Multifractal approach to urban green spaces distribution in Est-Paris agglomeration (France) and potential benefits.

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Abstract

The growth of the world's population living in urban areas has led to change from natural to highly dense and impermeable landscapes. Moreover, the intensity and frequency increase of extreme events resulting from climate change (e.g. inundations, heat waves) produce a degradation of urban systems resilience capacity. The integration of nature-based solutions NbS in urban spaces has been widely accepted, like a sustainable strategy that allows to tackle these urban challenges while building resilience and improving well-being and health. NbS are inspired by the nature, favouring natural processes in the cities like water infiltration or evapotranspiration (ET). Thanks to the latest, the vegetation shadow and wind dynamics favours air temperature reduction during heatwave events or mitigation of Urban Heat Island (UHI) phenomenon. Consequently, the distribution of urban green spaces might impact heat fluxes dynamics, by reducing temperature and its perception. They may also reduce virus spreads and also the sensitivity factors to them. Following a spatial approach, this study aims to analyse the green space distribution across different scales in the agglomeration located in the east of Paris (France) and various scenarios of its development. To achieve this goal, the spatial simulation model "Fractalopolis" is used. This allows to generate fractal urban forms using an iterative downscaling scheme (IFS: Iterative Function System) applied to existing large scale patterns of green areas. This work enables to analyse i) the access of population to the nearest green area and the fractal dimension of public urban green spaces; and ii) the impact of temperature reduction of different land-use scenarios by coupling a multifractal analysis of ET scaling behaviour measured at the local scale.

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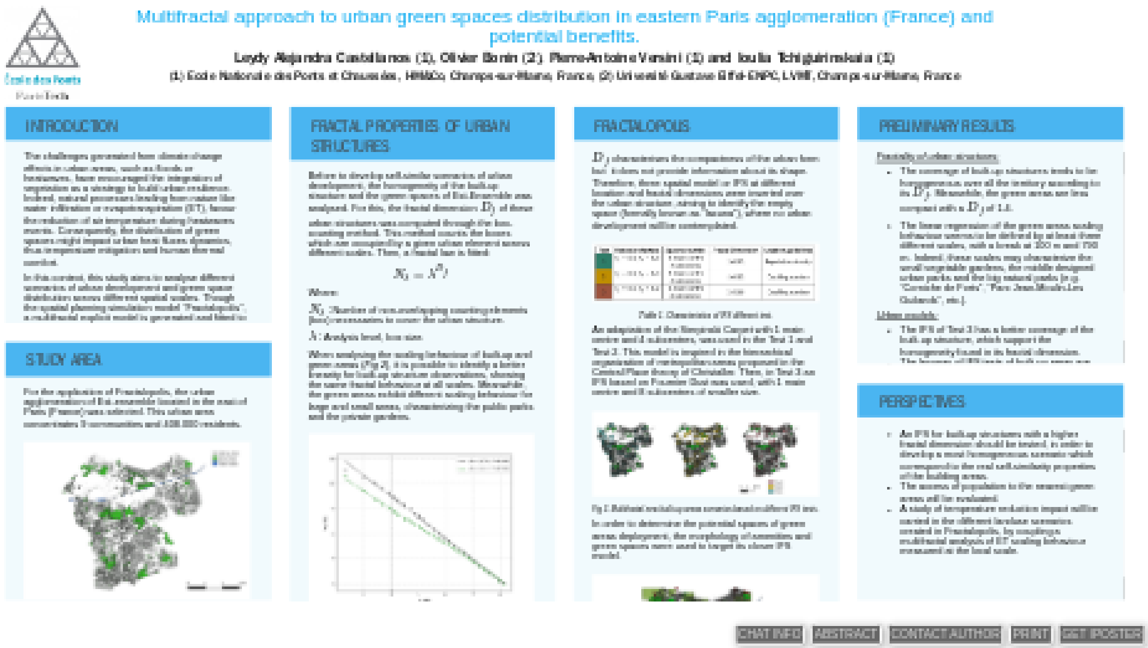

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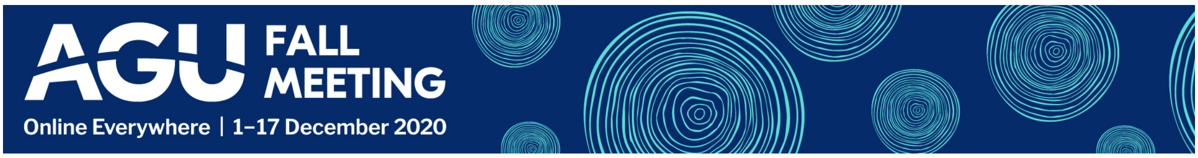

INTRODUCTION

The challenges generated from climate change effects in urban areas, such as floods or heatwaves, have encouraged the integration of vegetation as a strategy to build urban resilience. Indeed, natural processes leading from nature like water infiltration or evapotranspiration (ET), favour the reduction of air temperature during heatwaves events. Consequently, the distribution of green spaces might impact urban heat fluxes dynamics, thus temperature mitigation and human thermal comfort.

In this context, this study aims to analyse different scenarios of urban development and green space distribution across different spatial scales. Though the spatial planning simulation model “Fractalopolis”, a multifractal explicit model is generated and fitted to the territory, parametrised by an IFS (iterated function system). This approach allows the design of new building-up and green areas, based on a geometrical fractal logic developed over existing patterns of urban forms.

This work is done into the framework of the French ANR project called EVNATURB (https://hmco.enpc.fr/portfolio-archive/evnaturb/). EVNATURB aims to develop a platform to assess the eco-system services provided by vegetation at the district scale, and to promote the re-naturation of cities.

STUDY AREA

For the application of Fractalopolis, the urban agglomeration of Est-ensemble located in the east of Paris (France) was selected. This urban area concentrates 9 communities and 408.000 residents.

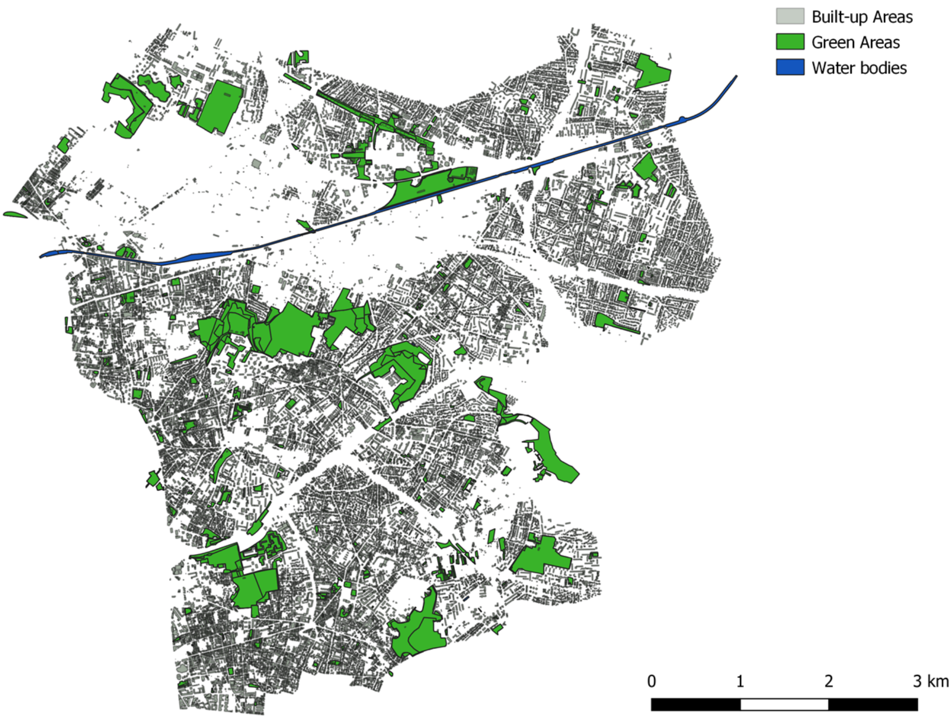

Fig 1. Est Ensemble, study area.

FRACTAL PROPERTIES OF URBAN STRUCTURES

Before to develop self-similar scenarios of urban development, the homogeneity of the built-up structure and the green spaces of Est-Ensemble was analysed. For this, the fractal dimension D_f of these urban structures was computed through the box-counting method. This method counts the boxes which are occupied by a given urban element across different scales. Then, a fractal law is fitted:

$$N_\lambda = \lambda^{D_f}$$

Where:

N_λ :Number of non-overlapping counting elements (box) necessaries to cover the urban structure.

λ :Analysis level, box size.

When analysing the scaling behaviour of built-up and green areas (*Fig 2*), it is possible to identify a better linearity for built-up structure observations, showing the same fractal behaviour at all scales. Meanwhile, the green areas exhibit different scaling behaviour for large and small areas, characterizing the public parks and the private gardens.

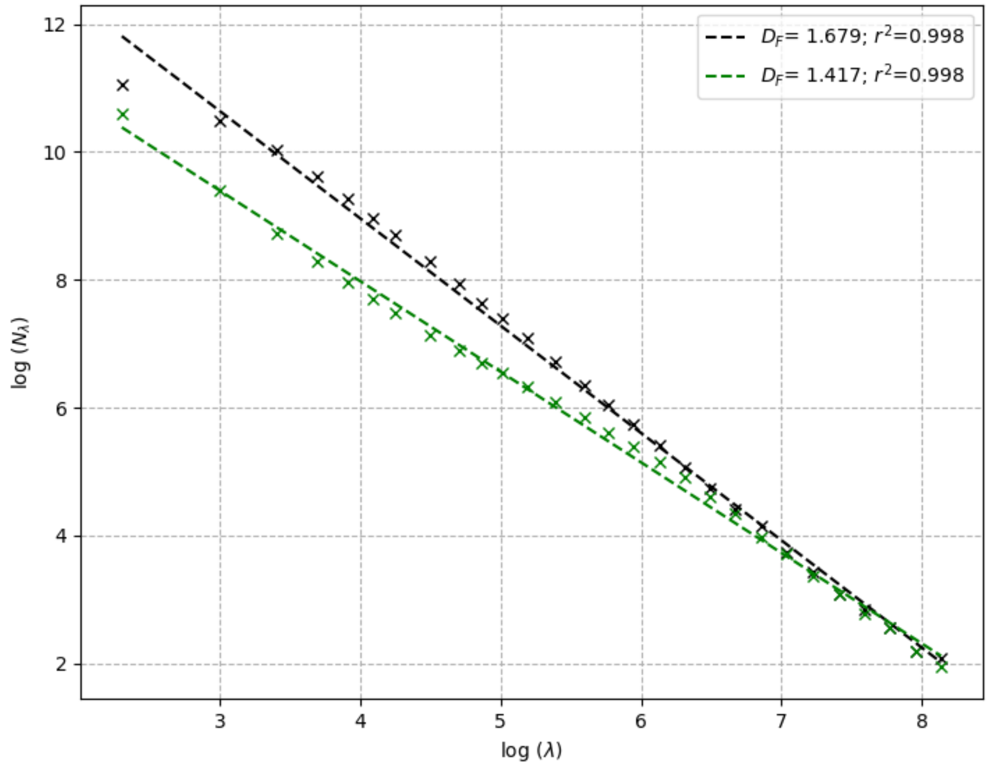

Fig 2: Fractal dimension of built-up (black) and green spaces (green) in Est-Ensemble.

Concerning the fractal dimension, we can confirm the higher homogeneity of built-up areas in the whole territory with an estimation of 1.6, compared to green spaces (1.4).

FRACTALOPOLIS

D_f characterises the compactness of the urban form but it does not provide information about its shape. Therefore, three spatial model or IFS at different location and fractal dimensions were inserted over the urban structure, aiming to identify the empty space (formally known as "lacuna"), where no urban development will be contemplated.

Test	Reduction factors	Squares number	Fractal Dimension	Location guidelines
1	$r_1 = 0.4, r_2 = 0.3$	1 main centre 4 subcentres	1.4163	Population density
2	$r_1 = 0.4, r_2 = 0.3$	1 main centre 4 subcentres	1.4163	Dwelling number
3	$r_1 = 0.3, r_2 = 0.2$	1 main centre 8 subcentres	1.4166	Dwelling number

Table 1. Characteristics of IFS different test.

An adaptation of the Sierpinski Carpet with 1 main centre and 4 subcentres, was used in the Test 1 and Test 2. This model is inspired in the hierarchical organization of metropolitan areas proposed in the Central Place theory of Christaller. Then, in Test 3 an IFS based on Fournier Dust was used, with 1 main centre and 8 subcentres of smaller size.

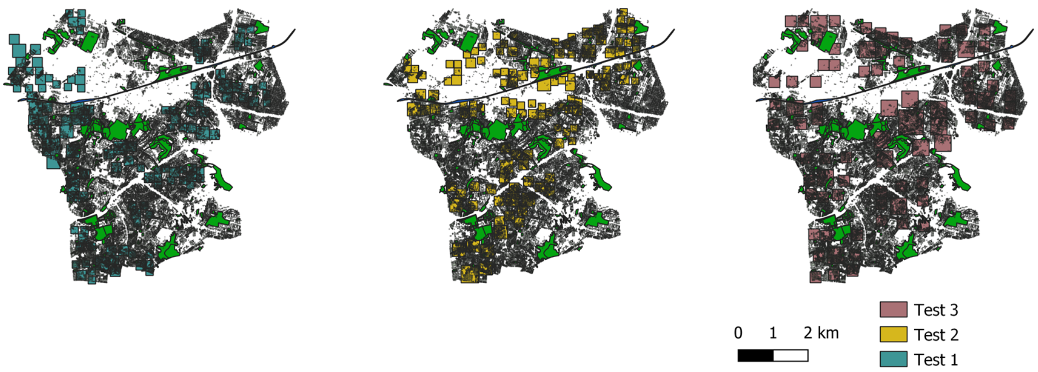

Fig 3. Multifractal new built-up areas scenarios based on different IFS tests.

In order to determine the potential spaces of green areas deployment, the morphology of amenities and green spaces were used to target its closer IFS model.

Fig 4. Multifractal green areas configuration.

PRELIMINARY RESULTS

Fractality of urban structures:

- The coverage of built-up structures tends to be homogeneous over all the territory according to its D_f. Meanwhile, the green areas are less compact with a D_f of 1.4.
- The linear regression of the green areas scaling behaviour seems to be defined by at least three different scales, with a break at 100 m and 790 m. Indeed, these scales may characterize the small vegetable gardens, the middle designed urban parks and the big natural parks (e.g. “Corniche de Forts”, “Parc Jean-Moulin-Les Guilands”, etc.).

Urban models:

- The IFS of Test 3 has a better coverage of the built-up structure, which support the homogeneity found in its fractal dimension.
- The lacunas of IFS tests of built-up areas are mainly overlapping the transportation infrastructure and green amenities.
- The IFS of green areas has a higher fractal dimension compared to the real green structure. However, it promotes the installation of green spaces in the north of the territory, where future urban development is foreseen by the local urban planning.

PERSPECTIVES

- An IFS for built-up structures with a higher fractal dimension should be tested, in order to develop a most homogeneous scenario which correspond to the real self-similarity properties of the building areas.
- The access of population to the nearest green areas will be evaluated.
- A study of temperature reduction impact will be carried in the different landuse scenarios created in Fractalopolis, by coupling a multifractal analysis of ET scaling behaviour measured at the local scale.

ABSTRACT

The growth of the world's population living in urban areas has led to change from natural to highly dense and impermeable landscapes. Moreover, the intensity and frequency increase of extreme events resulting from climate change (e.g. inundations, heat waves) produce a degradation of urban systems resilience capacity. The integration of nature-based solutions NbS in urban spaces has been widely accepted, like a sustainable strategy that allows to tackle these urban challenges while building resilience and improving well-being and health.

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