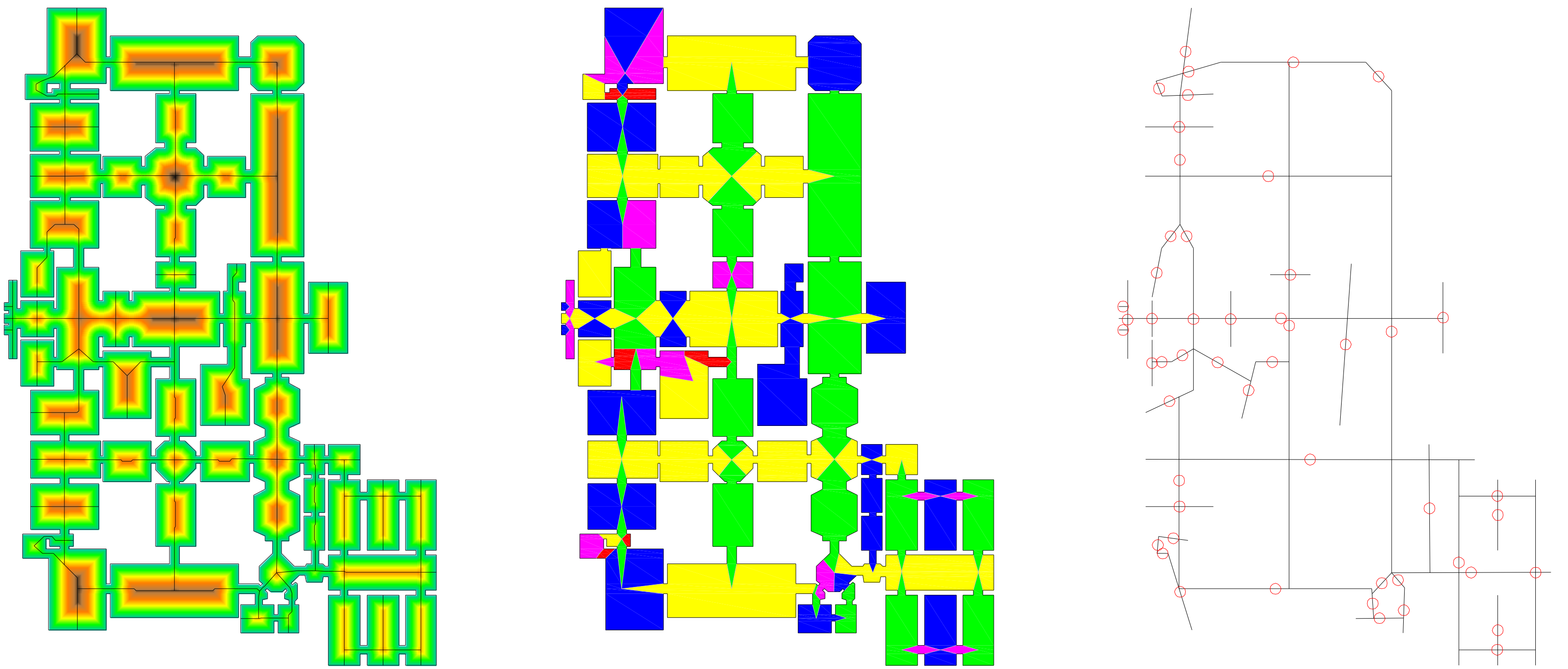
(a) The traced medial axes on top of the distance field map.
(b) The final convex-space sets colored to differentiate.
(c) The final axial lines with their midpoints.

4.1 Experiments with a set of urban environments *(continued)*



- Row (a), (b), and (c): the testing result of the shape distortion, imprecise tracing, and slim partitioning cases, respectively.
- Column (1): traced medial axes on top of the distance field map.
- Column (2): the initially partitioned convex subspaces with some of the circumscribed circles colored in blue.
- Column (3): the merged convex spaces.
- Column (4): the final set of generalized medial axes, that is, axial lines on top of associated convex-space sets.
- Column (5): the final convex-space sets colored to differentiate.

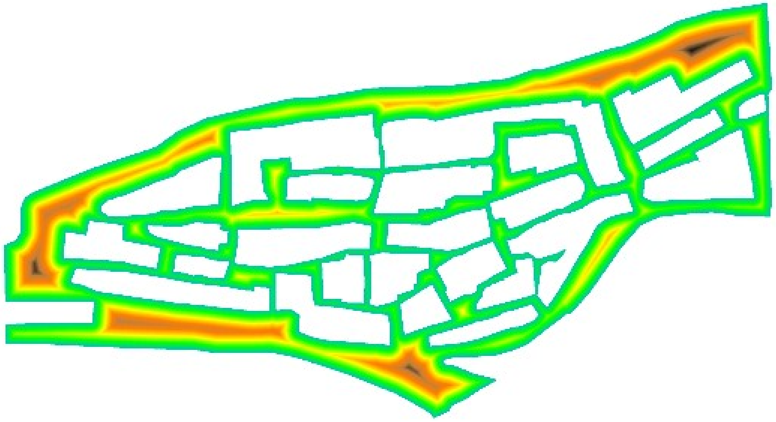
4.1 Experiments with a set of urban environments *(continued)*



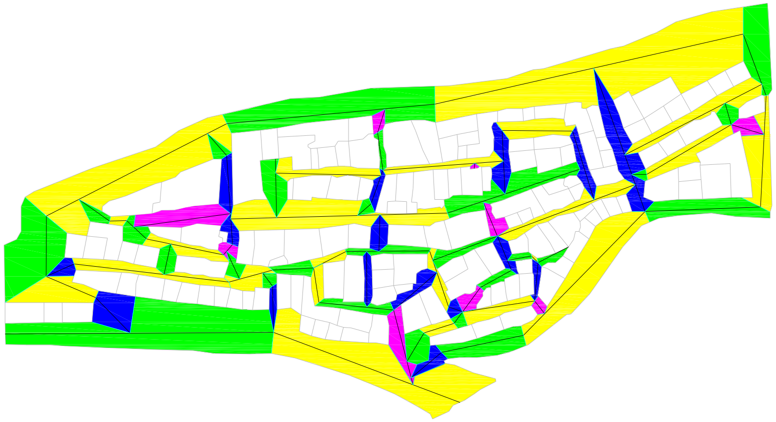
(a) (b) (c)

(a) The traced medial axes on top of the distance field map.
(b) The final convex-space sets colored to differentiate.
(c) The final axial lines with their midpoints.

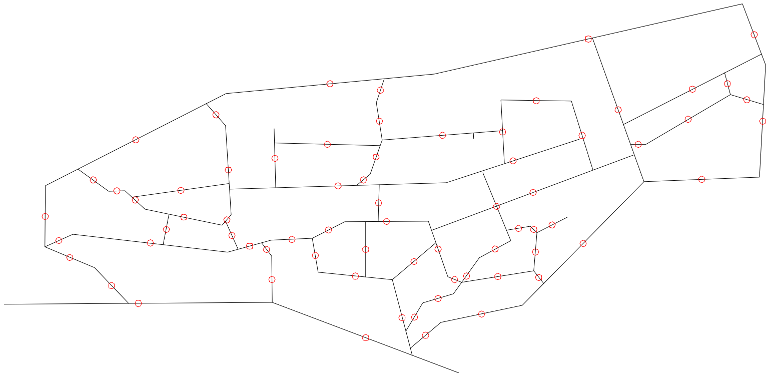
4.1 Experiments with a set of urban environments *(continued)*



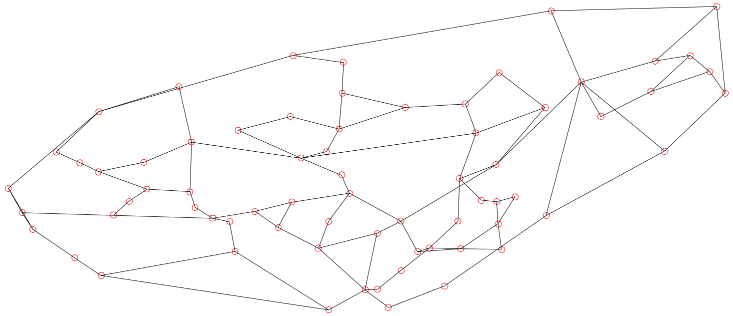
(a)



(b)



(c)



(d)

(a) The distance field map.
(b) The final axial lines on top of the final convex-space sets colored to differentiate.
(c) The final axial lines with their midpoints.
(d) The final dual graph.

4.2 Thoughts on implementation

- The algorithm is tested manually on a CADD system so far, but it is intended to be an automated solution on GRASS because:
  - GRASS has almost all required foundations in place, and
  - the author has prior experience in implementing simpler space syntax calculation on GRASS.
- The algorithm would be implemented as a dedicated vector command module written in C.

4.2 Thoughts on implementation *(continued)*

- Distinct phases of the algorithm that can be implemented individually:
  1. the generation of medial axis (r.cost/r.thin/v.voronoi)
  2. partitioning convex subspaces (v.delaunay)
  3. creating convex map (existing GRASS library functions)
  4. creating axial map (existing GRASS library functions)
- the implementation on GRASS can work as:
  - a modified v.generalize command, or
  - a dedicated spatial network analysis command module.

5. Conclusion

5. Conclusion

- The proposed algorithm specifically adapts for urban open spaces, and spaces inside buildings as well, and thus makes great use of the boundary information of these spaces.
- The boundary information is used to:
  1. generate the medial axis
  2. partition the whole space into convex subspaces
- The principle of continuity is used to:
  1. group individual convex subspaces into convex-space sets
  2. guide the generalization of medial axes into axial lines

5. Conclusion *(continued)*

- The algorithm downplays the absolutely longest axial lines but emphasizes the least angular change so that it can:
  1. effectively creates the axial map that is a slim set of generalized medial axes
  2. efficiently creates the complementary map of convex-space sets for further analysis
- Once implemented, the algorithm would be a great tool for the analysis of spatial configures of all kinds.

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Thank you for your listening

- Comments
- Questions