Analysis of spatial dimensions and explicit multifractal modelling for the deployment of green areas in an urban agglomeration

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Context

The necessity to increase urban resilience has favour and promote the installation of Nature-based Solutions (NBS) urban spaces to tackle impacts of urbanization and climate change effects.

"Solutions that are inspired and supported by nature…. help build resilience."
European Commission

Question?

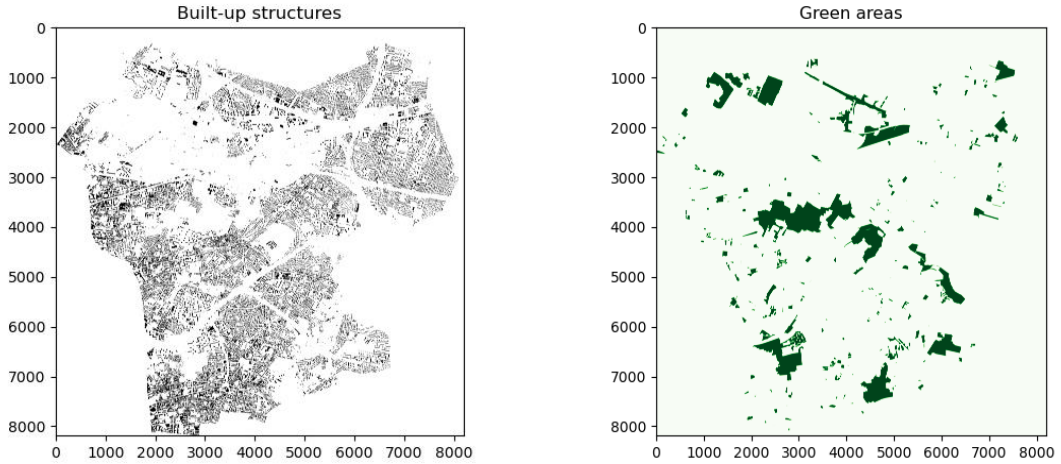
What is the most efficient way to distribute NBS across the territory taking into consideration the urban dynamics and the urban scales?

Clue: Fractal geometry!!

Properties fractal geometry in urban geography

Fractal geometry can be a useful approach to describe morphology complexity of urban patterns.

Self-Similarity	• Similar forms at different scales of observation. • Characterized by a scale-invariance.
Fractal Dimension	• Characterize the self-similarity of an object (e.g. urban pattern).
Lacunarity	• Fractal dimension counterpart • Gaps and heterogeneity of fractal object.



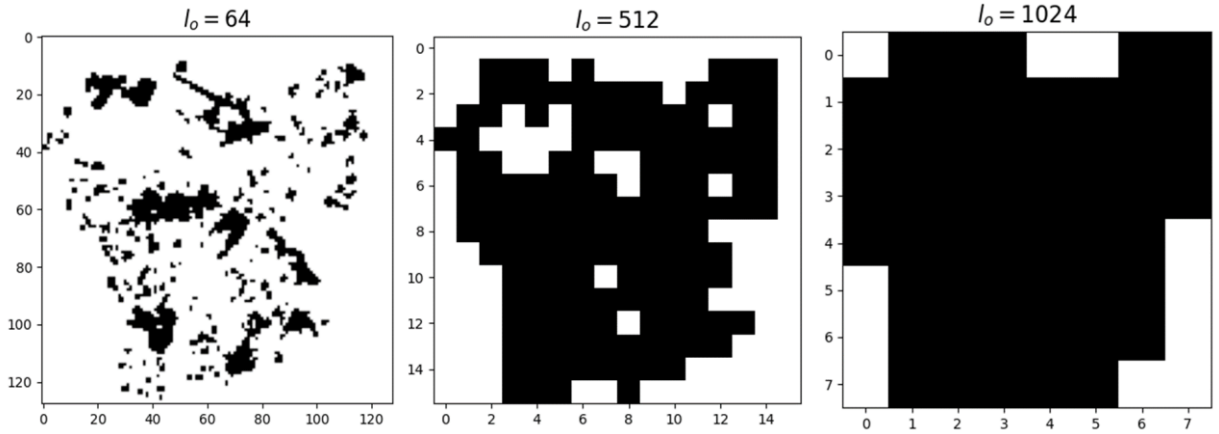
Built-up and green areas map of Est-Ensemble, France.

By means of the urban fractal properties, is it possible to characterize the scales and location of NBS deployment?

Analysis of built-up and green areas fractal properties of Est-Ensemble, an urban agglomeration at the east of Paris.

Fractal Dimension by Box-Counting Technique

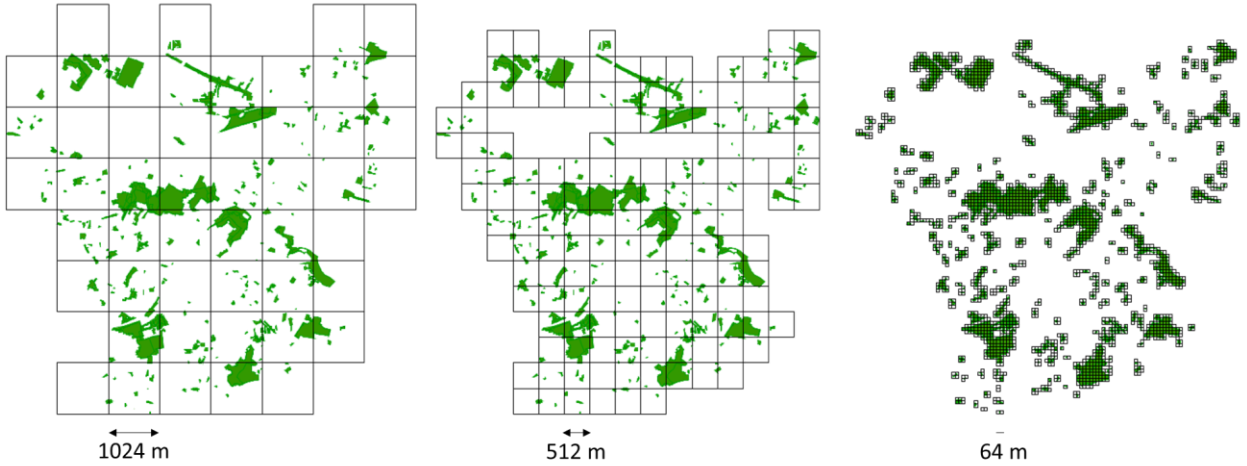
- **Pixel Approach: Increase pixel size**



$$N_\lambda = \lambda^D \qquad \lambda = \frac{L}{l_o}$$

N_λ = Number of non-overlapping pixels of size l_o
λ = Spatial resolution
l_o = Scale of observation
L = Outer scale of the object

- **Grid analysis (Fractalyse*): Grid is covering the object.**



$$N_\varepsilon = \varepsilon^{-D}$$

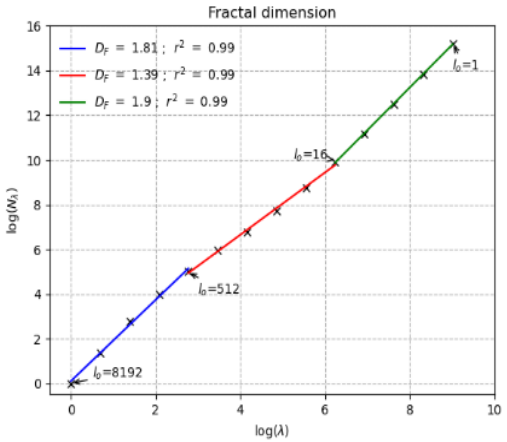
N_ε= Number of boxes that include part of the image.
ε = Length box size

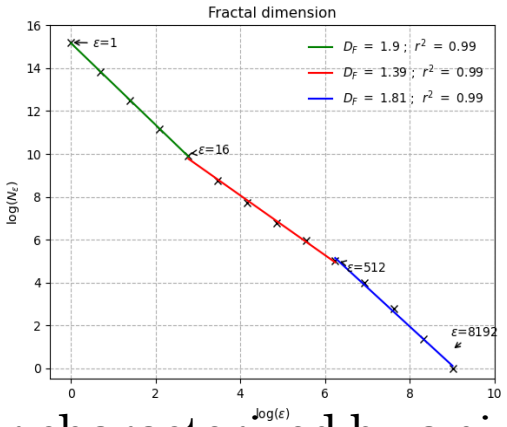
Fractal Dimension by Box-Counting Technique

- **Pixel Approach: Increase pixel size**
  - Increase pixel size only by a integer and no values are rounded.
  - Size of the 2D image to exploit should be a power of 2.

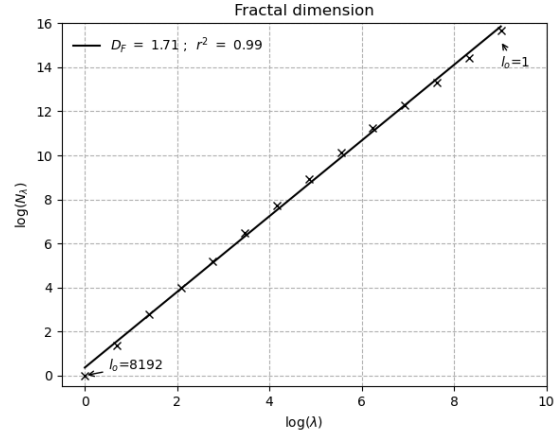
- **Grid analysis: Grid is covering the object.**
  - Base of the box could raise by a non integer factor.
  - Impact of grid size and grid layout.

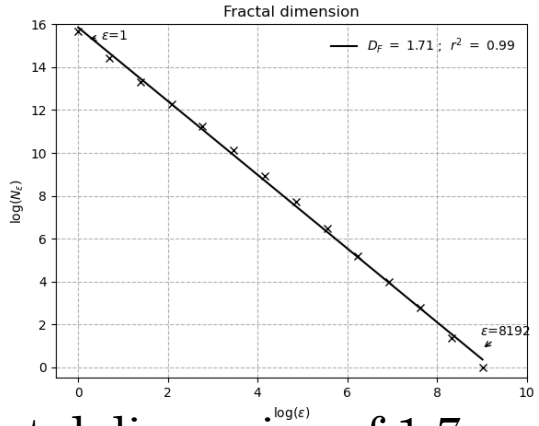
Green spaces





Built-up





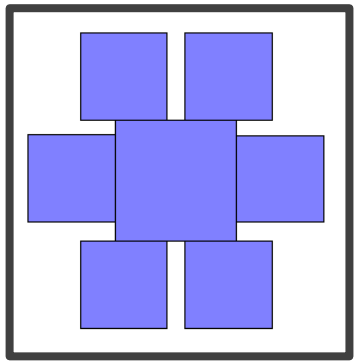
- Built-up structures follow a scaling behaviour characterized by a single fractal dimension of 1.7 from 1m to 8192m.
- Green spaces follow a hierarchical distribution characterized by three scaling ranges: 1 -16m (D=1.9), 16 - 512m (D=1.4) and 512 - 8192m (D=1.8).

Self-Similarity scenario of urban development (Fractalopolis*)

Based on fractal dimension results, an iterative downscaling multifractal scenario of urban development at the urban-space (Est-Ensemble) was developed, inspired on the polycentric approach at region-scale (Metropole du Grand Paris).

The lacunas of this scenario represent the non-suitable areas for development where green areas can be installed.

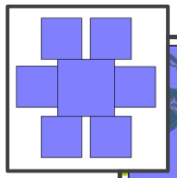
Aim: Identify the potential "lacunas" where NBS can be installed by inserting an IFS over the built-up areas.



IFS

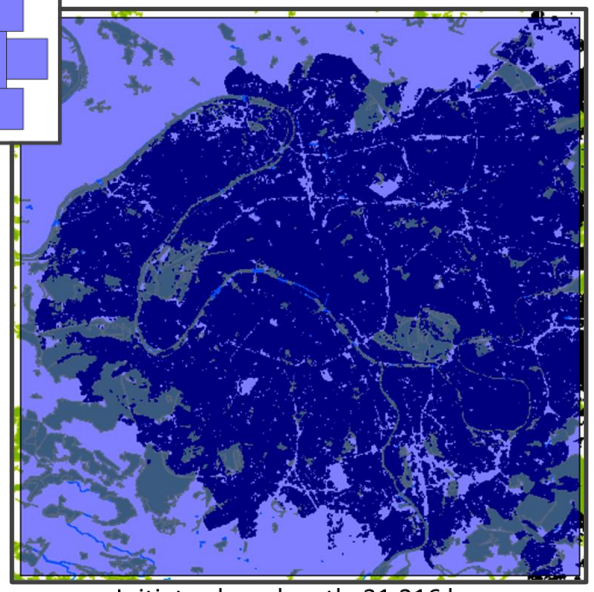
Reduction factors	**Squares number**	**Fractal Dimension**
$r_1 = 0.35, r_2 = 0.25$	1 main centre 6 subcentres	**1.46**

Regional Scale: Polycentric approach

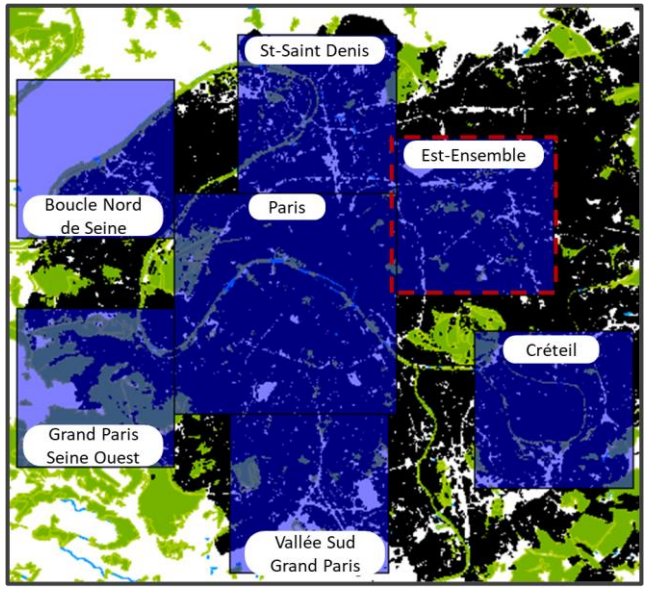


Main centre is placed in Paris and two sub centres in each of surrounded departments:

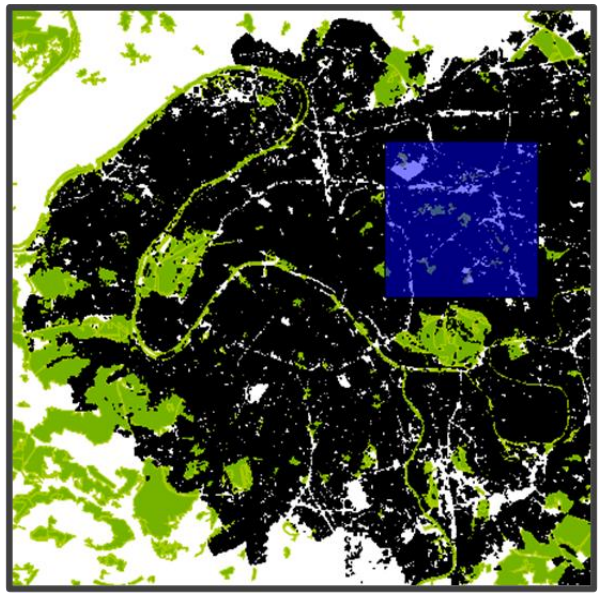
- Hauts de Seine
- Seine-St-Denis
- Val de Marne



Initiator, base length: 31.216 km



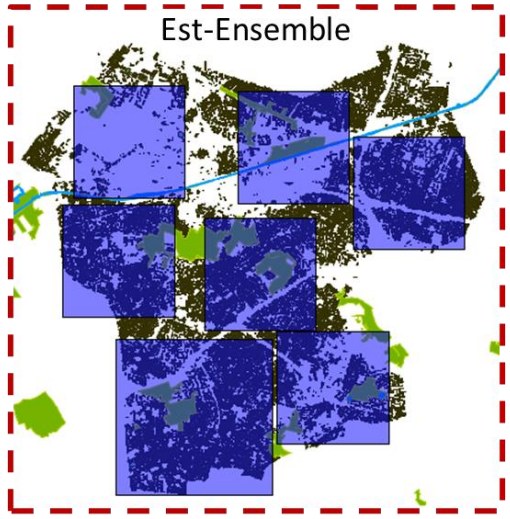
Iteration step 1



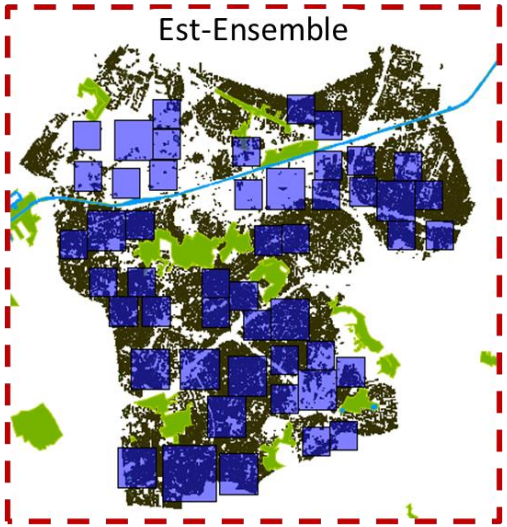
Base length: 7804 km

Urban Scale: Polycentric approach

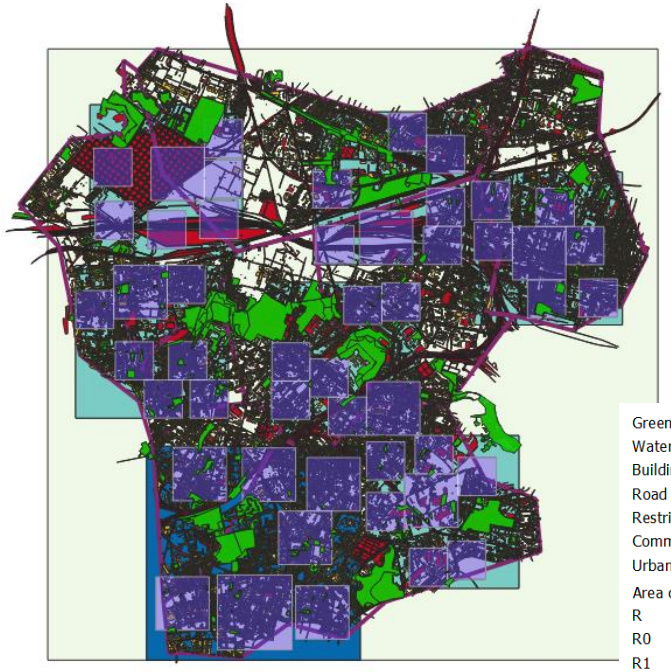
New urban planned centres are located out of essential green spaces of the territory.



Iteration step 2

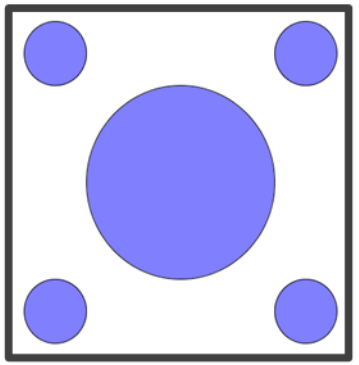


Iteration step 3



Self-similarity scenario of green spaces deployment

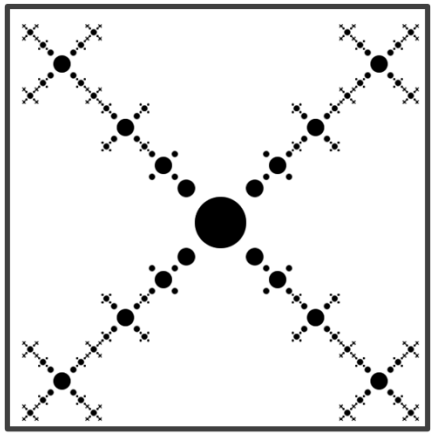
A fractal object (IFS) with self-similarity properties and characteristic scales ranges of urban green spaces is deployed over the lacunas of the multifractal urban development.



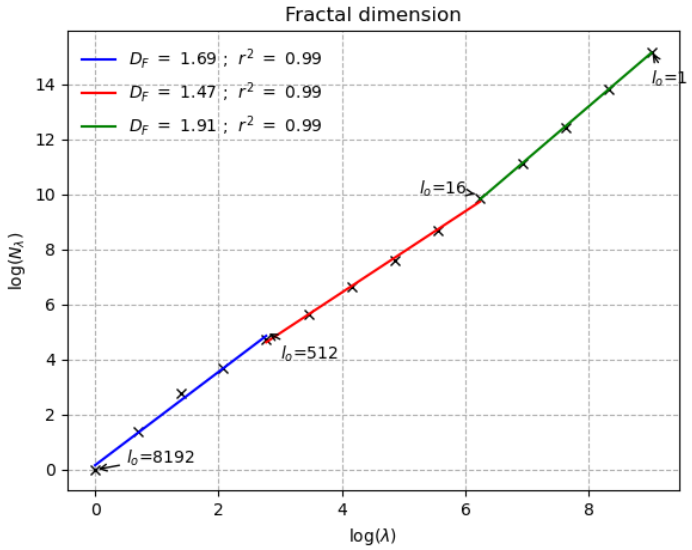
IFS

IFS inspired on a Sierpinski carpet without continuity.

Reduction factor	Circles number	Fractal Dimension
$r_1 = 0{,}6\ (3/5)$ $r_2 = 0{,}2\ (1/5)$	1 main circle 4 small circle	$D_f = 1.307$

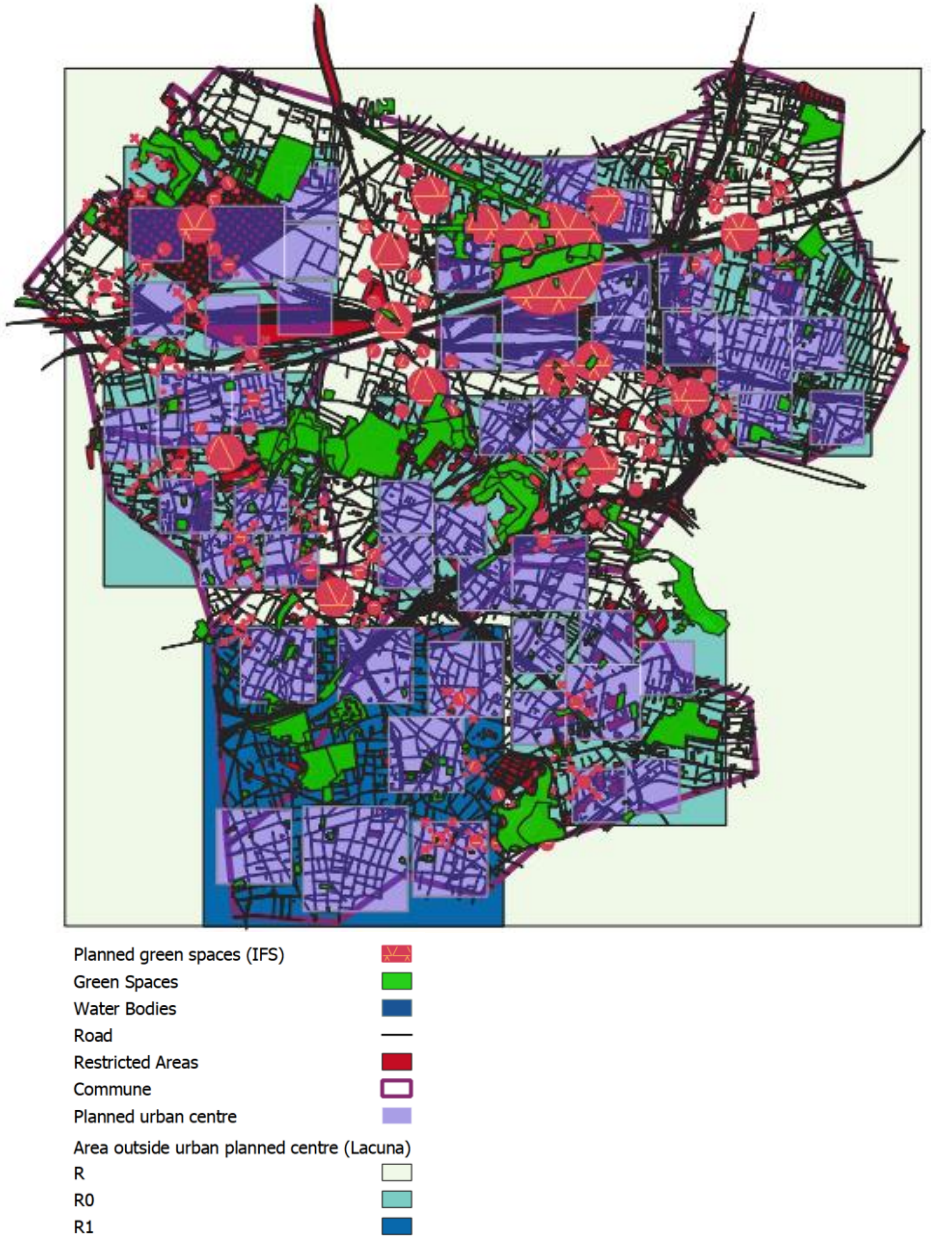


IFS after iteration step 4



D_f of IFS at iteration step 4, over a plane of 8192px x 8192px.

- Fractal dimension of new green spaces after iteration step 4 over a scale of 8192mx8192m.
- Results of IFS fractal dimension, indicated two break-ups and three scaling regimes, similar to green spaces distribution.



IFS Scenario for iteration step 4.

Level*	Number	Size (m)**
1	1	892,45
2	4	297,48
3	20	99,16
4	100	33,05
5	500	11,02

* Hierarchical level of each planned green space.
** Diameter of each planned green space.

Total number of new planned green spaces: 625

- This scenario favours the deployment of bigger green spaces over the lacuna R (from iteration 1 of urban centres).
- Smallest green spaces are locater over the communities with few availability of vegetation and highest population density.
- Location of green spaces over lacunas of urban development is not completely respected.
- Overlapping of planned urban centres and planned green spaces can lead to the NBS location proposal over private built-up areas, where potentially green roofs, privative rain garden can be installed.

First conclusions & Perspectives

- Fractal properties of urban green space morphology provides characteristics for urban green spaces deployment over the territory.
- Lacunas of urban development scenario determine location for green spaces implementation.
- Fractal dimension of green spaces characterizes scales of deployment.
- Characteristic scales found by fractal dimension, will be used for further distance evaluation to planned green spaces.
- Multifractal analysis of evapotranspiration data measured at the local scale, will confirm the scaling behavior and temperature reduction in the new scenario of green spaces implementation.
- The authors acknowledge the financial support from ANR EVNATURB project and the Chair Hydrology for Resilient Cities (endowed by Veolia) of the École des Ponts ParisTech.

References:

- * Fractalyse (software of spatial analysis): https://sourcesup.renater.fr/www/fractalyse/
- * Fractalopolis (software of spatial simulation): https://sourcesup.renater.fr/www/fractalopolis/