About the existence or non-existence of an urban envelope in the framework of a multi-scale approach

Cécile Tannier
Pierre Frankhauser
Gilles Vuidel

ThéMA (Besançon)
National Centre for Scientific Research
University of Franche-Comté

ERG S4
Workshop MODUS - Modelling Urban Space
27th of April 2006

ThéMA
UMR 6049
CNRS - Universités de Franche-Comté et de Bourgogne

Identification of the envelope of an urban area

-> identification of the limit of a coherent settlement system...

if such a limit exists (see Batty, 2001)

-> what about the morphological reality of urban areas?

Basic definition

Envelope: continuous virtual line, which defines the morphological limit of an urban area

Basic definition

Envelope: continuous virtual line, which defines the morphological limit of an urban area

Border: outlines of existing built-up elements

Limit: either borders or envelope

Urban area: one or several central built-up clusters and the peri-urban areas related to them

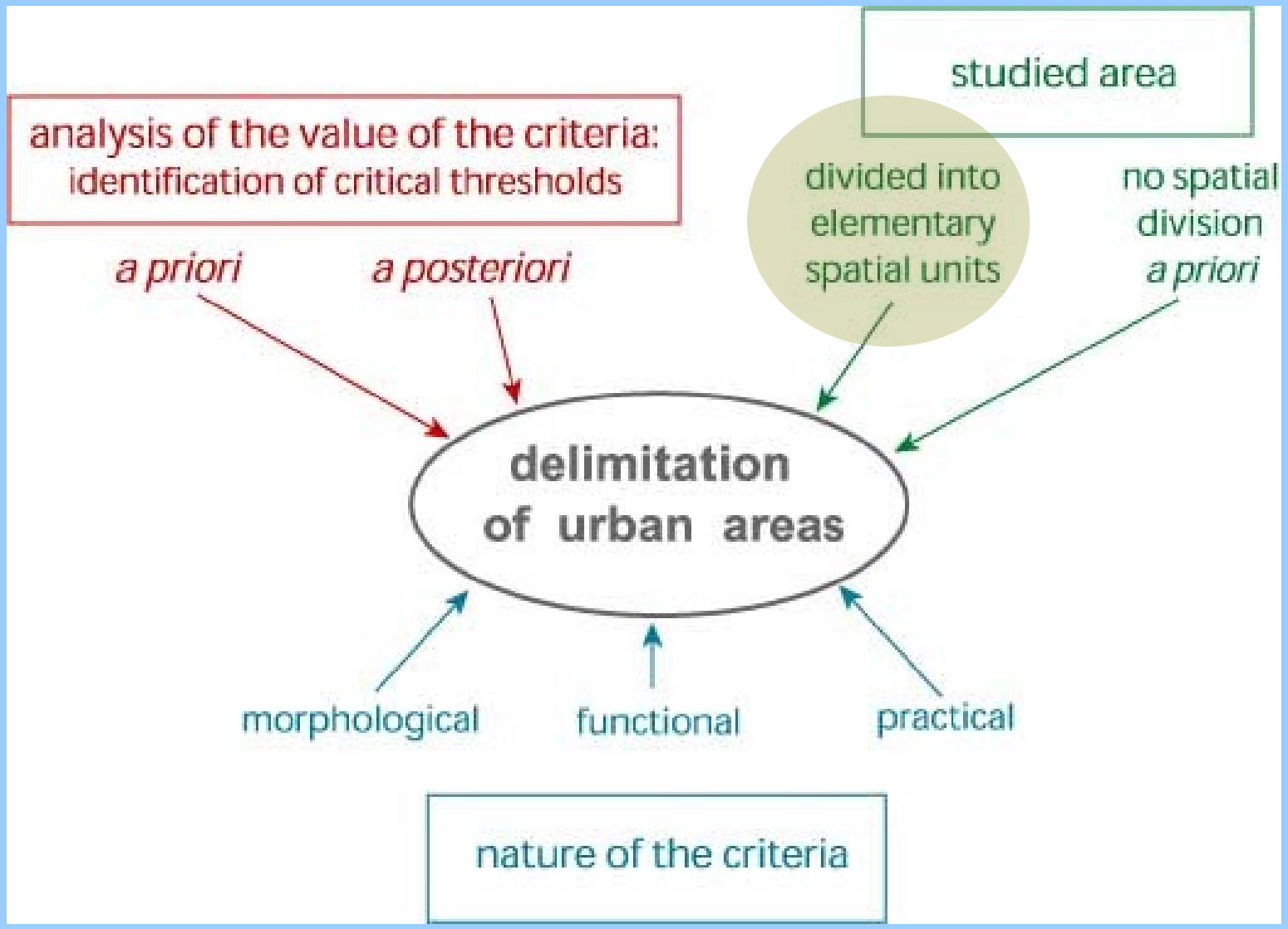
- *Peri-urbanisation: locution taken from the French speaking literature* (Caruso et al., 2001)

Plan of the presentation

- General framework: the question of Rural/Urban Delimitation
- Choice of a methodology for generating the envelope of an urban area: theoretical argument
- Application: generating the envelope of a series of theoretical and real urban patterns

First part

General framework: the question of Rural/Urban Delimitation



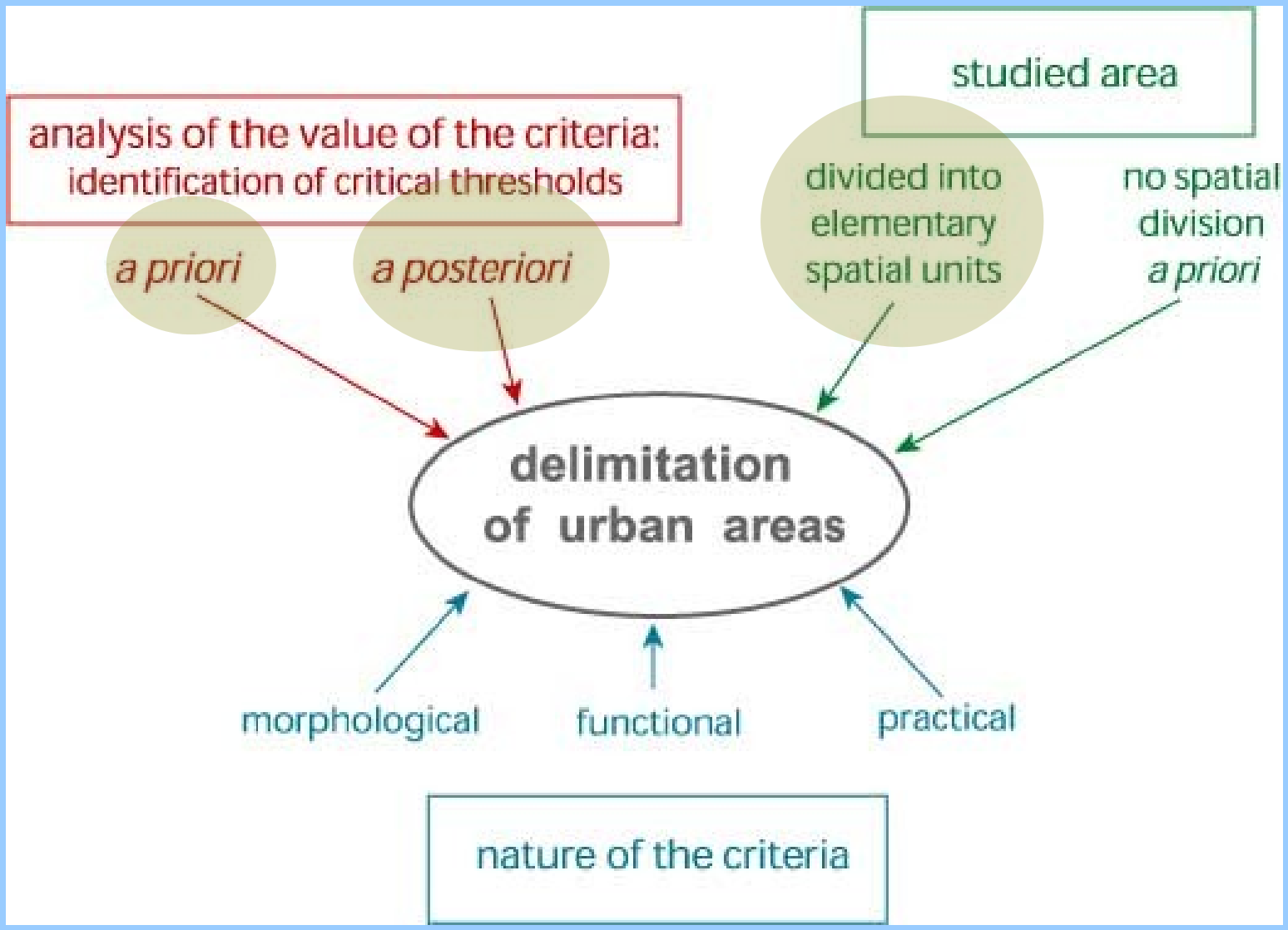
First part

General framework: the question of Rural/Urban Delimitation

1. Urban and Rural Definition: classifications of elementary spatial units

First part

General framework: the question of Rural/Urban Delimitation



First part

General framework: the question of Rural/Urban Delimitation

1. Urban and Rural Definition: classifications of elementary spatial units

2 ways of improvement:

- new morphological criteria
- multi-scale approach

First part
General framework: the question of Rural/Urban Delimitation

1. Urban and Rural Definition: classifications of elementary spatial units

2 ways of improvement:

- new morphological criteria
  - improve the quality of diachronic analyses
  - define an urban limit on the base of few criteria
    - international comparisons
    - modelling urban spatial dynamics

      (Batty, Longley, 1986): "In designing the models, it was thought important to keep the variables in the models as simple as possible and, at the same time, easily measurable".

First part
General framework: the question of Rural/Urban Delimitation

1. Urban and Rural Definition: classifications of elementary spatial units

2 ways of improvement:

- new morphological criteria
- multi-scale approach

Example:
The new classification of rural and urban areas for England and Wales (Bibby, Sheperd, 2004)

Identification of settlement types -> residential density profiles

First part
General framework: the question of Rural/Urban Delimitation

1. Urban and Rural Definition: classifications of elementary spatial units

2 ways of improvement:

- new morphological criteria
- multi-scale approach

→ **Best answer to the practical requirement of urban-rural delimitation.**
But, no answer to the question of the morphological reality of urban areas.

The case of administrative or planning zonings:

- how much the practical constraints influence the definition of the town implicit to the use of different zonings? (Le Gléau *et al.*, 1997)
- How relevant are the spatial divisions with respect to different analyses? (Guérois, Paulus, 2002)

First part

General framework: the question of Rural/Urban Delimitation

1. Urban and Rural Definition: classifications of elementary spatial units

2 ways of improvement:

- new morphological criteria
- multi-scale approach

→ **Best answer to the practical requirement of urban-rural delimitation.**
But, no answer to the question of the morphological reality of urban areas.

The case of administrative or planning zonings:

→ **The issue of the morphological reality of planning zones logically also questions the morphological reality of the city itself.**

First part

General framework: the question of Rural/Urban Delimitation

1. Urban and Rural Definition: classifications of elementary spatial units

Conclusion

Classifications are required: framework for general statistical analyses and helpful for targeting funding

First part

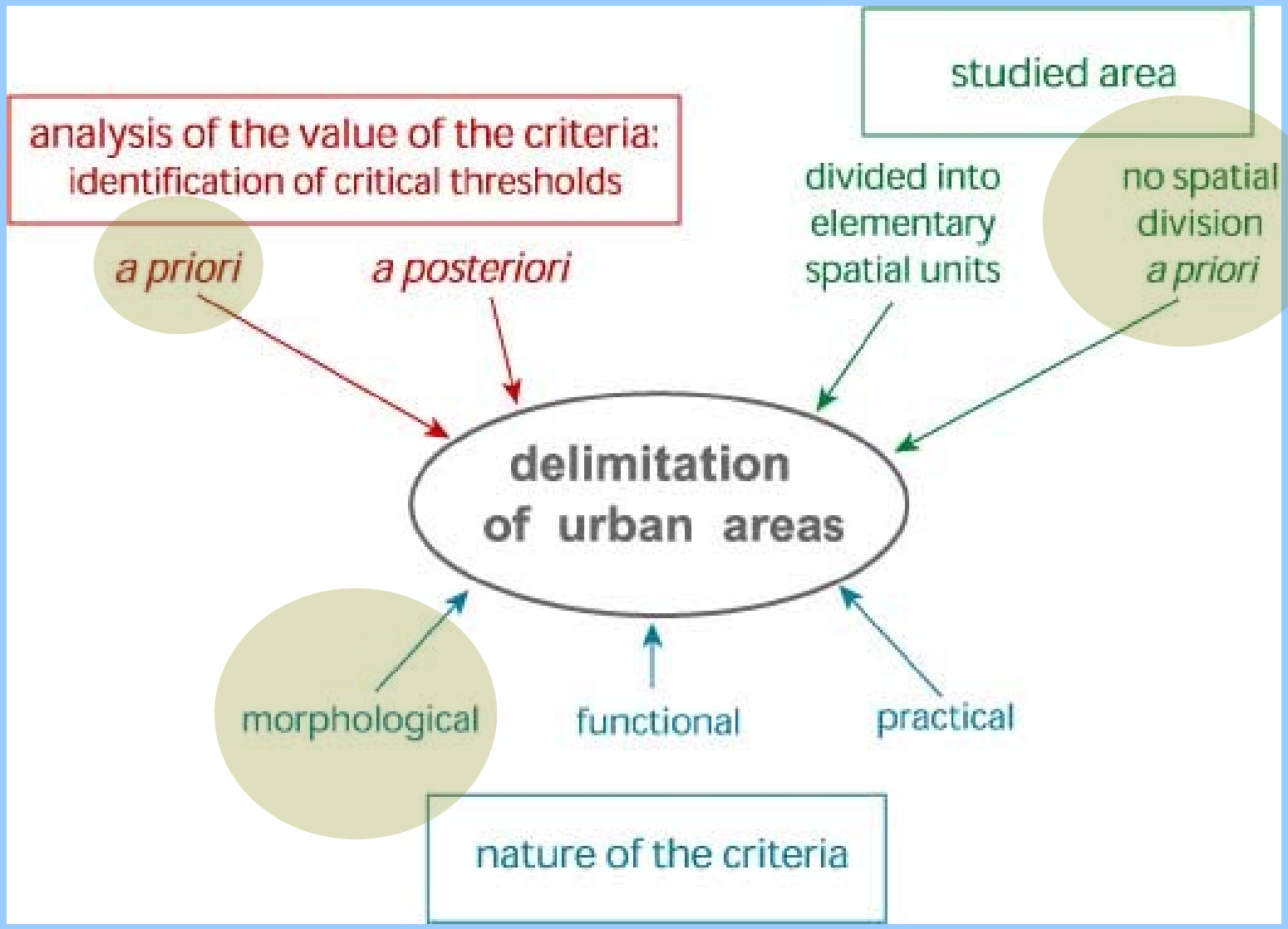
General framework: the question of Rural/Urban Delimitation

1. Urban and Rural Definition: classifications of elementary spatial units

→ **The debate on the morphological reality of urban areas remains open.**

First part

General framework: the question of Rural/Urban Delimitation



First part

General framework: the question of Rural/Urban Delimitation

1. Urban and Rural Definition: classifications of elementary spatial units

2. Another way of delimiting urban areas: no spatial units defined *a priori*

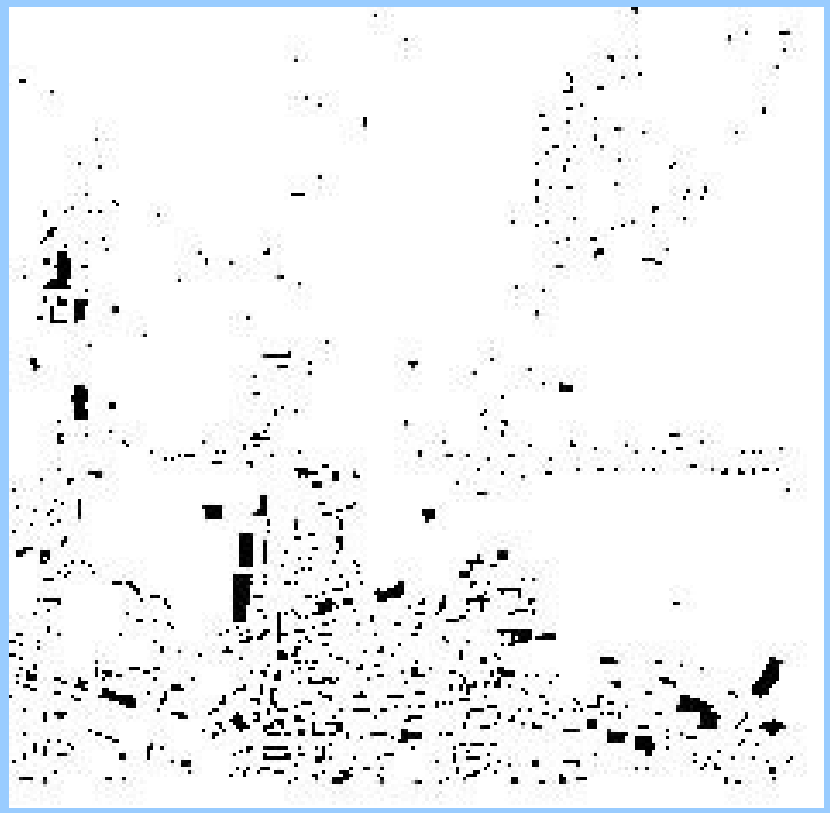
- **Morphological approach – thresholds defined *a priori***

  It is possible to define the limits of the densely built-up areas.

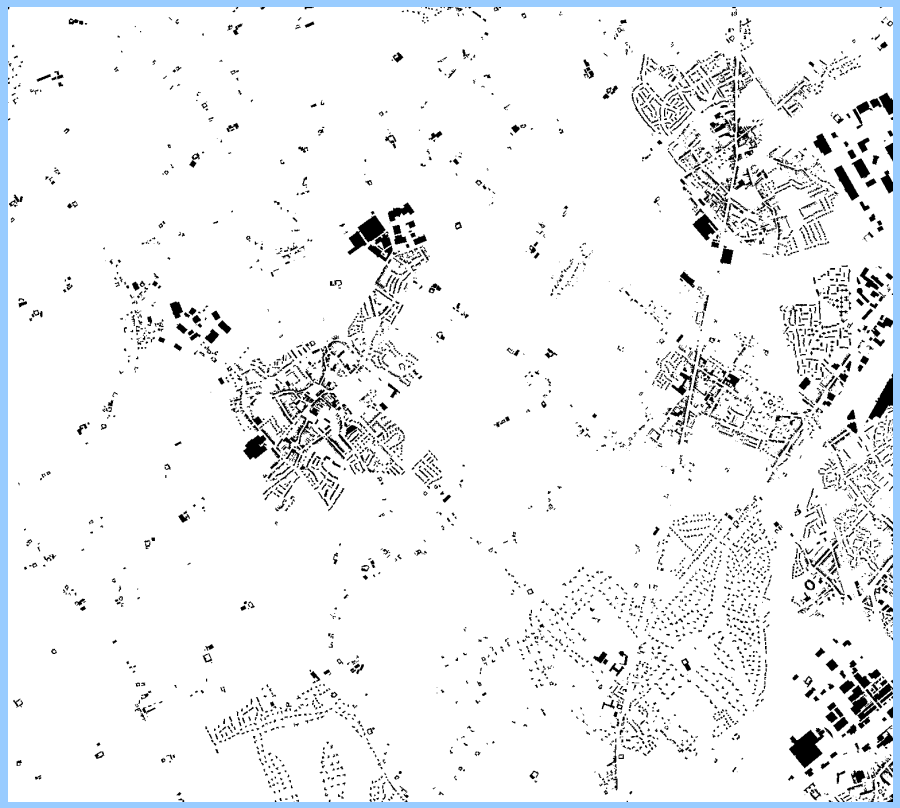
  -> *small range of distances separating neighbouring buildings*

  It is much more difficult to define the limit of peri urban areas.

Two examples, which illustrate the morphological contrasts in the peri urban built-up patterns



(a) ***The northern fringe of the city of Besançon (East of France)***



(b) ***The western part of the urban area of Lille (North of France)***

First part
General framework: the question of Rural/Urban Delimitation

1. Urban and Rural Definition: classifications of elementary spatial units

2. Another way of delimiting urban areas: no spatial units defined *a priori*

- **Morphological approach – thresholds defined *a priori***

  It is possible to define the limits of the densely built-up areas.

  -> *small range of distances separating neighbouring buildings*

  It is much more difficult for peri urban areas.

  ->*the morphological characteristics of peri-urban zones may vary a lot (Caruso, 2003);*

  ->*wide range of distances separating neighbouring buildings*

First part
General framework: the question of Rural/Urban Delimitation

1. Urban and Rural Definition: classifications of elementary spatial units

2. Another way of delimiting urban areas: no spatial units defined *a priori*

- **Morphological approach – thresholds defined *a priori***

  The research dealing with morphological characteristics of urban sprawl mainly aims to characterise (even evaluate) its attributes and not to delimit the spatial extend of peri-urbanisation.
  (Torrens and Alberti, 2000) (Galster *et al.*, 2001)

  An exception:
  -> the doctoral research of M. Guérois (2003). Dir. D. Pumain

First part
General framework: the question of Rural/Urban Delimitation

1. Urban and Rural Definition: classifications of elementary spatial units

2. Another way of delimiting urban areas: no spatial units defined *a priori*

- **Morphological approach – thresholds defined *a priori***

  Doctoral research of M. Guérois (2003). Dir. D. Pumain

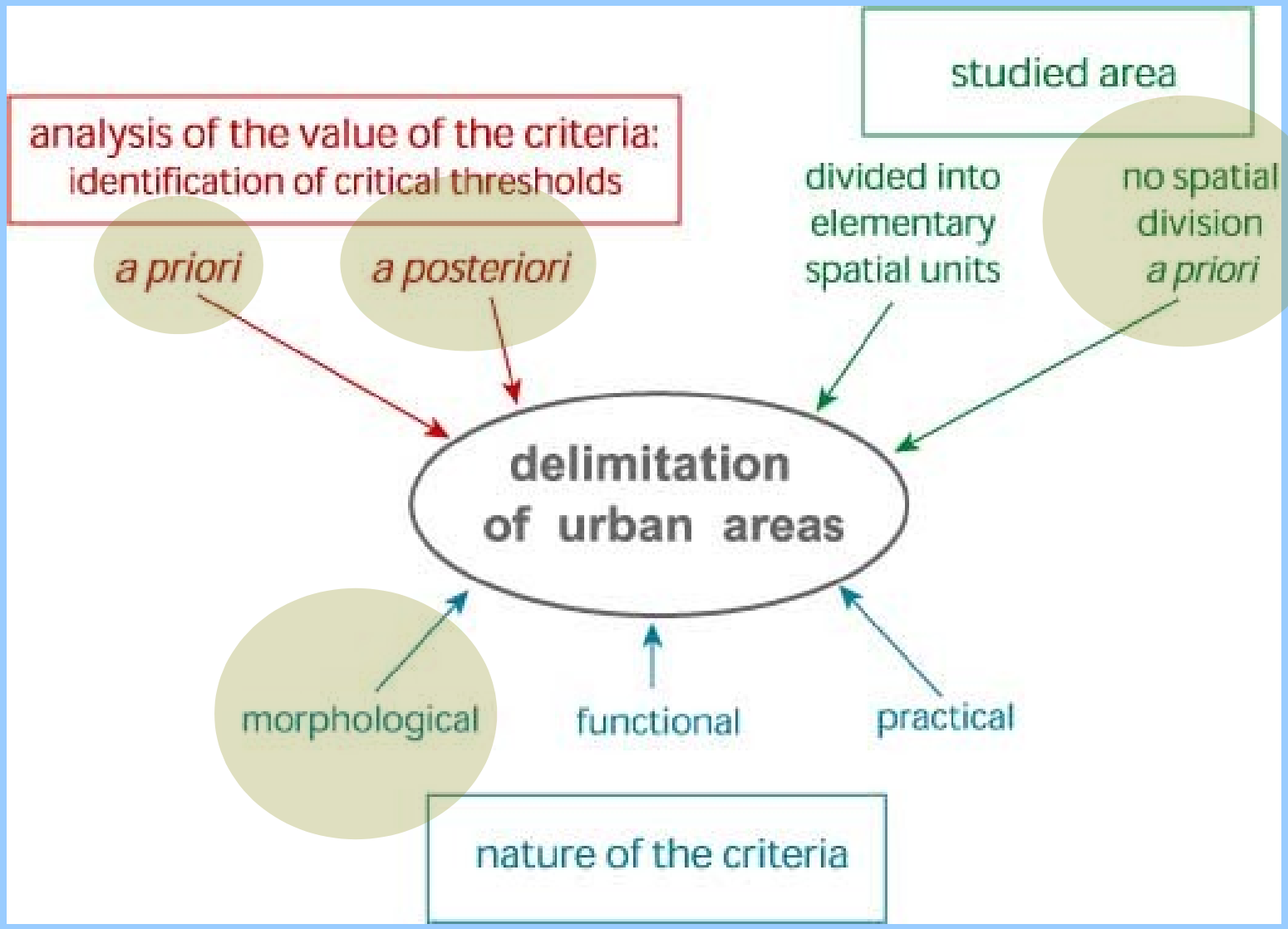
  → *Identification of the envelope of 40 urban areas using a dilation-erosion procedure*

  → *Width of the buffer used for the dilation: 400 m.*

  → *Interesting, but no deep argument about the choice of the distance thresholds.*

First part

General framework: the question of Rural/Urban Delimitation



First part
General framework: the question of Rural/Urban Delimitation

1. Urban and Rural Definition: classifications of elementary spatial units

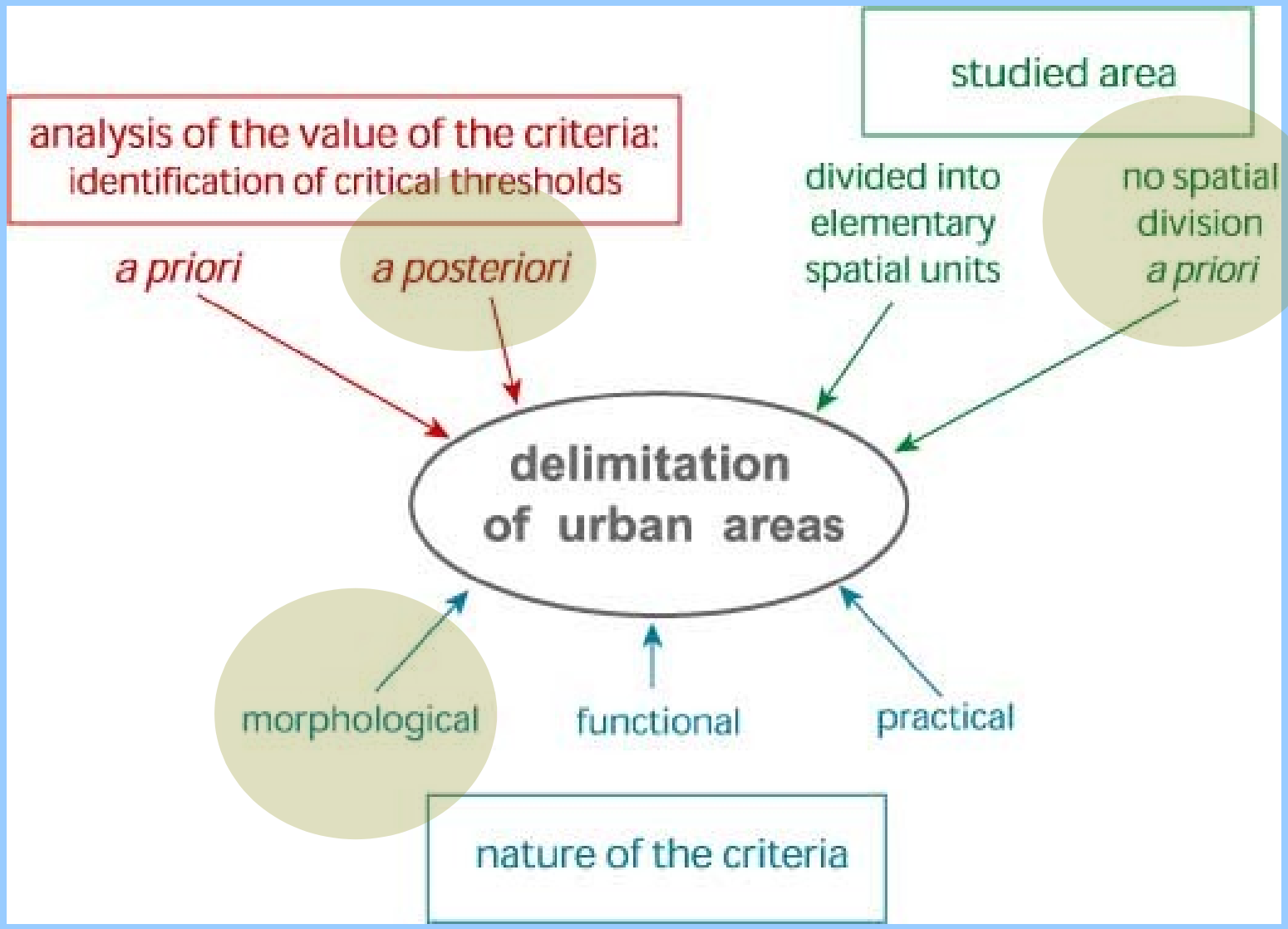
2. Another way of delimiting urban areas: no spatial units defined *a priori*

- **Morphological approach – No thresholds defined *a priori***

  Doctoral research of M. Guérois (2003). Dir. D. Pumain

First part

General framework: the question of Rural/Urban Delimitation



First part
General framework: the question of Rural/Urban Delimitation

1. Urban and Rural Definition: classifications of elementary spatial units

2. Another way of delimiting urban areas: no spatial units defined *a priori*

- **Morphological approach – No thresholds defined *a priori***

  Tannier, Frankhauser

  → *Choice of a multi-scale approach based on fractal geometry* (early exploration of the interest of fractal geometry for analysing the shape of geographical boundaries: P. Longley and M. Batty in 1989)

  Goals:

  -> to link the borders of urban areas to their envelope

  -> to answer (at least partially) the question of the existence or not of an urban limit

Second part

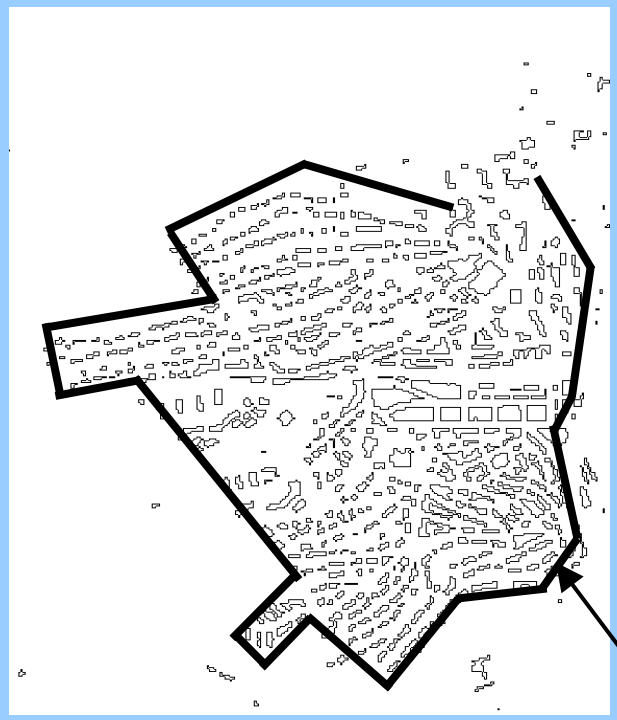
Choice of a methodology for generating the envelope of an urban area: theoretical argument

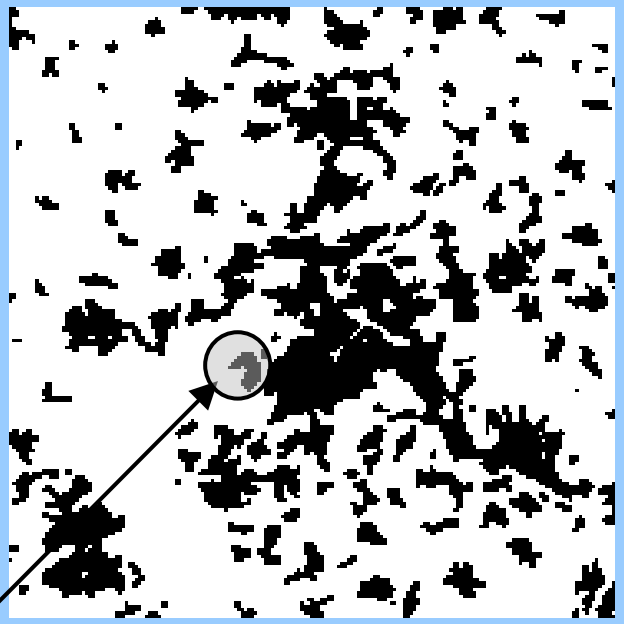
Preliminary reflexions, which introduce the notion of envelope

- The morphological definitions of urban limits, which refer to arbitrarily fixed criteria as distances between neighbouring buildings -> *attempts to define an envelope*

- Coarse-grained maps on small scales -> *cartographers tend also to "materialise" the envelope*

A same place at two different cartographic scales





Outskirts of Stuttgart, Botnang

Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

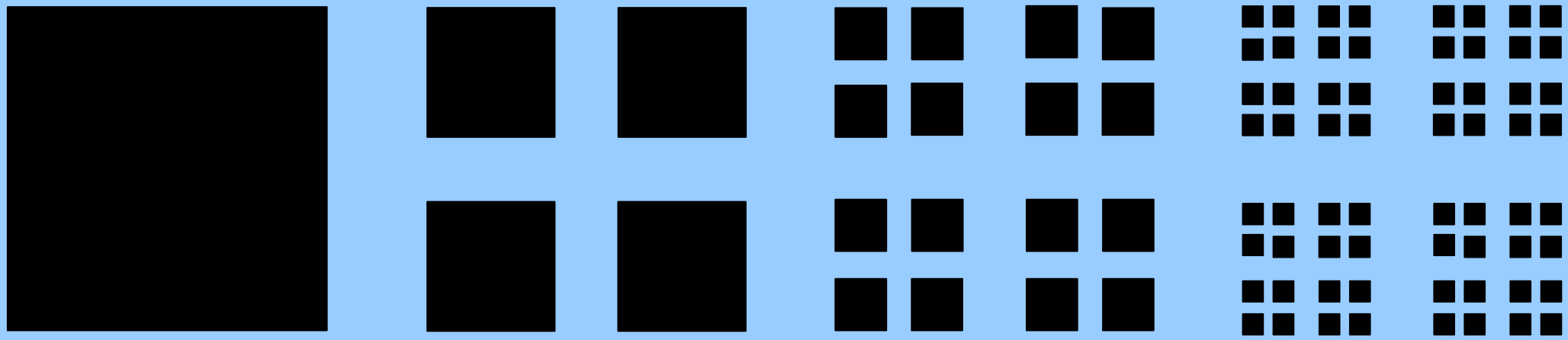
Is it possible to draw up a theoretical argument, which shows that it is relevant and meaningful to try to generate an urban envelope?

-> Introduction of fractal models to answer this question.

Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1. Borders and envelope of a first model: the Fournier dust



the initiator | first step: the generator | second step | third step

The generator defines:

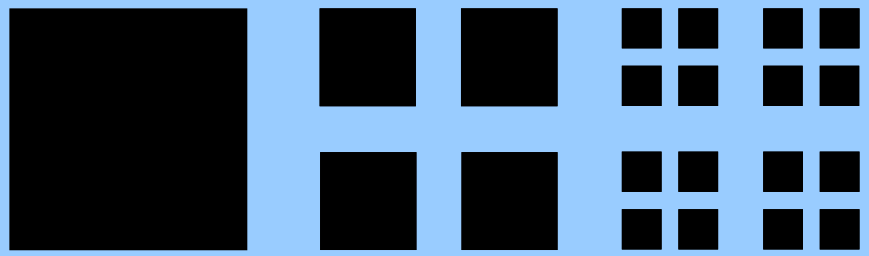
- the reduction factor *r*
- the number *N* of elements
- the position of the elements

Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1. Borders and envelope of a first model: the Fournier dust

1.1 The borders of a Fournier dust: what changes and what remains at different analysis levels?

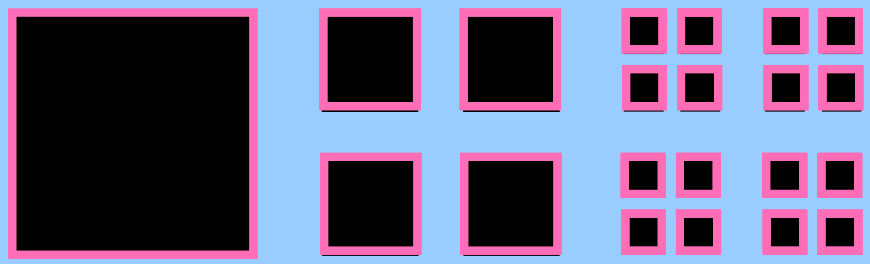


Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1. Borders and envelope of a first model: the Fournier dust

1.1 The borders of a Fournier dust: what changes and what remains at different analysis levels



Identification of the borders at different analysis levels

In course of the iterations the borders change, as the elements also change

Second part

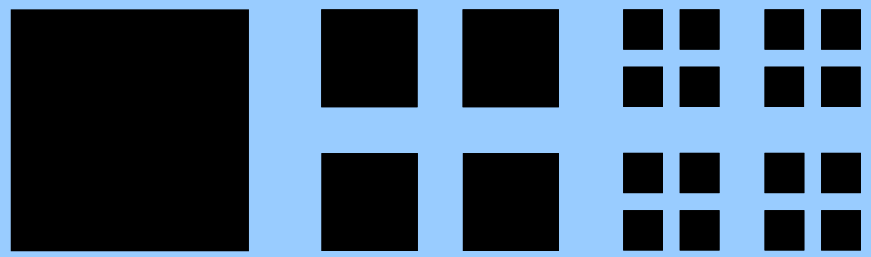
Choice of a methodology for generating the envelope of an urban area: theoretical argument

1. Borders and envelope of a first model: the Fournier dust

1.1 The borders of a Fournier dust: what changes and what remains at different analysis levels

→ The number of elements is multiplied by N at each step and increases according to a geometric series. For a given step n, the number of elements N_n is:

$$N_n = N^n$$



$N_0 = 1$ $N_1 = 4$ $N_2 = 4^2 = 16$

Second part

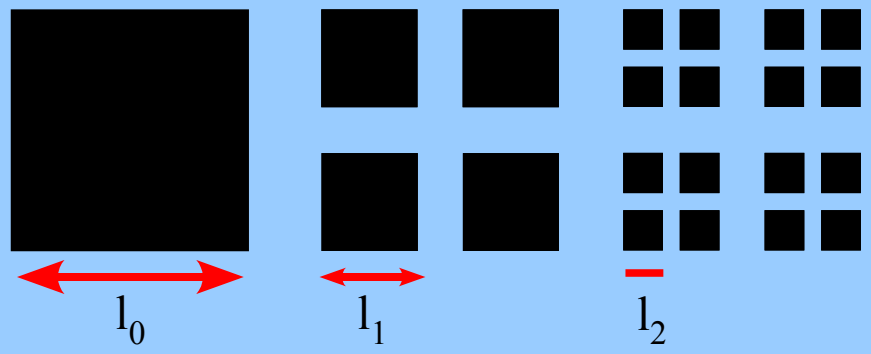
Choice of a methodology for generating the envelope of an urban area: theoretical argument

1. Borders and envelope of a first model: the Fournier dust

1.1 The borders of a Fournier dust: what changes and what remains at different analysis levels

→ At each step of iteration, the size of the elements is reduced by the factor r and the base length of the elements l_n decreases according to a geometric series, too:

$$l_n = r^n \cdot l_0$$



Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

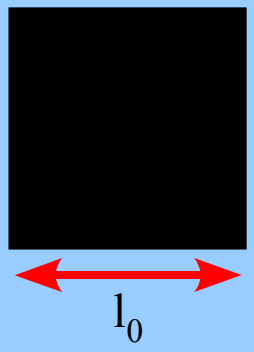
1. Borders and envelope of a first model: the Fournier dust

1.1 The borders of a Fournier dust: what changes and what remains at different analysis levels

p_n length of the border of an element at the iteration step n

The length of the border of the initiator is:

$$p_0 = 4 \cdot l_0$$



The Euclidean geometric form of the initiator comes into play.

Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1. Borders and envelope of a first model: the Fournier dust

1.1 The borders of a Fournier dust: what changes and what remains at different analysis levels

p_n length of the border of an element at the iteration step n

$$p_n = a \cdot l_n = a \cdot l_0 \cdot r^n$$

form factor

with $a = 4$ when the initiator is a square

$$\lim_{n \to \infty} p_n = 0$$

Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1. Borders and envelope of a first model: the Fournier dust

1.1 The borders of a Fournier dust: what changes and what remains at different analysis levels

P_n length of the border of **all the elements** at the iteration step n

P_n **cumulated border** at the iteration step n

$$P_n = N_n \cdot p_n = a \cdot N_n \cdot l_n = a \cdot l_0 \cdot N^n \cdot r^n = a \cdot l_0 \cdot (N \cdot r)^n$$

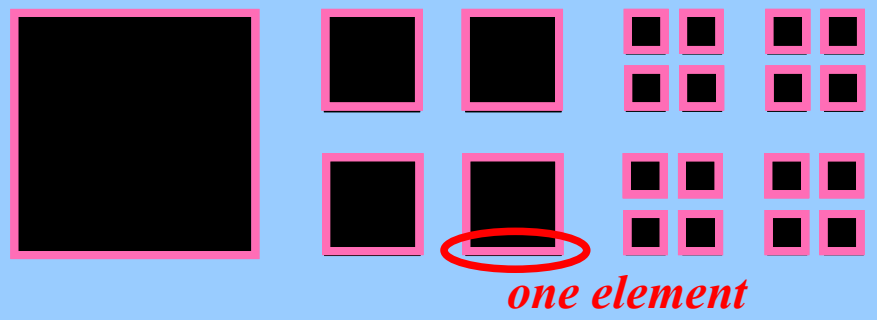
Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1. Borders and envelope of a first model: the Fournier dust

1.1 The borders of a Fournier dust: what changes and what remains at different analysis levels

Introduction of the fractal dimension



N_{bord} number of elements of the **border**

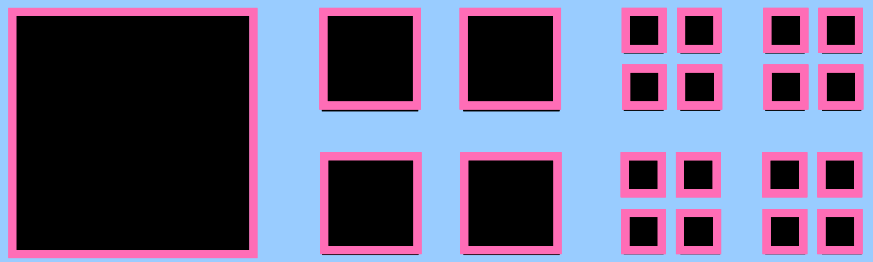
Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1. Borders and envelope of a first model: the Fournier dust

1.1 The borders of a Fournier dust: what changes and what remains at different analysis levels

Introduction of the fractal dimension



$N_{bord(0)} = 4$ $N_{bord(1)} = 16$ $N_{bord(2)} = 64$

$$D_{bord} = -\frac{\log N_{bord}}{\log r}$$

Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1. Borders and envelope of a first model: the Fournier dust

1.1 The borders of a Fournier dust: what changes and what remains at different analysis levels

Introduction of the fractal dimension

$$D_{bord} = - \frac{\log N_{bord}}{\log r}$$

Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1. Borders and envelope of a first model: the Fournier dust

1.1 The borders of a Fournier dust: what changes and what remains at different analysis levels

p_n **length of he border of one element** at the iteration step n

P_n **cumulated border** at the iteration step n

$\mathcal{P}$ **generalized perimeter**

$$\mathcal{P} = N_n \cdot (p_n)^D = (a \cdot l_0)^D$$

→ **The two variables $\mathcal{P}$ and D link up the notion of border and the notion of envelope.**

Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1. Borders and envelope of a first model: the Fournier dust

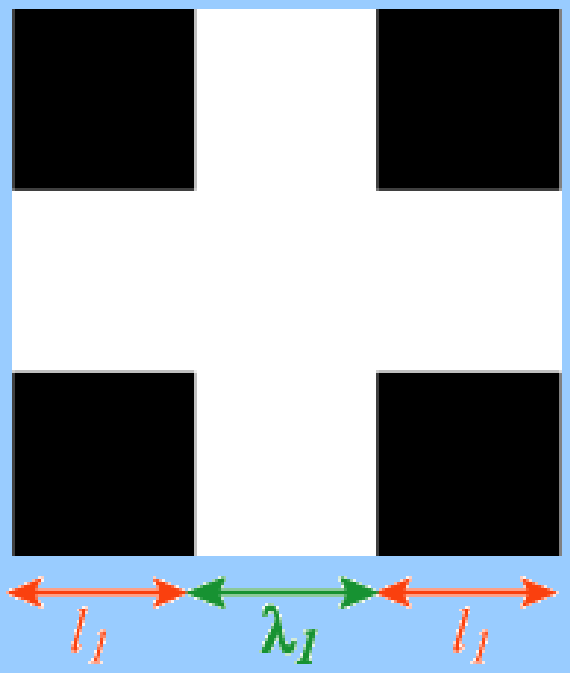
1.1 The borders of a Fournier dust: what changes and what remains at different analysis levels?

1.2 How to generate the envelope of a Fournier dust?

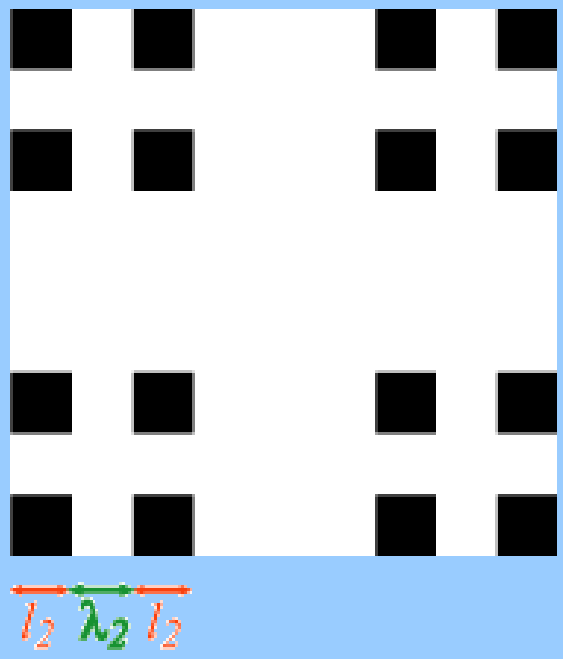
Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1.2 How to generate the envelope of a Fournier dust?



1st iteration step
(generator)

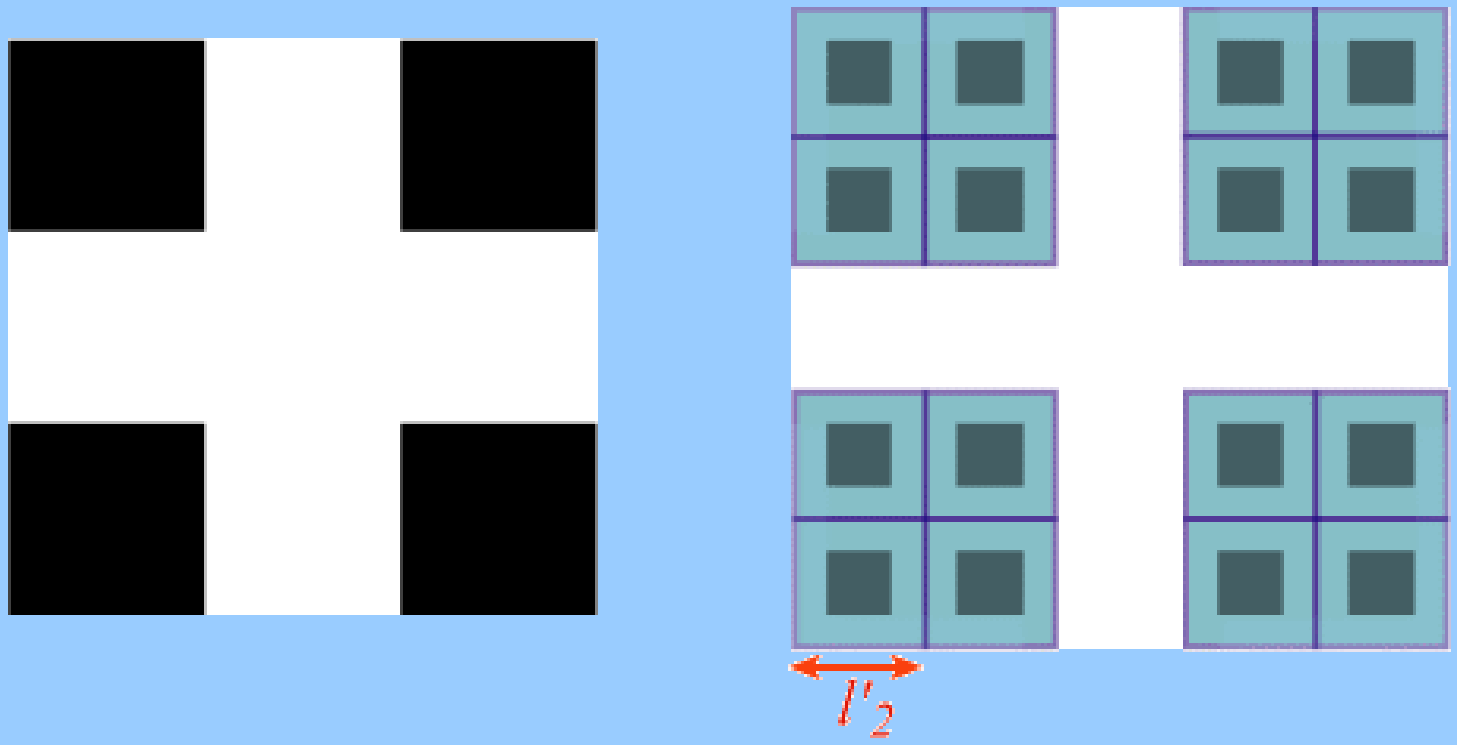


2nd iteration step

Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

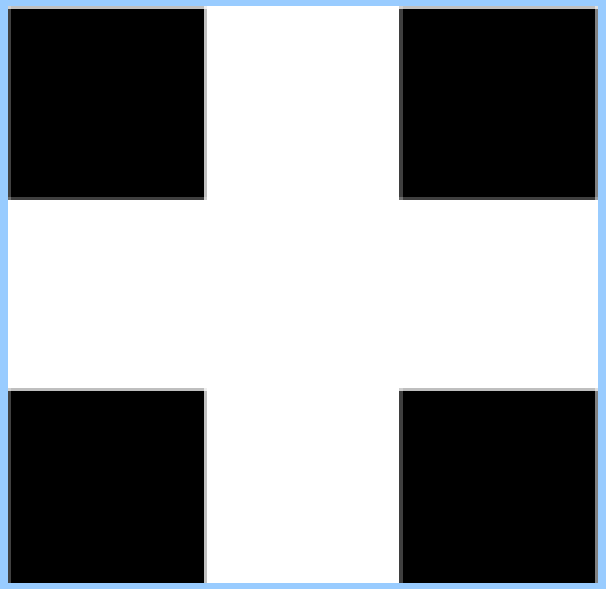
1.2 How to generate the envelope of a Fournier dust?

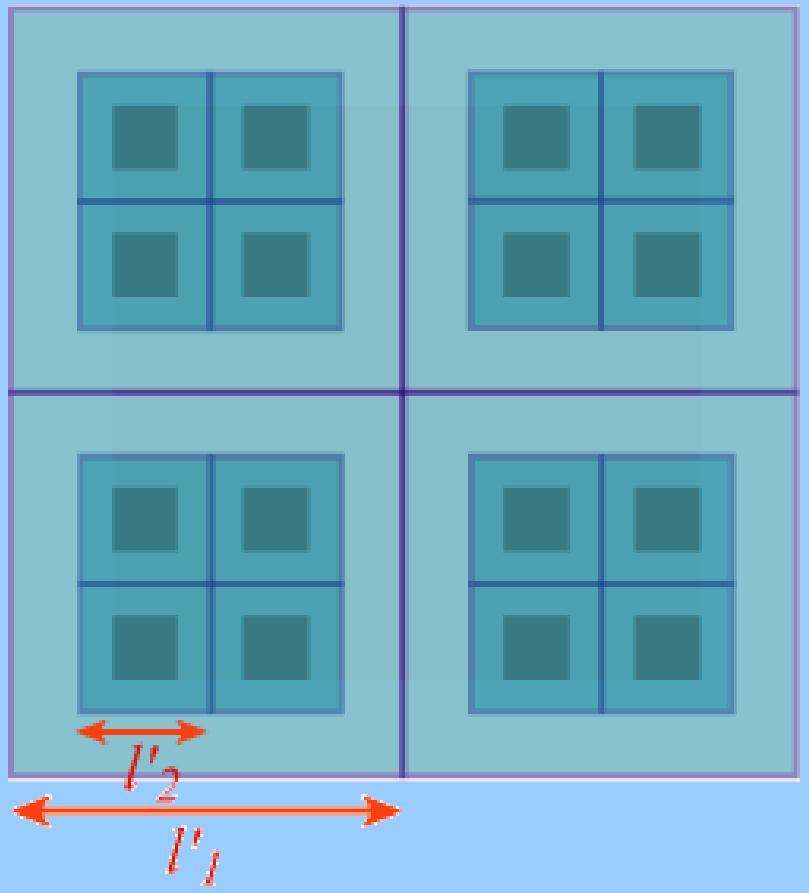


Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1.2 How to generate the envelope of a Fournier dust?

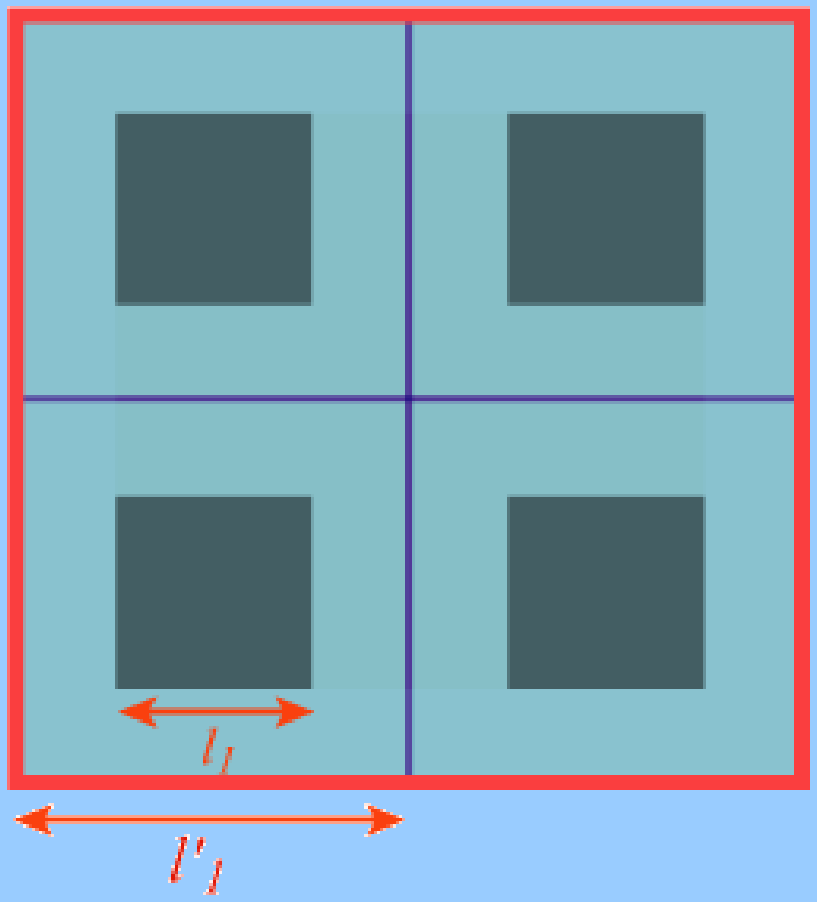


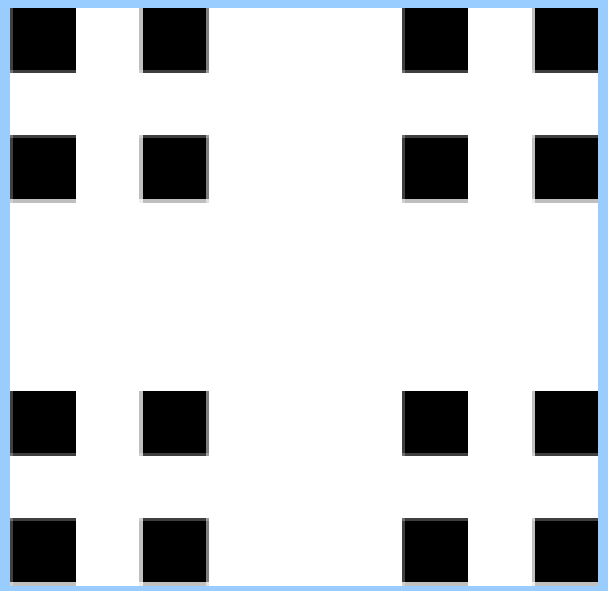


Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1.2 How to generate the envelope of a Fournier dust?





Envelope generated by covering

Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1. Borders and envelope of a first model: the Fournier dust

1.2 How to generate the envelope of a Fournier dust?

First assessment

- The envelope generated by a covering procedure bounds a morphological set, which is coherent through the scales.

- On a morphological point of view, an urban area is a morphological set coherent through the scales.

→ **The generation of an envelope using a covering procedure can be used for delimiting an urban area.**

Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1. Borders and envelope of a first model: the Fournier dust

1.1 The borders of a Fournier dust: what changes and what remains at different analysis levels?

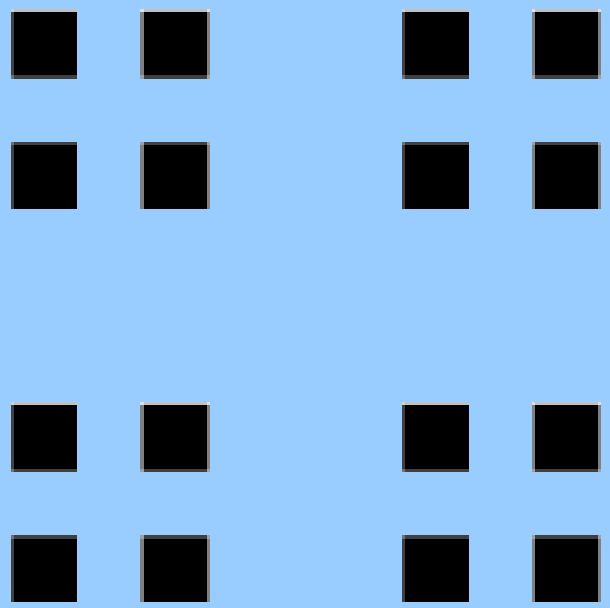
1.2 How to generate the envelope of a Fournier dust?

1.3 From the general covering procedure to the dilation

Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

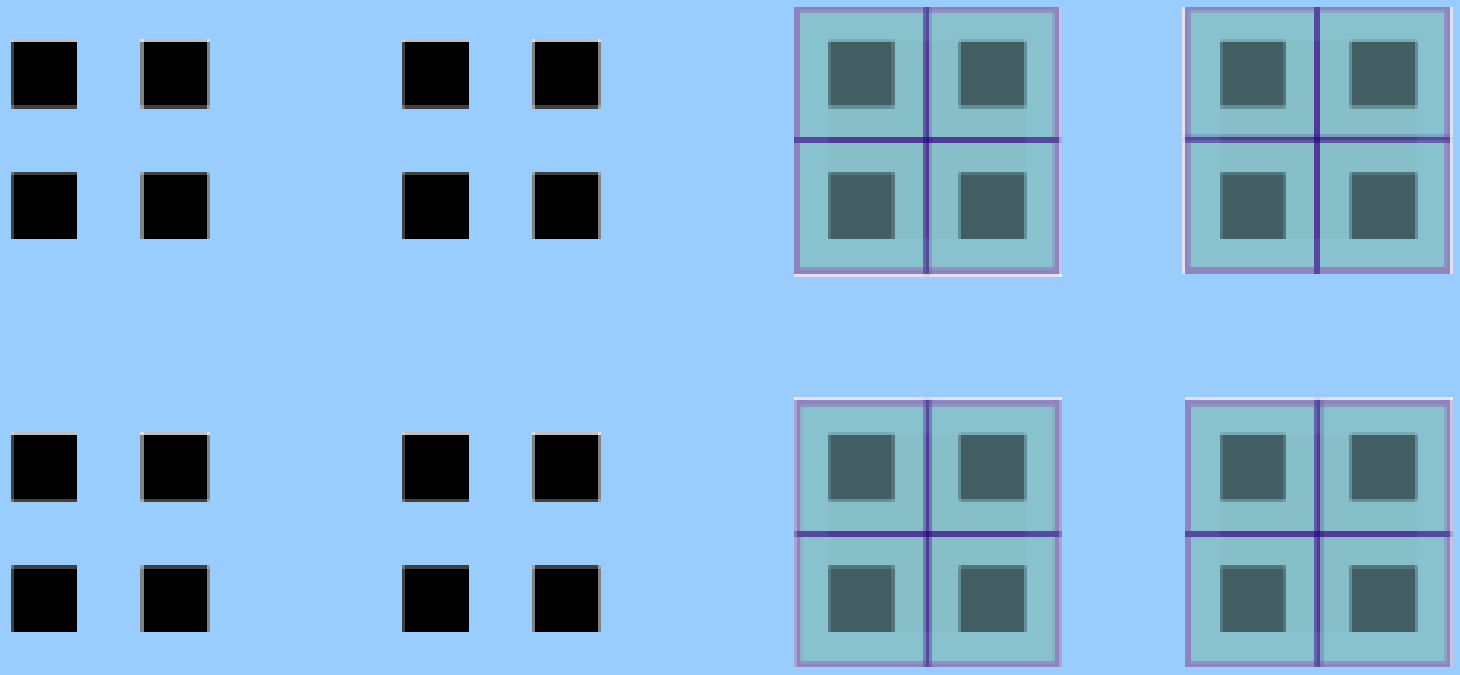
1.3 From the general covering procedure to the dilation



Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1.3 From the general covering procedure to the dilation

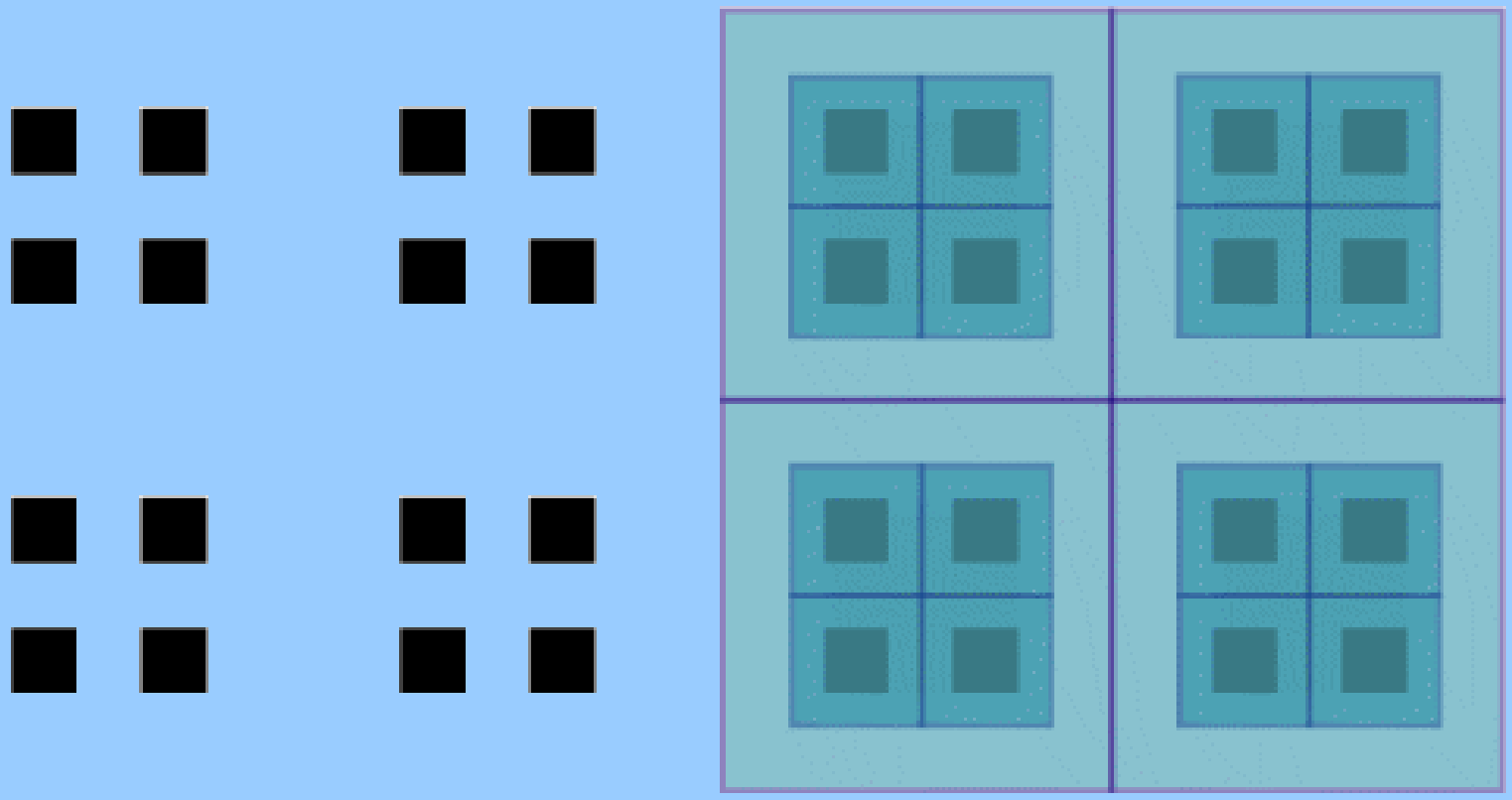


1st step of dilation

Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1.3 From the general covering procedure to the dilation



3rd step of dilation

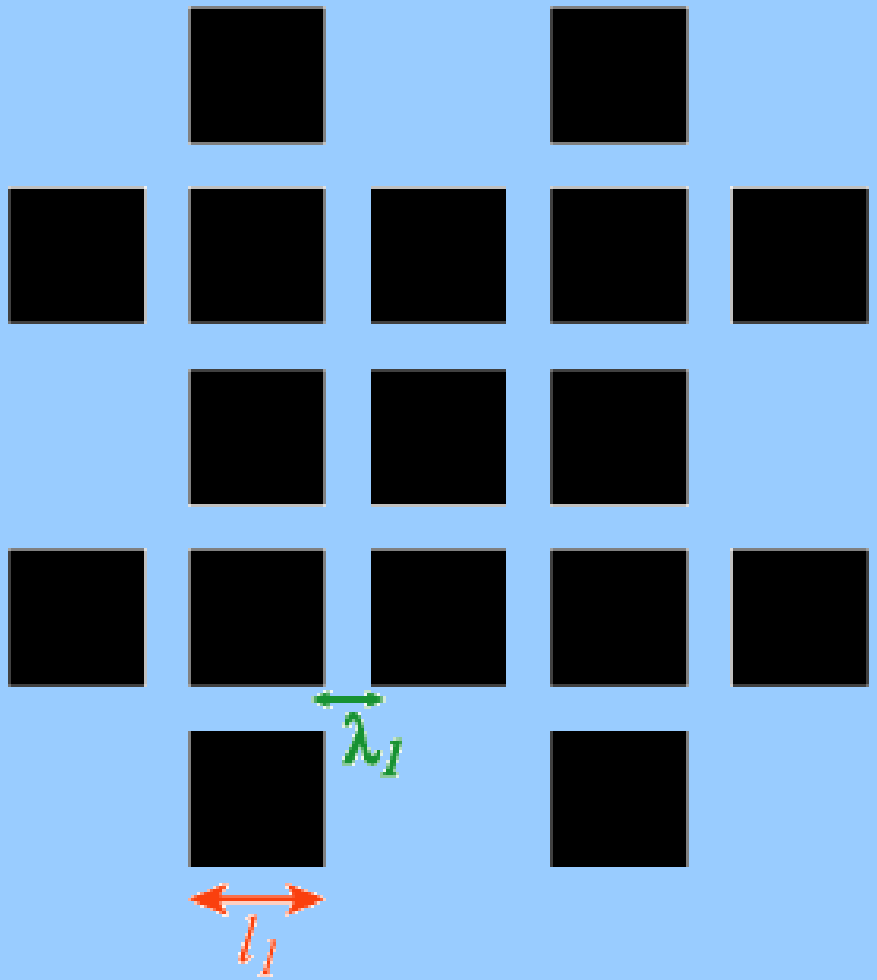
The envelope generated by dilation is identical to the one generated by covering.

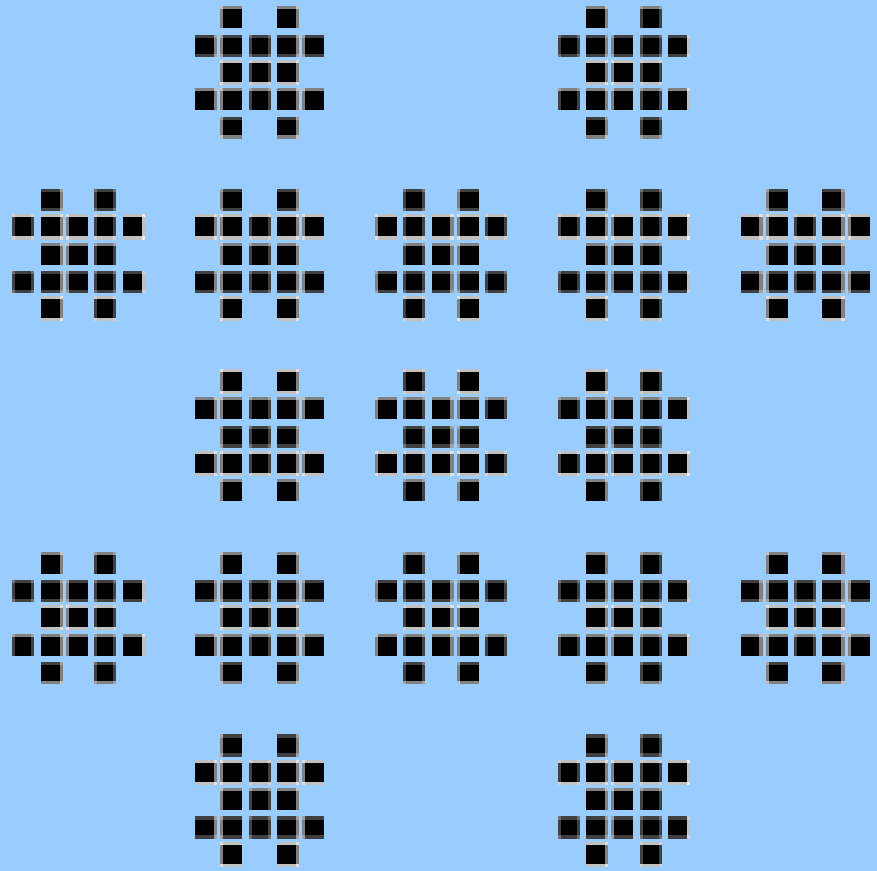
Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1.3 From the general covering procedure to the dilation

A more complex Fournier dust



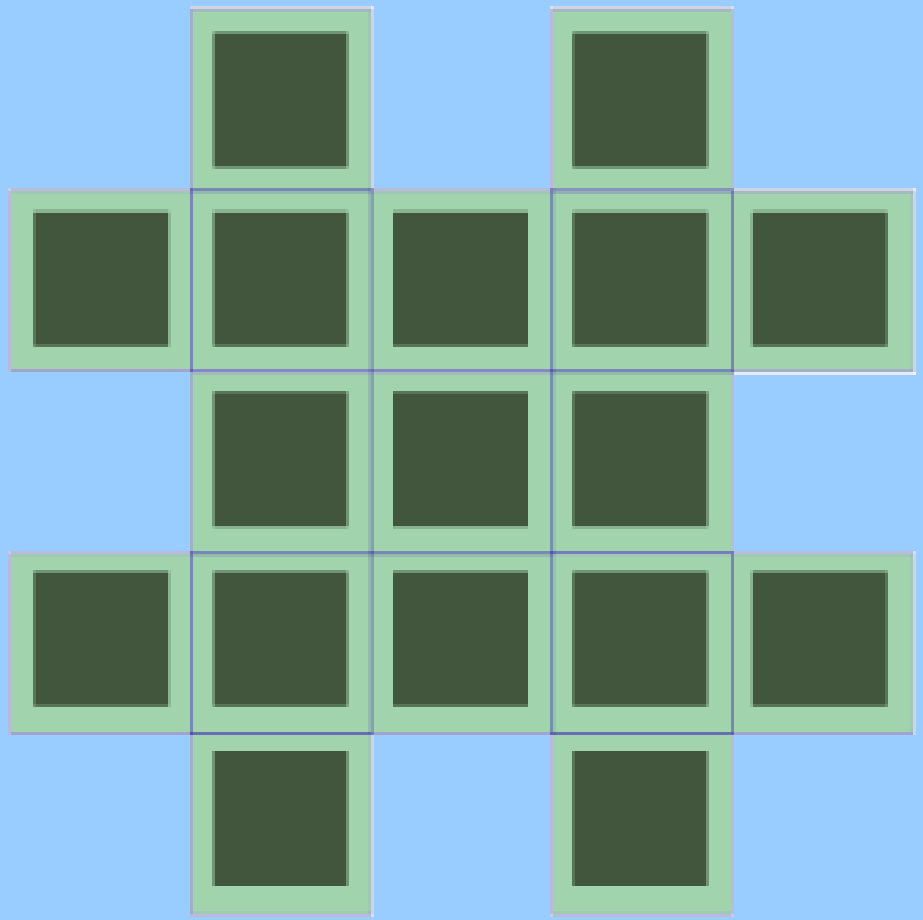


Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1.3 From the general covering procedure to the dilation

Covering of this last Fournier dust



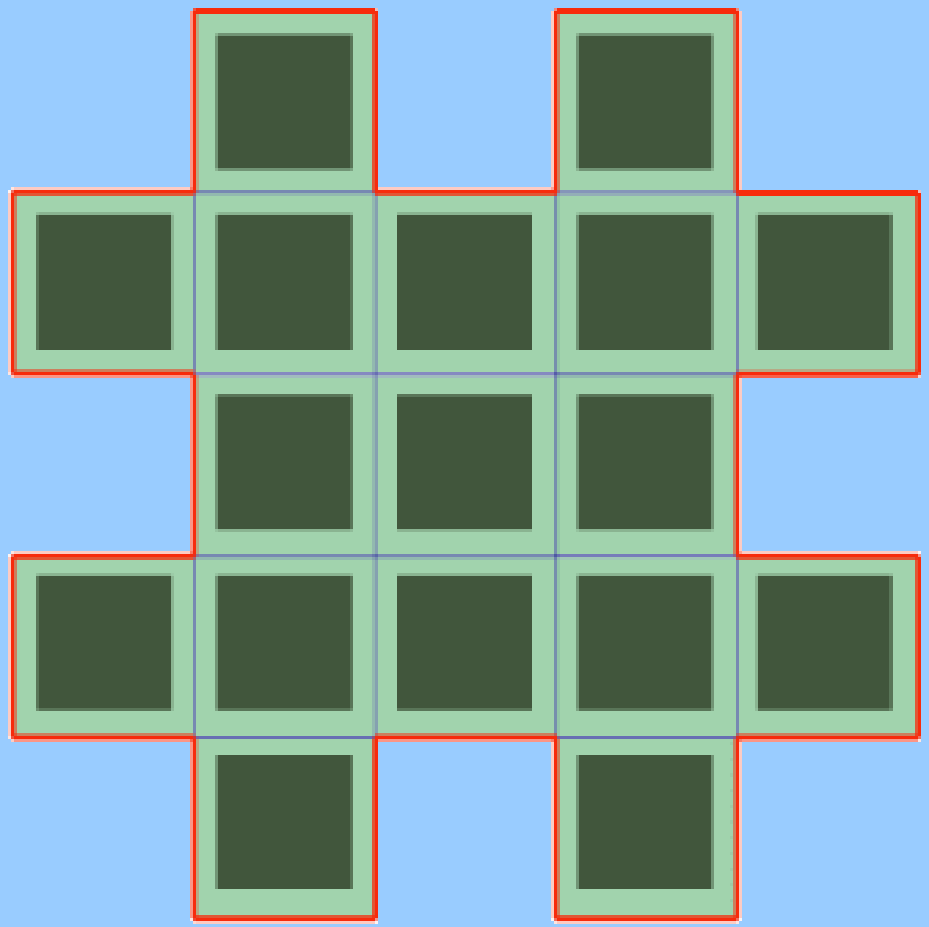
Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1.3 From the general covering procedure to the dilation

Covering of this last Fournier dust

-> the envelope does not correspond to the initiator

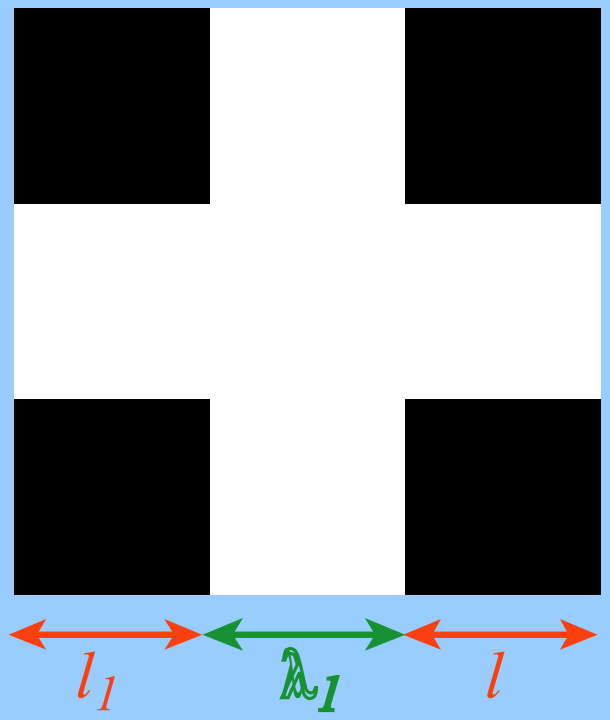


Second part

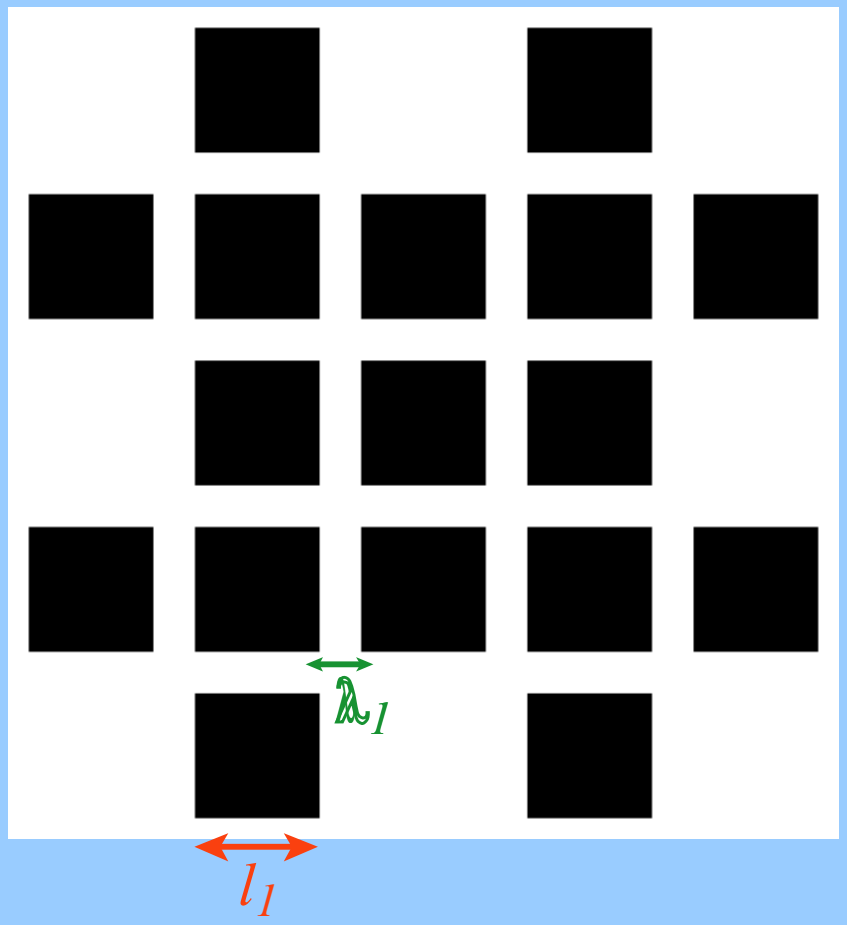
Choice of a methodology for generating the envelope of an urban area: theoretical argument

1.3 From the general covering procedure to the dilation

one size of lacunas in the generator



two sizes of lacunas in the generator

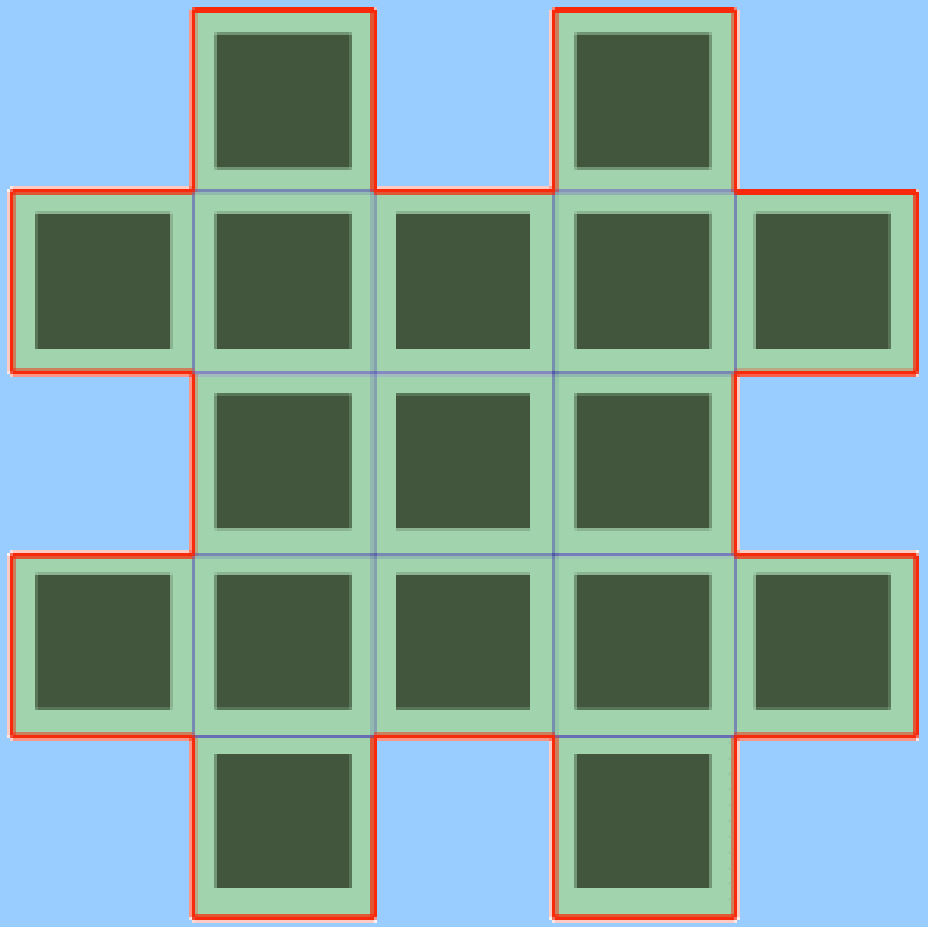


Second part

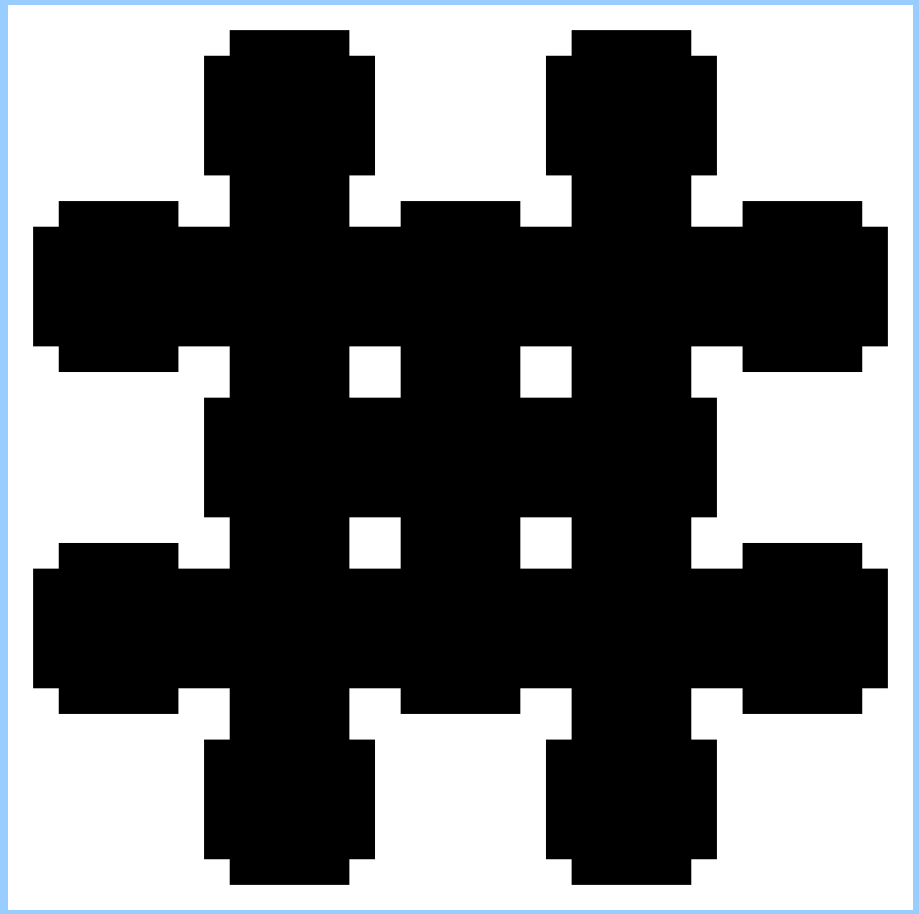
Choice of a methodology for generating the envelope of an urban area: theoretical argument

1.3 From the general covering procedure to the dilation

covering



dilation



Second part

Choice of a methodology for generating the envelope of an urban area: theoretical argument

1.3 From the general covering procedure to the dilation

- Linking the two procedures of covering and dilation by using the notion of fractal dimension
  - The covering is re-used from the method proposed by Hausdorff and Besikovich for determining the fractal dimension of a structure (Mandelbrot 1982).
  - The dilation does not provide a way for constructing an associated fractal having the same self-similarity dimension
  - But, Cantor, Minkowski and Bouligand used the dilation for determining fractal dimensions (Mandelbrot, 1982).

- **It is justified to use the procedure of dilation instead of the covering to generate the envelope of a pattern**

Third part

Application: generating the envelope of theoretical and real urban patterns

1. Generation of the envelope of a regular fractal pattern using the dilation

Iterative construction -> Application of a given fractal generator to a given initial form

→ Iterated Functions Systems (IFS) - (Barnsley, 1988)

Reduction and translation of the elements generated at the previous step of iteration

Third part

Application: generating the envelope of theoretical and real urban patterns

1. Generation of the envelope of a regular fractal pattern using the dilation

Iterative construction -> Application of a same fractal generator to a given initial form

- Iterated Functions Systems (IFS)
- Software: Constrained Fractal Generator (CFG) - G. Vuidel
  - precise definition of the IFS numerically and graphically
  - possibility to export the results suitable for an analysis using *Fractalyse*

http://www.fractalyse.org

Third part

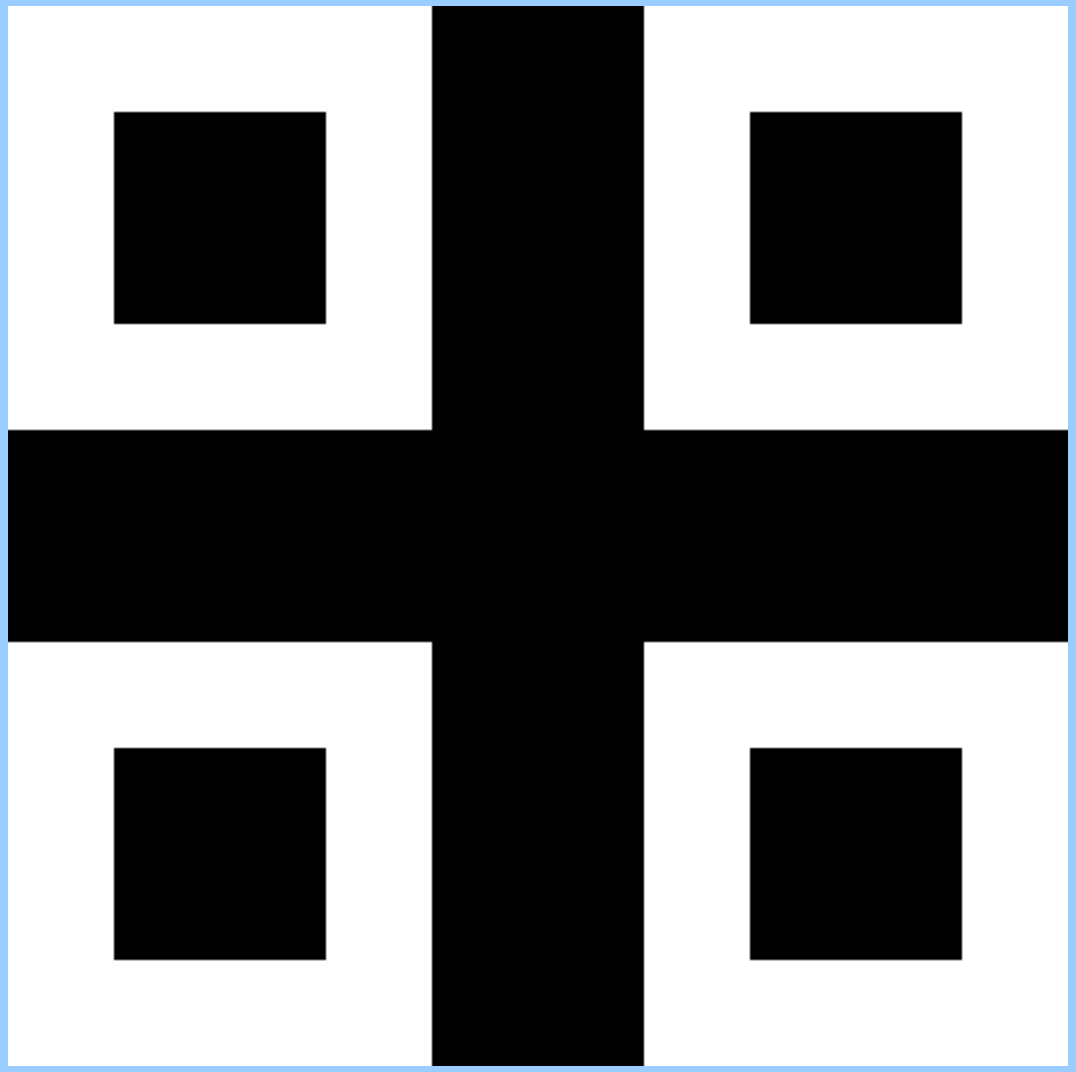
Application: generating the envelope of theoretical and real urban patterns

1. Generation of the envelope of a regular fractal pattern using the dilation

Example: hybrid Sierpinski carpet

Two subsystems:

- 4 isolated clusters in the corners
- a central cluster -> Sierpinski carpet



Third part

Application: generating the envelope of theoretical and real urban patterns

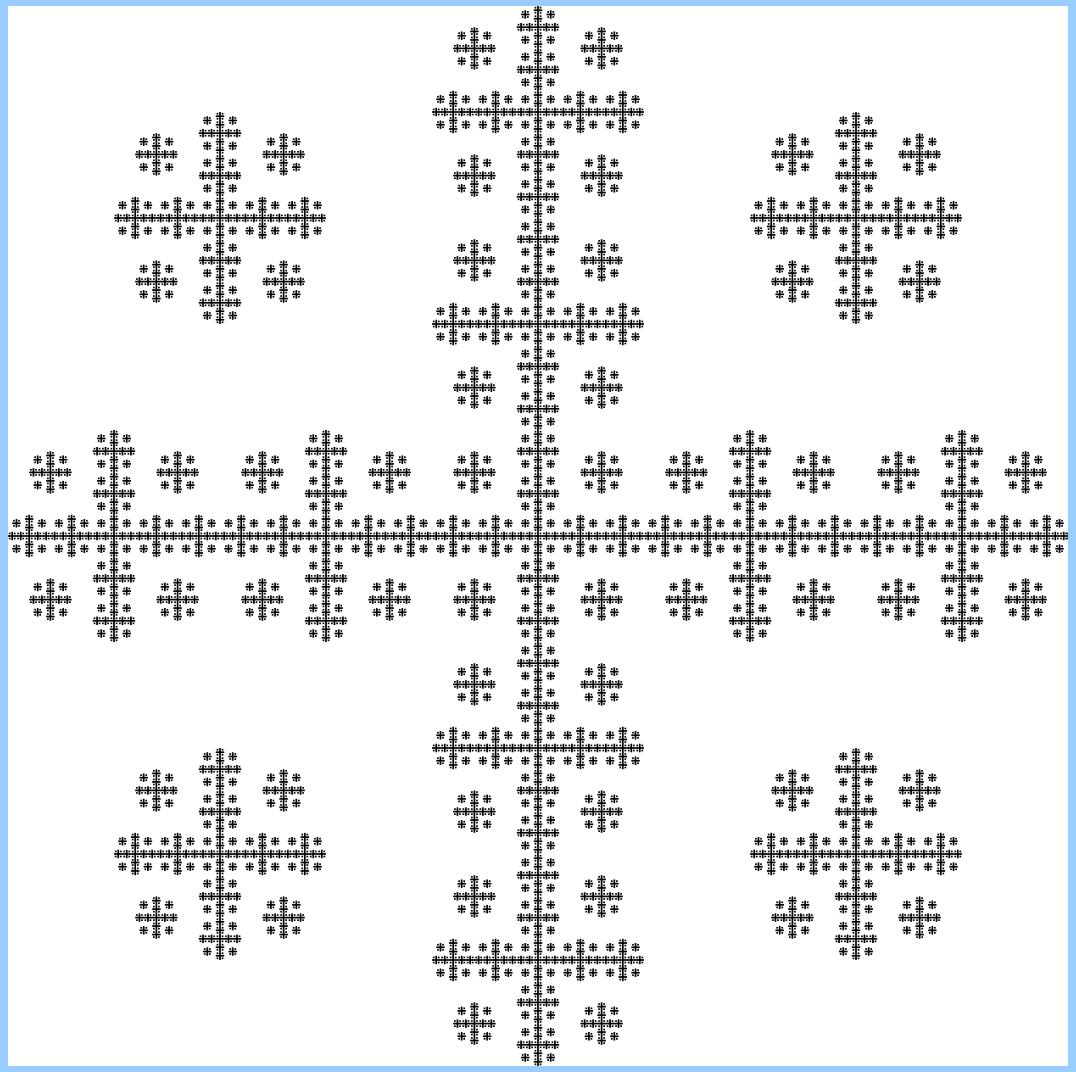
1. Generation of the envelope of a regular fractal pattern using the dilation

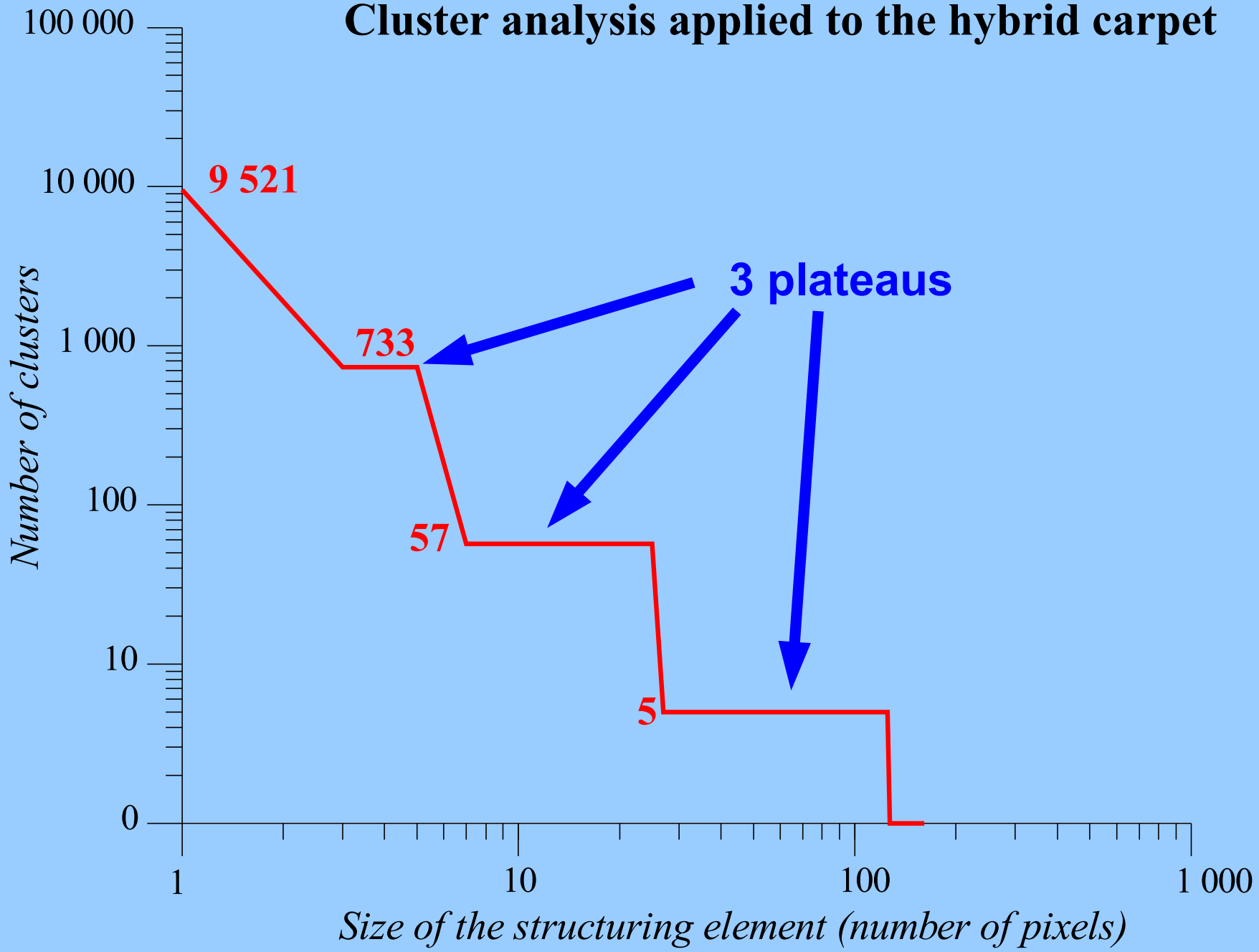
Example: hybrid Sierpinski carpet

Two subsystems:

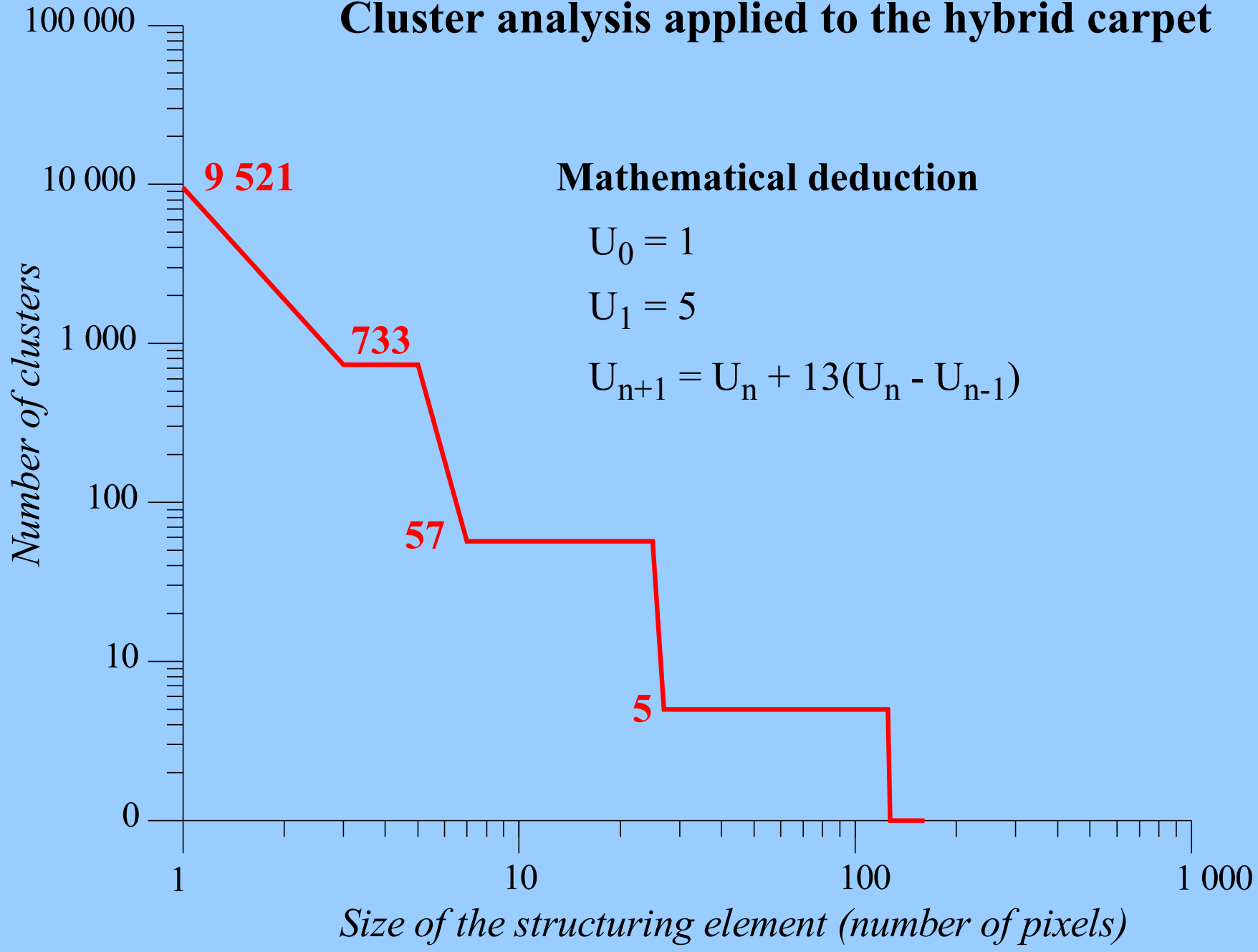
- 4 isolated clusters in the corners
- a central cluster -> Sierpinski carpet

Iteration generates more and more smaller Sierpinski carpets





Cluster analysis applied to the hybrid carpet

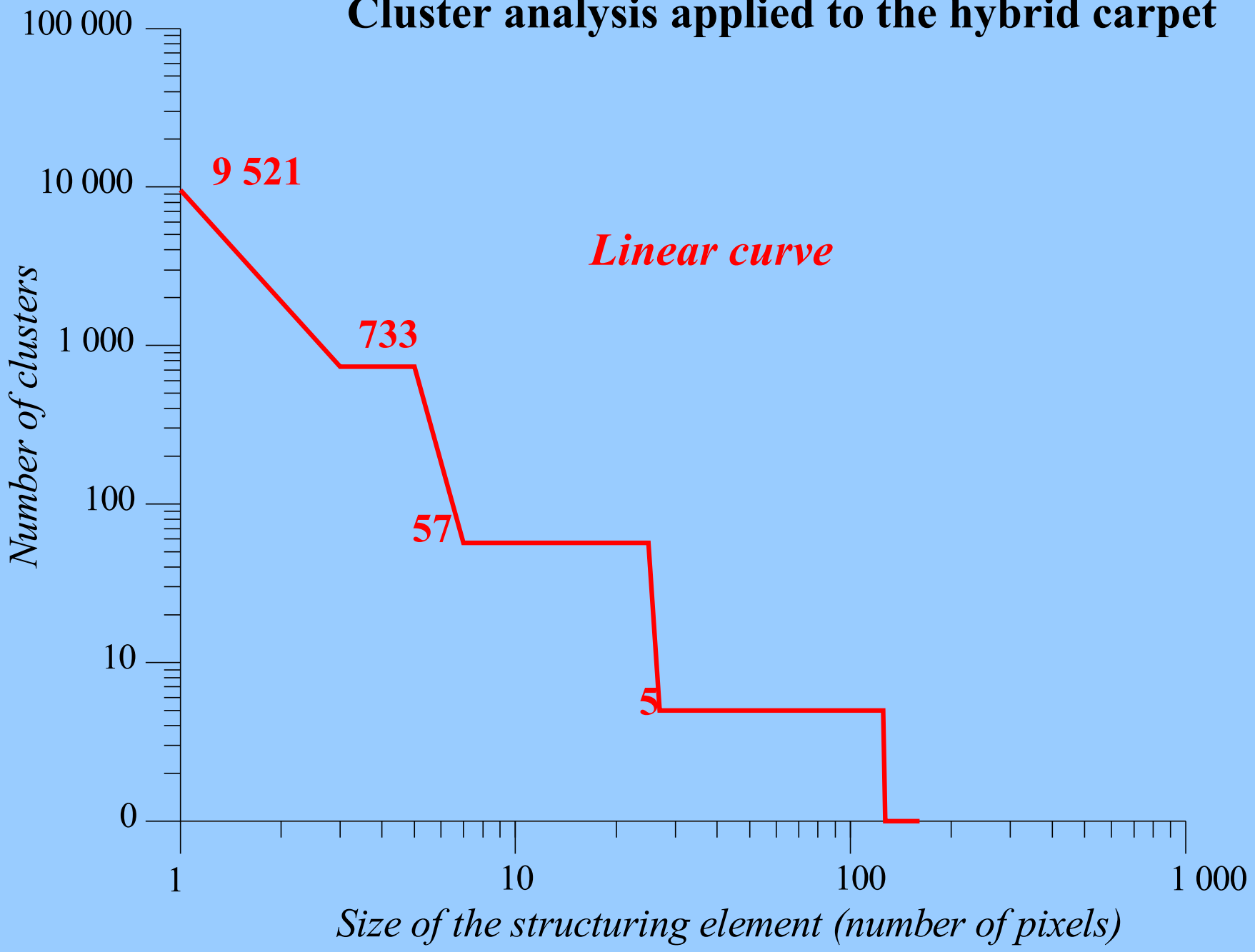


Mathematical deduction

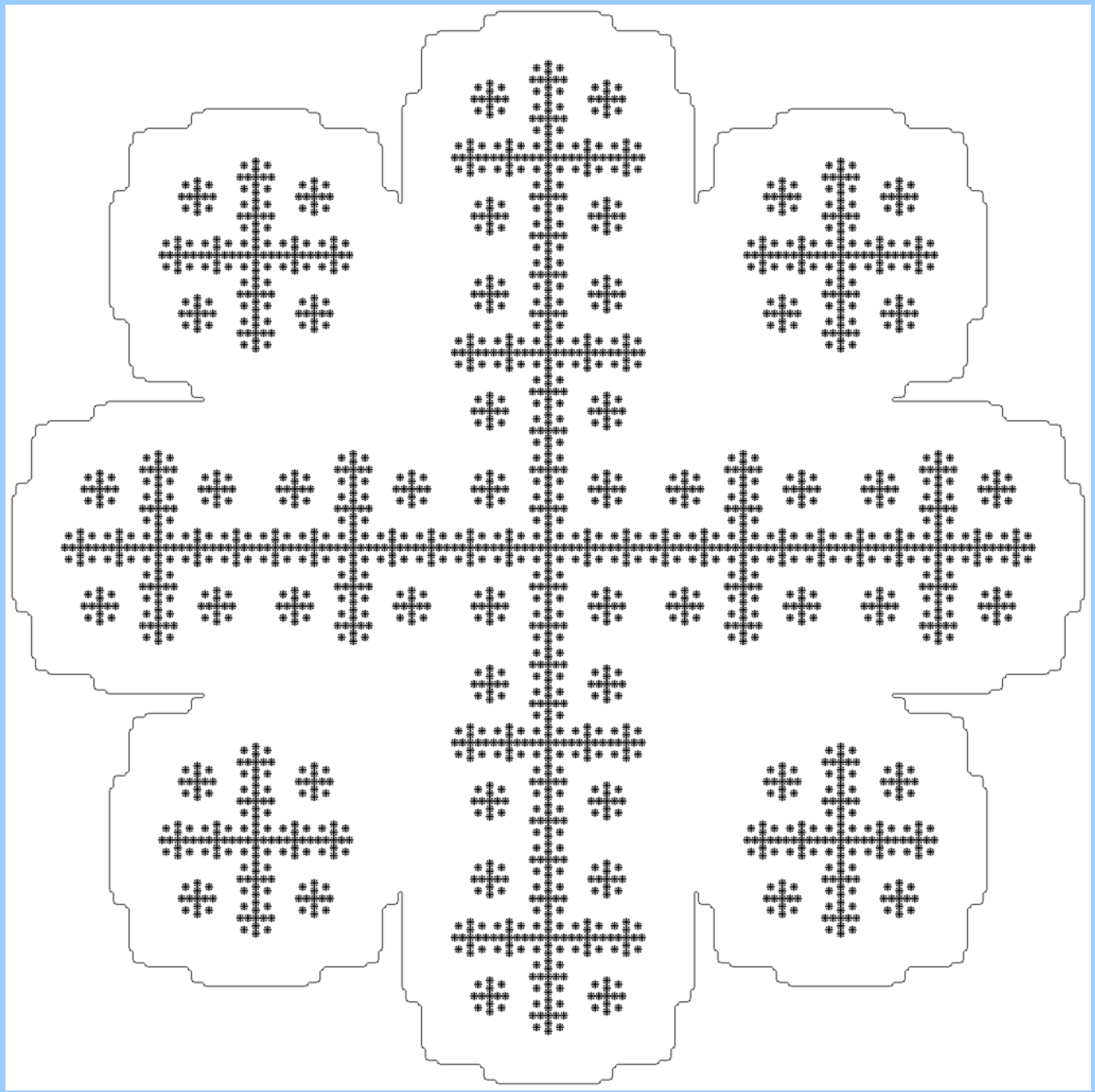
$U_0 = 1$

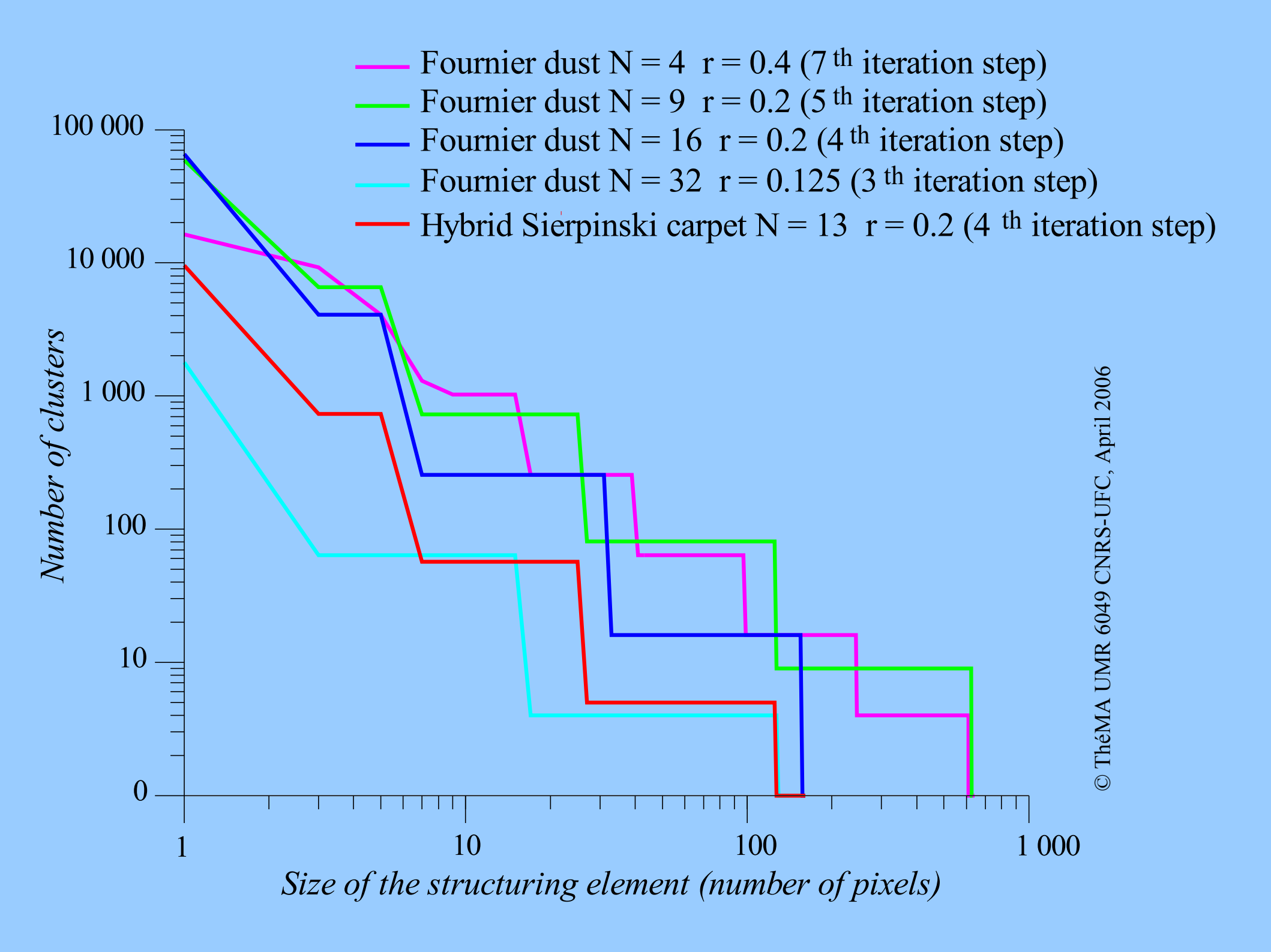
$U_1 = 5$

$U_{n+1} = U_n + 13(U_n - U_{n-1})$



Envelope of the hybrid carpet




Fournier dust N = 4 r = 0.4 (7 th iteration step)
Fournier dust N = 9 r = 0.2 (5 th iteration step)
Fournier dust N = 16 r = 0.2 (4 th iteration step)
Fournier dust N = 32 r = 0.125 (3 th iteration step)
Hybrid Sierpinski carpet N = 13 r = 0.2 (4 th iteration step)
100 000
10 000
1 000
100
10
0
Number of clusters
1
10
100
1 000
Size of the structuring element (number of pixels)
© ThéMA UMR 6049 CNRS-UFC, April 2006

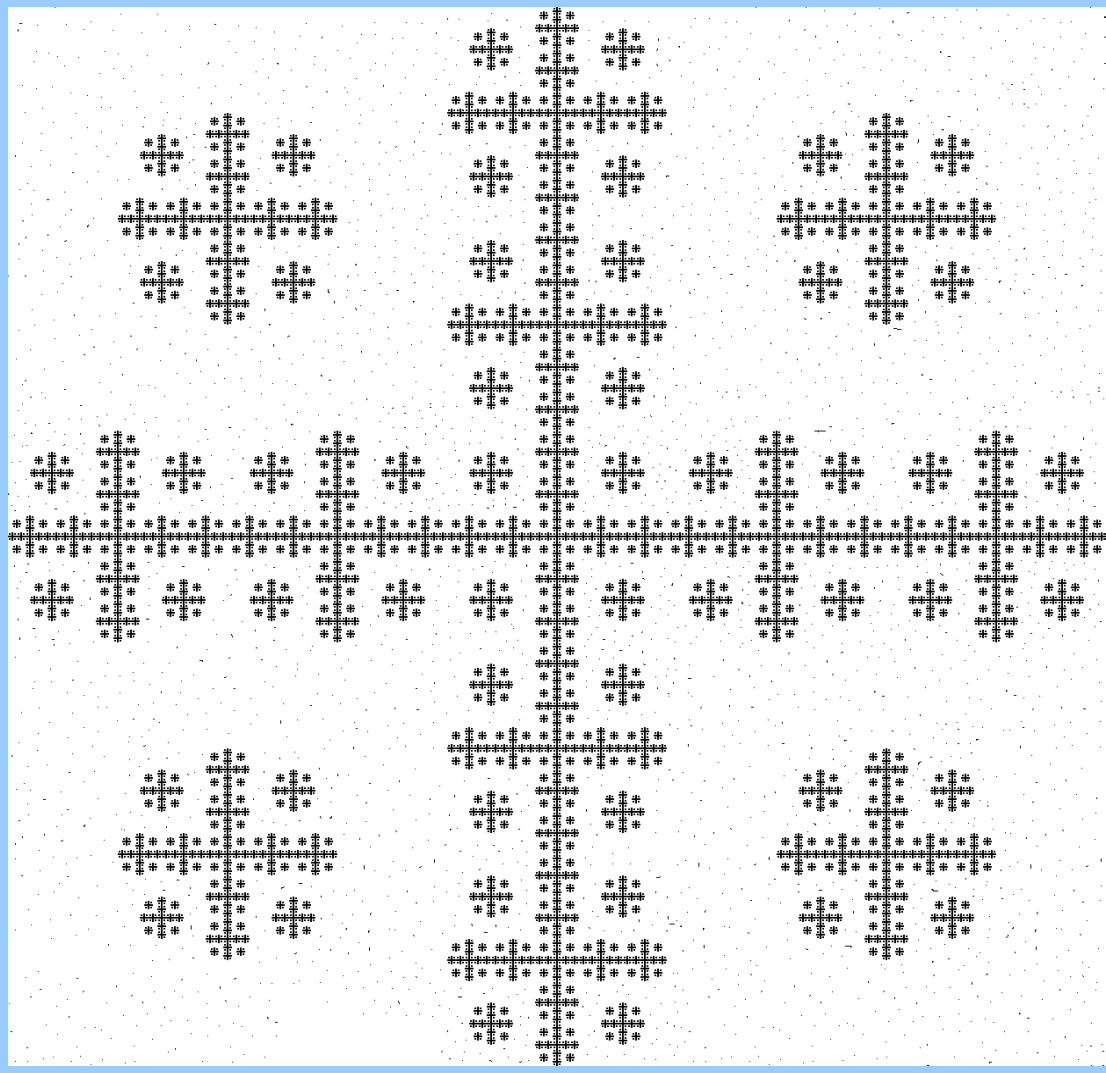
Third part

Application: generating the envelope of theoretical and real urban patterns

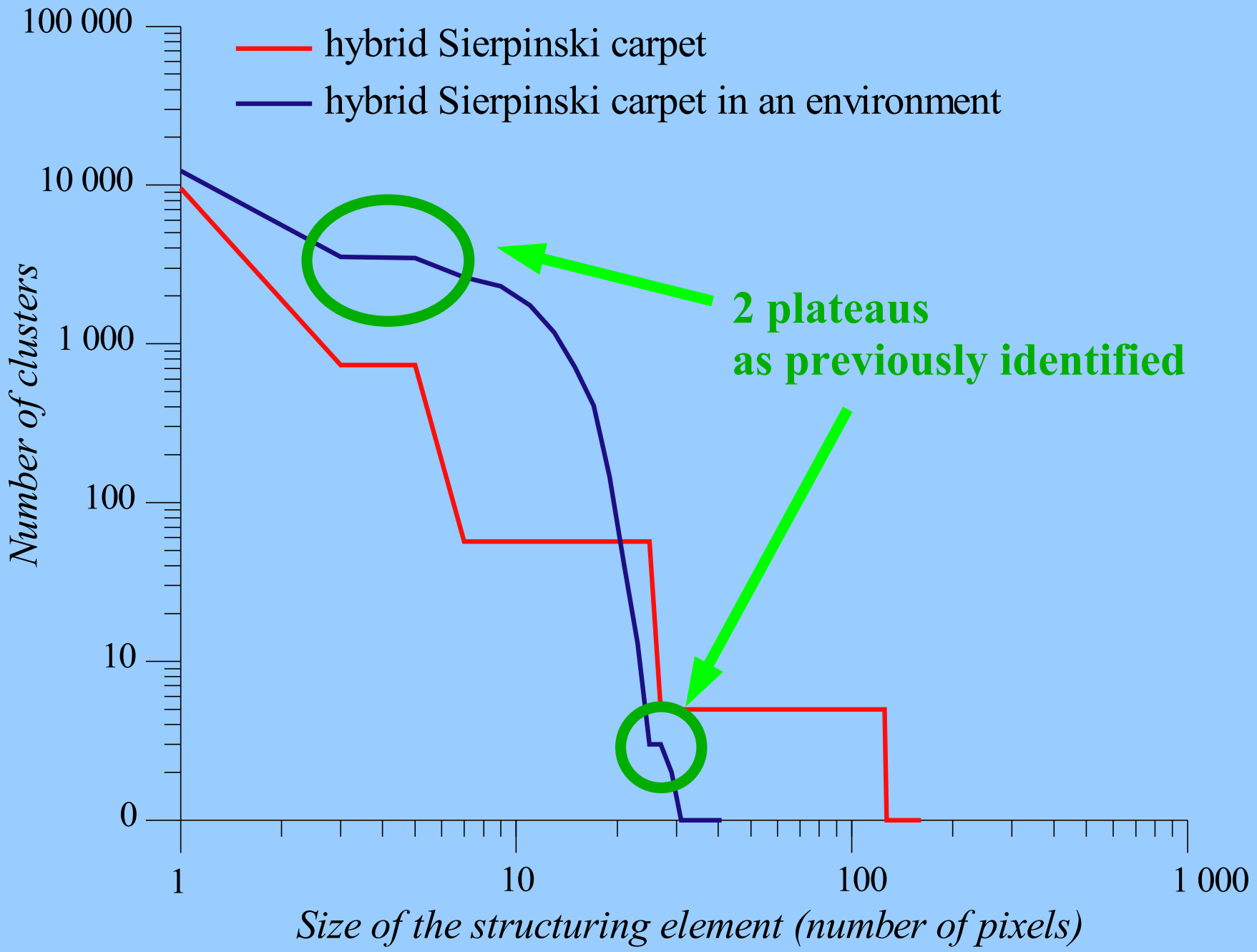
2. Generation of the envelope of a regular fractal pattern in a non fractal environment

Example: hybrid Sierpinski carpet surrounded by randomly distributed elements

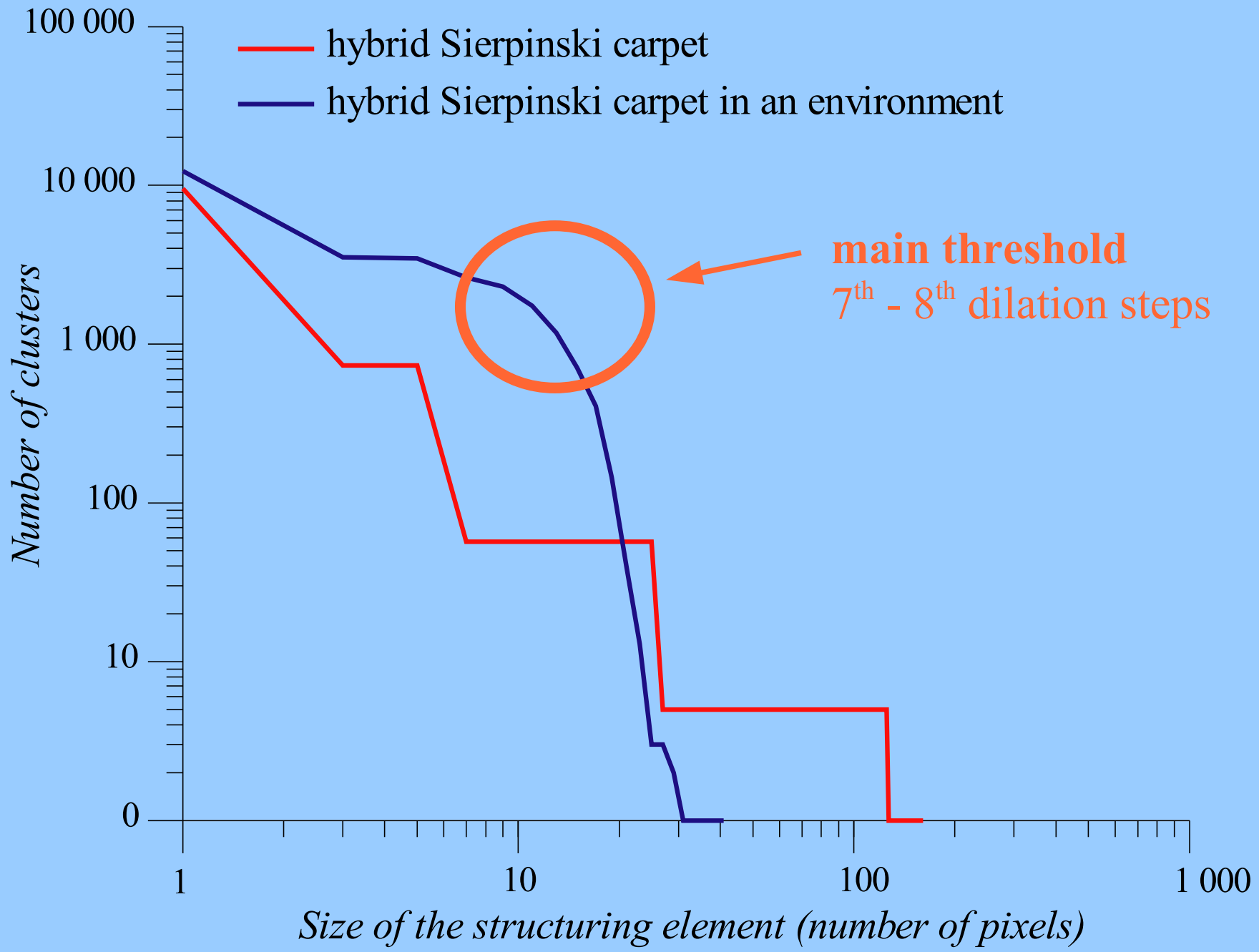
Metaphor of a city surrounding by rural settlements

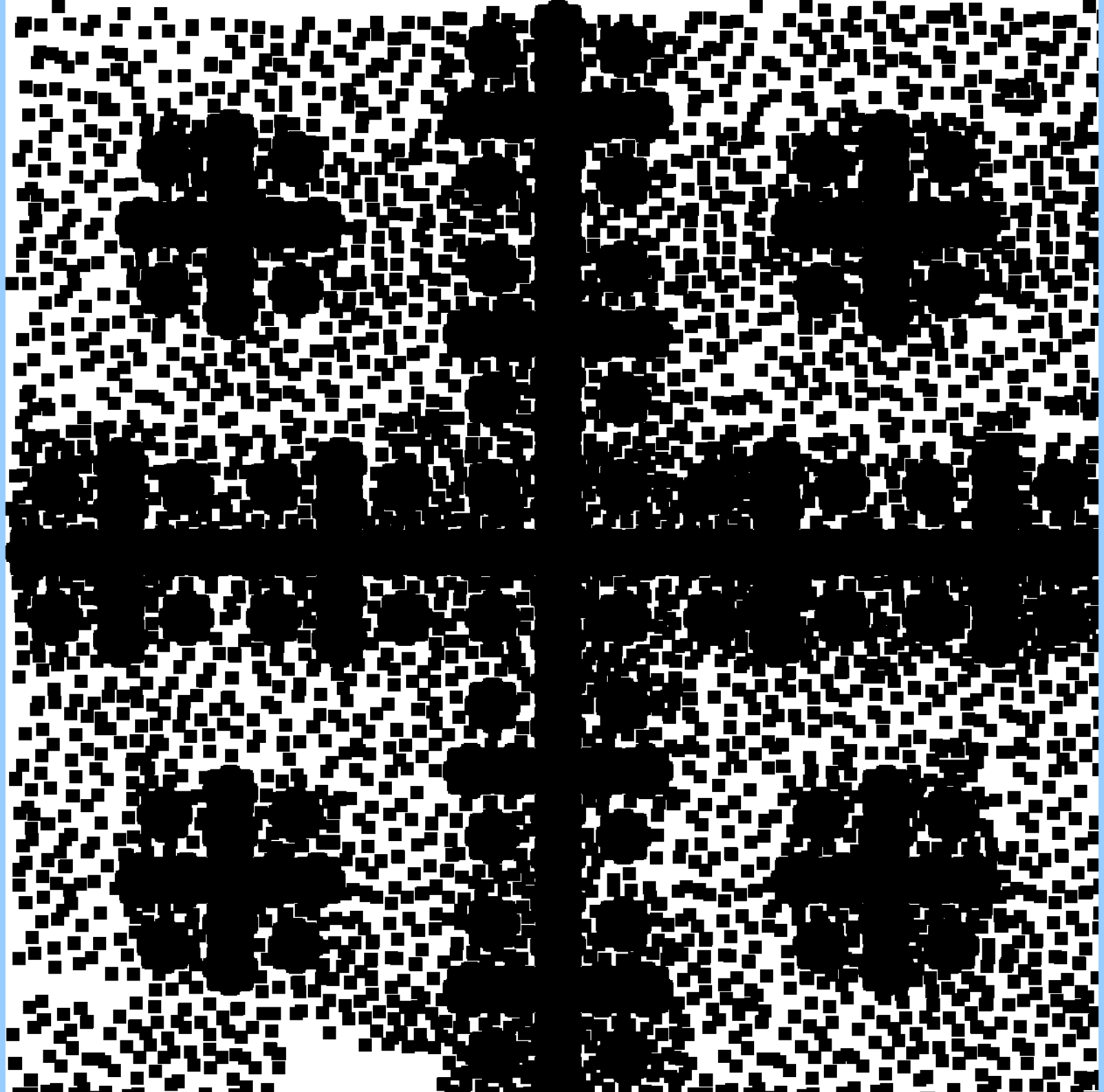


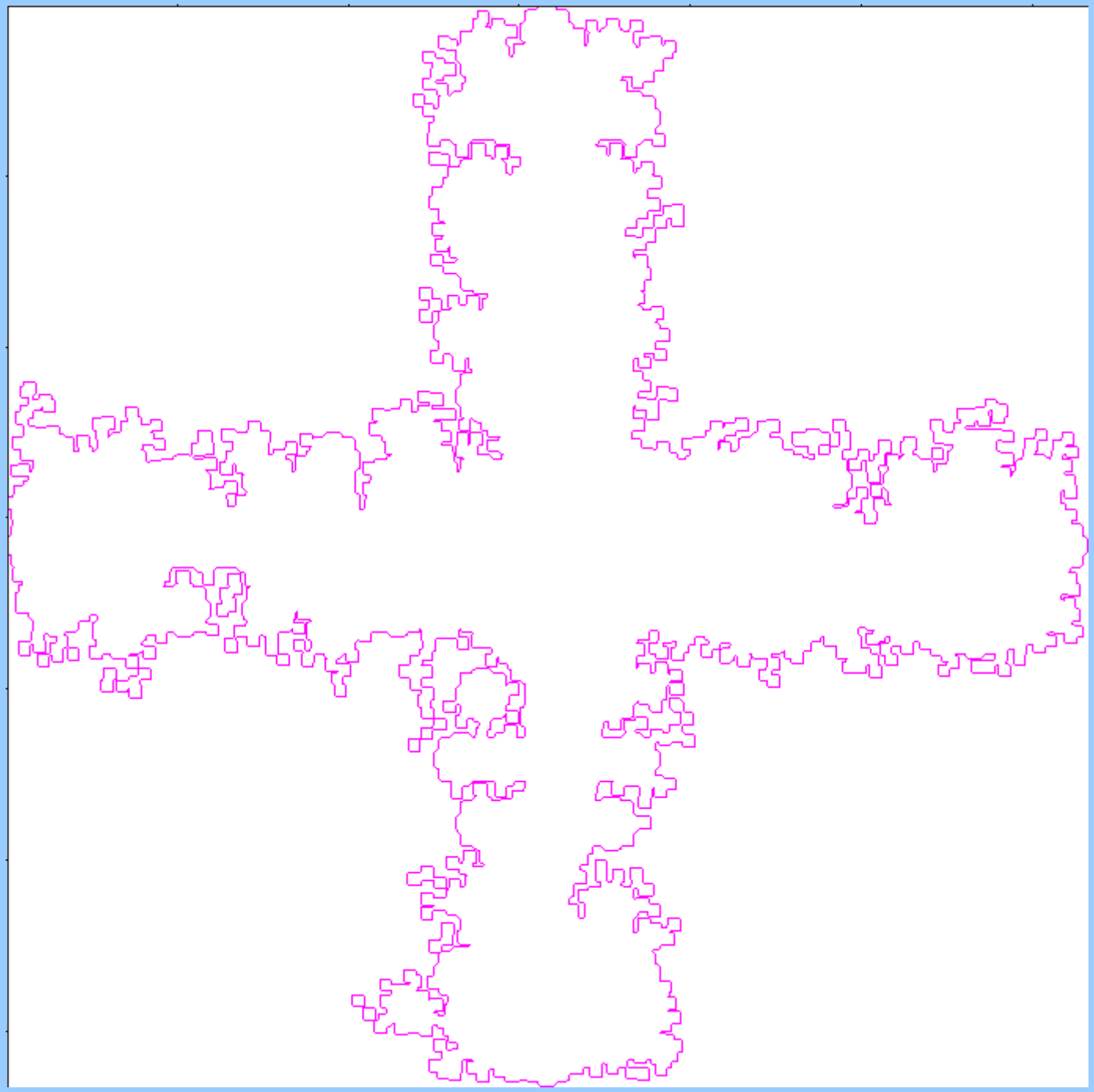
Results of the cluster analysis



Results of the cluster analysis







Third part

Application: generating the envelope of theoretical and real urban patterns

3. Generation of the envelope of real urban patterns

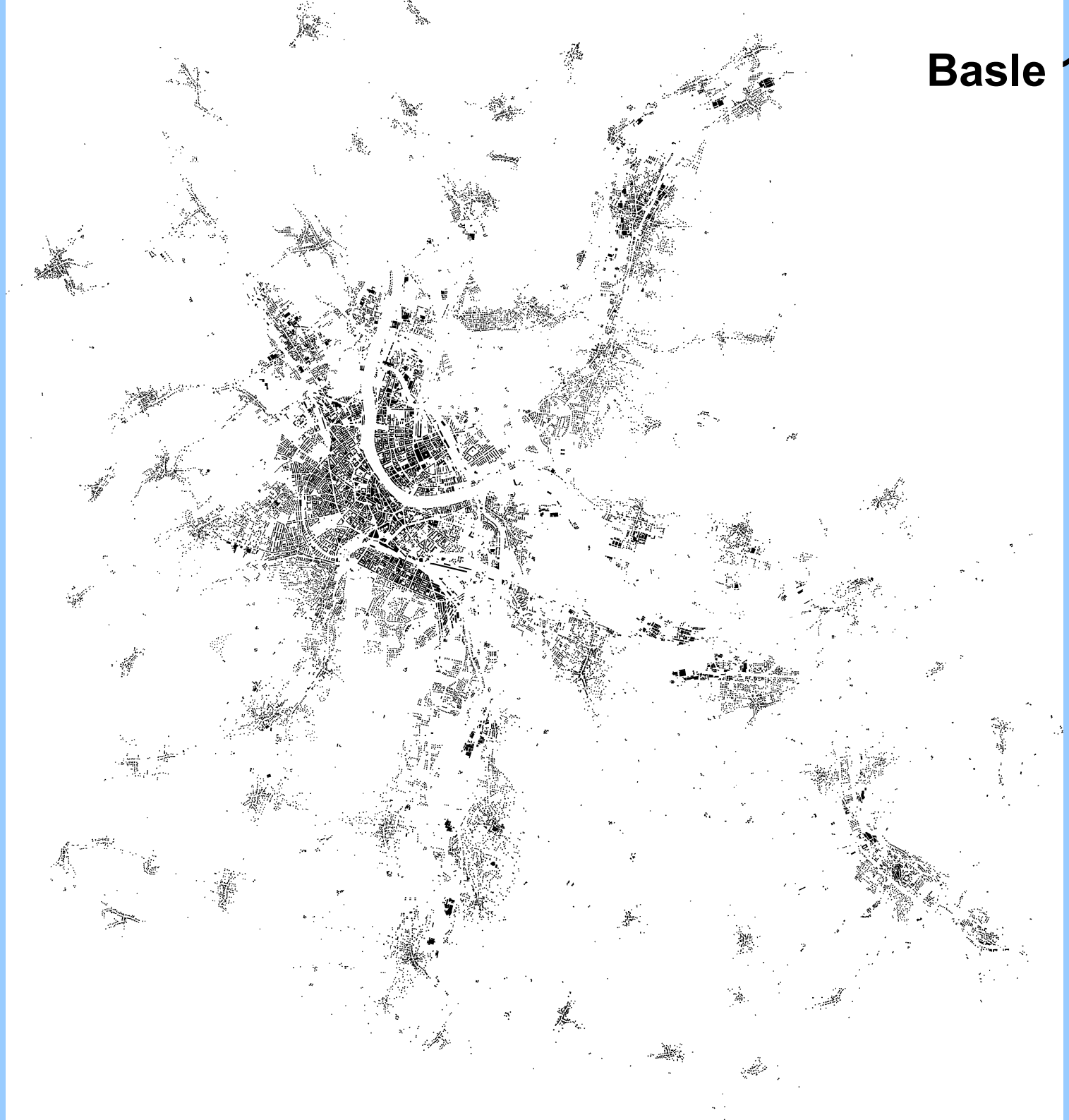
Basle in 1882, 1957 and 1994
Besançon
Lille
Stuttgart

Third part

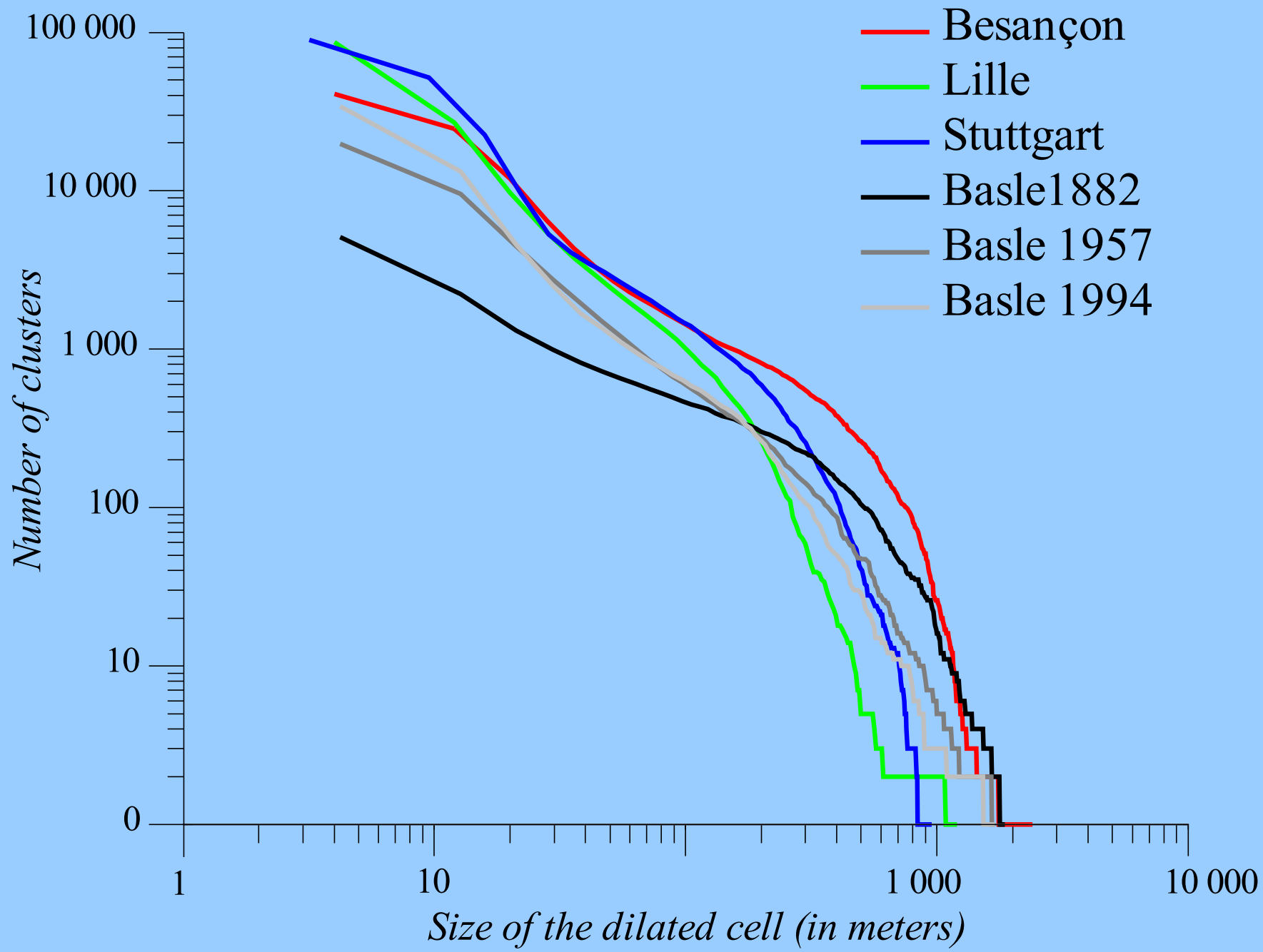
Application: generating the envelope of theoretical and real urban patterns

3. Generation of the envelope of real urban patterns

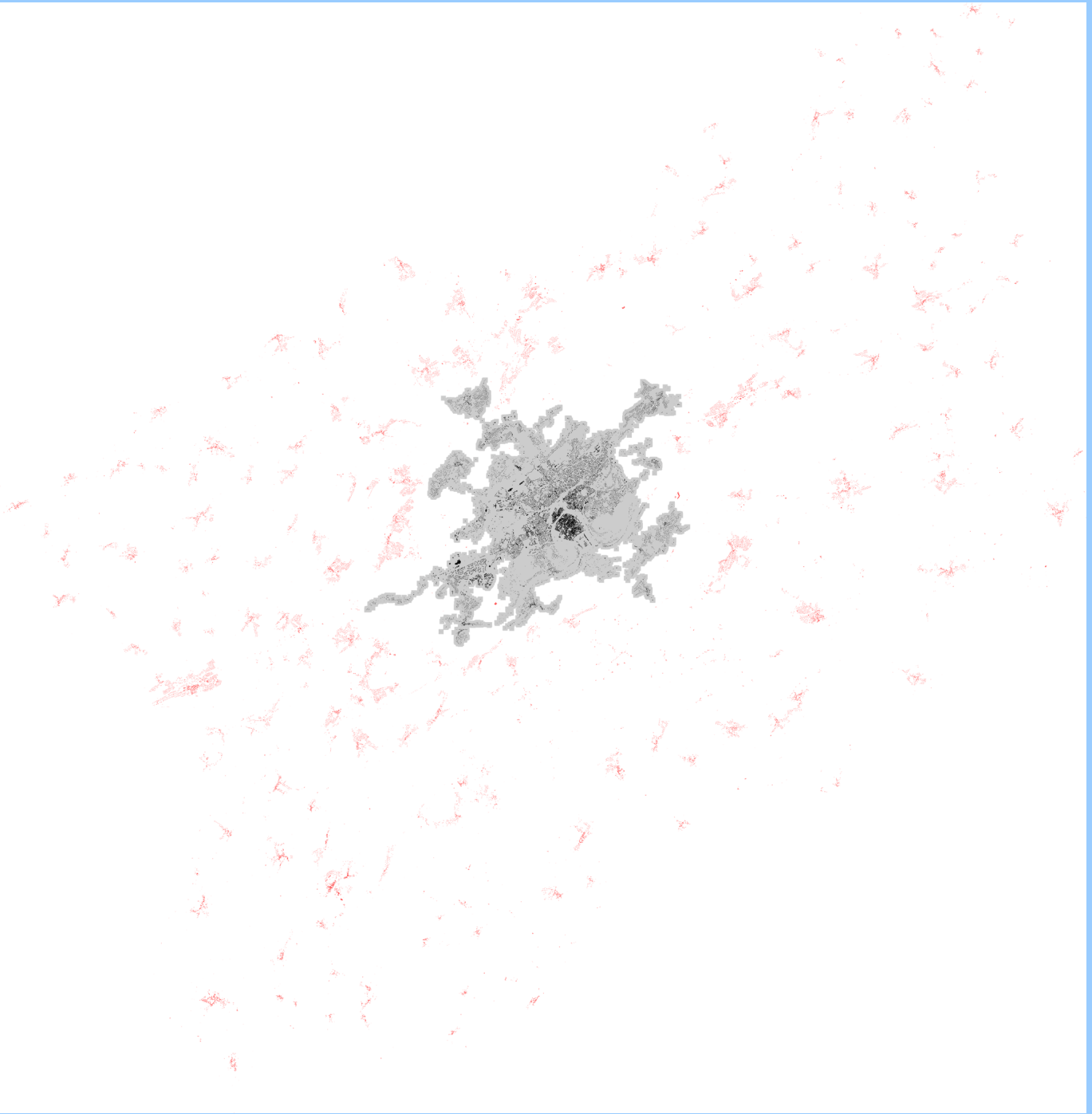
- *black and white images of the built-up surface of the urban areas*
- *precise images: good identification of each building*
- *a black cell represents a part of a building*
- *size of each studied area: large*


Basle 1957

Results of the cluster analysis



Envelope of the urban area of Besançon



About the existence or non-existence of an urban envelope in the framework of a multi-scale approach

Conclusion

- The generation of an urban envelope is possible and meaningful: identification of morphological sets coherent through the scales
- We mathematically demonstrated that it is relevant to use the dilation to generate an urban envelope
- Research that links up the physical aspects of a settlement and its envelope

  borders of an existing pattern

  virtual line emerging through the dilations
- Higher power of analysis and description of urban forms
- The multi-scale analysis of the urban forms has required heavy methodological explorations and theoretical reflections
- Research which should go ahead...