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Deliverable 4.2: Multiscale spatial scenarios of NBS deployment

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Résumé de la démarche

La nécessité d'accroître la résilience des zones urbaines face aux problèmes induits par l'urbanisation et les effets du changement climatique (inondations, îlots de chaleur urbains, pandémies, etc.), a conduit à proposer plusieurs stratégies telles que les solutions fondées sur la nature (SFN). Celles-ci ont pour objectif de restaurer des processus naturels tels que l'infiltration et l'évapotranspiration (ET) dans les zones urbaines. En conséquence, l'intérêt croissant pour la mise en œuvre des SFN (fortement soutenu par le programme H2020 de la Commission Européenne) par les urbanistes, les décideurs, les chercheurs et la population résidente a conduit à s’interroger sur les moyens les plus efficaces pour déployer des SFN. Dans ce contexte, les dynamiques urbaines (par exemple la densité de population, les modes d'occupation des sols, le réseau de transport, etc.) et la répartition des espaces verts à différentes échelles spatiales jouent un rôle clé qui caractérise le développement urbain sur un territoire donné.

Basée sur l'étude de l’agglomération urbaine Est-Ensemble, située à l'est de Paris (France), ces travaux de recherche visent à : i) déterminer la dimension fractale des espaces bâtis et des espacesverts ; ii) définir les zones potentielles d'implantation des SFN, par l'élaboration d'un schéma itératif de descente d'échelle sur le bâti à l’aide du logiciel Fractalopolis, et suivant une approche polycentrique inspirée de la forme urbaine de la Région Ile-de-France, et iii) évaluer d’une part l’accès de la population aux espaces verts les plus proches et d’autre part au déficit d'espaces verts.

Summary

The need to increase the resilience of urban areas regarding the issues induced by urbanization and climate change effects (e.g. floods, Urban Heat Island, pandemics, etc.), has led to propose several strategies as Natural-Based Solutions (NBS), which are focus on restoring natural processes such as infiltration and evapotranspiration (ET) in urban areas. In consequence, the increasing interest on NBS implementation (highly supported by the H2020 program of the European Commission) by urban planners, decision-makers, researchers and the residing population has conducted to question the most efficient ways of NBS deployment. In this context, the urban dynamics (e.g. population density, land use patterns, transport network, etc.) and the distribution of green areas at different spatial scales play a key role that characterize the urban development in the territory.

Based on the study of an urban agglomeration named Est-Ensemble, located at the east of Paris (France), this research aims to: i) determinate the fractal dimension of the built-up and green areas; ii) set the potential areas to install NBS, through the development of an iterative downscaling scheme over the built-up structure with the software Fractalopolis, and following a polycentric approach inspired on the urban form of Ile de France Region, and iii) assess the population access to the nearest green spaces and deficit of green spaces.

1. Introduction

A special interest in the implementation of NBS may be foreseen to mitigate the UHI's intensity and more generally to improve urban system's resilience. Nevertheless, the complexity of social and economic dynamics occurring at different urban scales makes it difficult to find a spatial organisation that harmonises the urbanisation and installation of NBS. The competition of NBS with other usages of urban space, as well as the question of implementing new NBS or densifying the existing ones on a territory requires to conciliate different constraints. For example, the densification of NBS can be either small, disconnected patches, such as individual gardens or green roofs, or green strips, or large parks; a multitude of scales should be considered.

Through this deliverable, the development of a spatial modelling that optimise the location of NBS across several urban scales is investigated. For this purpose, multiscale approaches will be introduced, more specifically the fractal geometry and its properties for the analysis of complex forms observed at different scales. Then, the utility of those concepts in the analysis of urban morphologies and the development of spatial modelling is explored by means of a case study. Hence, the fractal geometry will be used operationally as a multiscale logic of generation of urban structures, in the spatial software Fractalopolis.

2. Spatial optimization principle to implement NBS

Several approaches have explored the most appropriate way to deploy NBS, and specifically several kinds of NBS on an existing territory. Some of them, based on urban planning, use quantitative indicators of population distribution and its proximity to NBS, such as "public green area per capita" or "distance/time to green areas" (Neuvonen et al., 2007; World Health Organization, 2016). Other approaches tend to maximise a particular ecosystem service from the NBS. For the reduction of temperature, the study results of Bao et al. (2016) and Zhang et al. (2017) demonstrated the installation of a single NBS on a large scale, such as the urban parks, offers a lower land surface temperature mitigation, compared to a disperse location of smaller NBS. By contrast, Masoudi & Tan (2019) stressed land surface temperature is lower with less fragmented and more aggregated large patches of NBS, because the proximity of NBS creates ventilator corridors of cool air. In this context, both approaches are not necessarily different, but can be envisioned as complementary rather than in competition.

The spatial organisation of urban structures, as well as the social and environmental contexts of the NBS's installation can vary from one site to another, which might affect the performance of NBS to tackle urban challenges. According to Cohen-Shacham et al. (2019), such context should be integrated in the analysis to determining the deployment of NBS. But this also includes the different spatial scales of analysis, from metropolis up to individual buildings. Nevertheless, the latest represents a major challenge for urban planners since most scientific evidence is framed at local scales where the NBS benefit is perceived. Correspondingly, scientific community and urban planners have been interested in investigating how NBS can be integrated into the built-up space to maximise their benefits at different urban scales, without disrupting the existing spatial organisation, the social and economic dynamics of the cities. This question may look like an optimisation problem that could be addressed through a scale invariance indicator.

The fractal geometry has demonstrated to be a helpful tool to characterize and simulate the complexity and hierarchy of cities. According to Tannier & Pumain (2005), fractal geometry is useful for describing non regular spatial patterns, characterised by alternate patterns of continuity and fragmentation, or some degrees of concentration, and include similar structures at different scales of analysis. Hence, resorting to fractal geometry appear as a convenient approach to develop multiscale urban planning scenarios of NBS deployment. Let's introduce just below the fractal geometry and its properties to better understand their use in analysis and modelling of urban patterns.

2.1 The fractal geometry

In 1982, the American-French-Polish mathematician Benoit Mandelbrot introduced the notion of Fractal, inspired by the Latin word "fractus" and the irregular and fragmented objects that do not fit with the classical Euclidean geometry. Formally Mandelbrot defined a fractal as "a set for which the Hausdorff-Besicovitch dimension is greater than its topological dimension" B. Mandelbrot (1982).

The fractal object is characterized by an invariance of scale when zoom-in and zoom-out, which makes this looks similar at different scales of observation. This property is known as self-similarity and it was pointed out as the core feature of fractals in the paper "How long is the coast of Britain?" of B. Mandelbrot (1967). Indeed, in this paper Mandelbrot examined through lines of different sizes the length of the coastline of Great Britain, arguing geographical curves can be considered as superpositions of features of widely scattered characteristic size. In this way, it was demonstrated that depending on the scale of the line used, the total length of the coast will vary. Because, as finer features are taken into account, the measure total length increases.

Despite the notion of fractal being introduced during the second half of the 20th century, numerous objects with self-similarity properties were early invented, such as the Cantor set which appeared in 1883, the Koch curve in 1904 or the Sierpinski carpet in 1916 (see Figure 1).

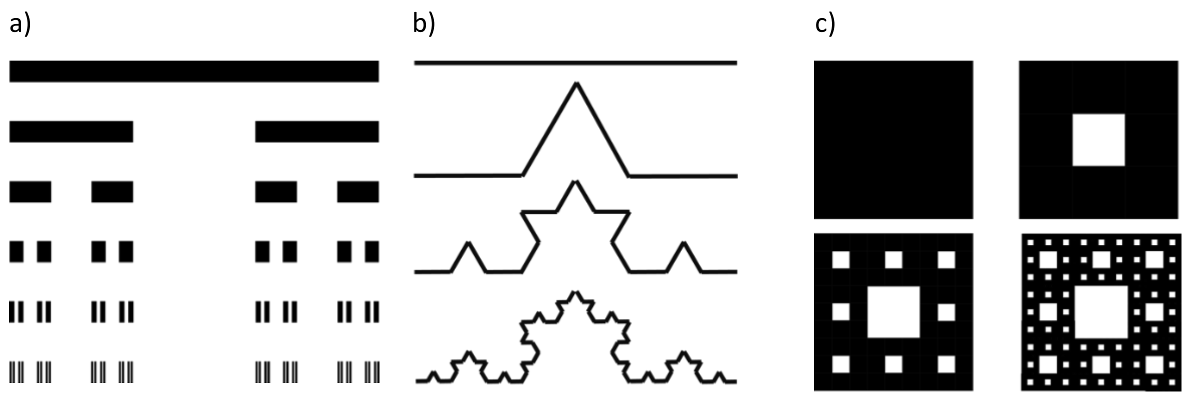


Figure 1. Fractal objects a) the Cantor set, b) the Koch curve and c) the Sierpinski carpet.

These geometrical objects are built iteratively. In the Cantor set case, at each iteration the open middle third of a set of line segments is deleted, leaving two segments. Then, the length of the Cantor set decreases, as the length of the segment is reduced with the number of iterations. The Koch curve is created from a straight line divided into three equal segments. At each iteration the middle third of each interval is replaced by the two sides of an equilateral triangle of the same length as the segment being removed. The shape of the figure is very irregular, and its length increases with the number of iterations, since four copies of the line segment reduced to 1/3 of the original length are created at each iteration. Regarding the Sierpinski carpet, initially a square is necessary, which is divided into nine equal squares (based on a 3x3 grid) and the central square is removed. For the remaining eight subsquares, the process division is repeated iteratively. As a part of the square is removed at each iteration, its area tends to zero as the number of iterations tends to infinity.

2.2 The fractal dimension

The topological dimension in the fractal framework refers to the classical geometry used to describe regular spaces. This geometry recognizes major categories of integer dimensions: 0D is a point, 1D is a straight line or curve, 2D is a planar figure and 3D is a volume.

If we have an object embedded in a Euclidean dimension, N smaller models (copies of itself) will be necessary to constitute the whole object, with a scale factor λ used to create the model. In this way the dimension of an object (D), can be defined as follows:

$$N = \lambda^D \qquad (1)$$

The scale ratio (λ) is defined as the relationship between the outer scale (L) and the observation scale (l_o):

$$\lambda = \frac{L}{l_o} \qquad (2)$$

For classical geometry objects (see Figure 2):

- A straight line (1D) needs N lines of l_o length, to describe the initial line.
- A planar figure (2D) like as a square, requires N copies of l_o length size to reproduce the original object.
- A solid (3D) demands N copies of l_o length size to cover the original volume.

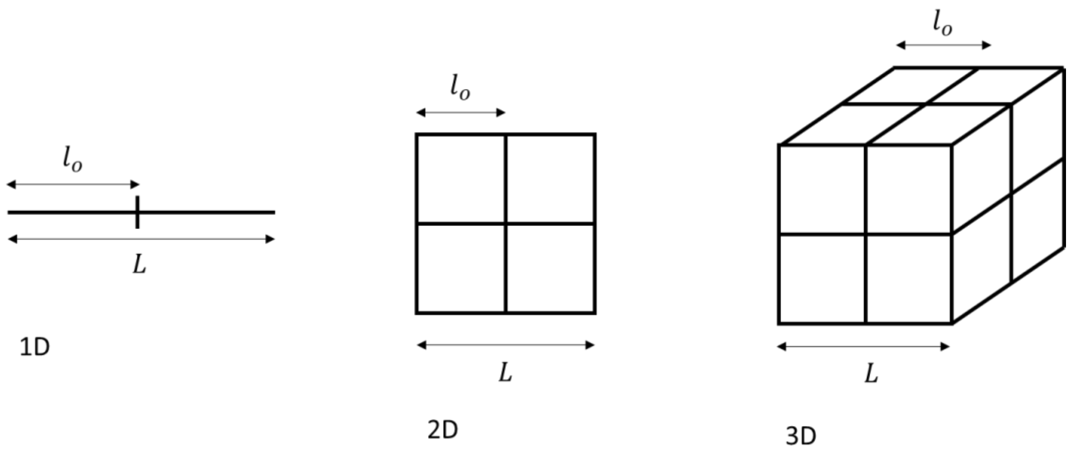


Figure 2. Fractal dimension of classical Euclidean objects.

Since the irregularity of fractal objects makes not possible to describe them with the topological dimension, the concept of fractal dimension (D_f) emerged. Then, D_f characterises the surface roughness of an object, which could be not-integer.

Let us consider an exactly self-similar fractal object as the Sierpinski triangle, which is based on an equilateral triangle of size $L = 1$ (see Figure 3). The mid points of each side of the triangle are used as vertices of an equilateral smaller triangle ($l_o = 1/2$), which is removed from the original and resulting three exact smaller copies of the original ($N = 3$). This iterative process yields to find $D = \frac{log(3)}{log(2)} \approx 1.58$ at all the scales of analysis. Then, D_f characterises the scaling property of the object over different scales.

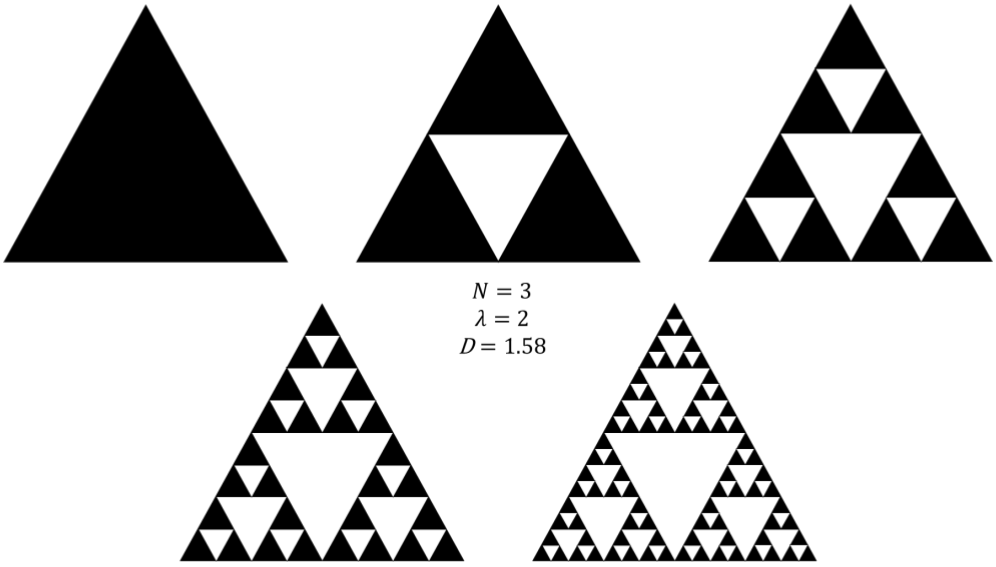


Figure 3. Sierpinski triangle at different iterations with a scale ratio $\lambda = 2$.

The D_f of not exact or statistically self-similar structures, such as a natural coastline, is rather complex to handle analytically as it was demonstrated by Mandelbrot. The Minkowski-Bouligand dimension or box-counting dimension was developed as a practical estimation of Hausdorff dimension (Mandelbrot, 1982; Schertzer & Lovejoy, 1991). The principle of this technique is to completely cover a fractal set with boxes (instead of balls) of a fixed size ε, creating a regular grid and counting the number of elements necessary to cover the set $N(\varepsilon)$. The size of the boxes is changed, and the fractal dimension (D_f) is given by the relationship:

$$D_f = \lim_{\varepsilon \to 0} \frac{\log N(\varepsilon)}{\log\left(\frac{1}{\varepsilon}\right)} \quad (3)$$

Through the linear regression between ε and $N(\varepsilon)$ at the logarithmic scale, the parameter D_f can be estimated. If D_f is close or equal to 2, the set is homogeneously distributed over the plan. In the case where the set is better represented by a line (or curve), the values of D_f will be close to 1. Finally, D_f will be close to 0 if the fractal set is punctually located or isolated.

In practice, there are different approaches to implement the box counting method. One of them is based on the grid-counting method, which is implemented in Fractalyse version 3 (http://www.fractalyse.org/), an open-source software, developed in the Franche-Comté University (Théma research laboratory), which analyses the fractal dimension of 2D images. Fractalyse follows a simple iteration principle that modifies artificially the level of the image analysis.

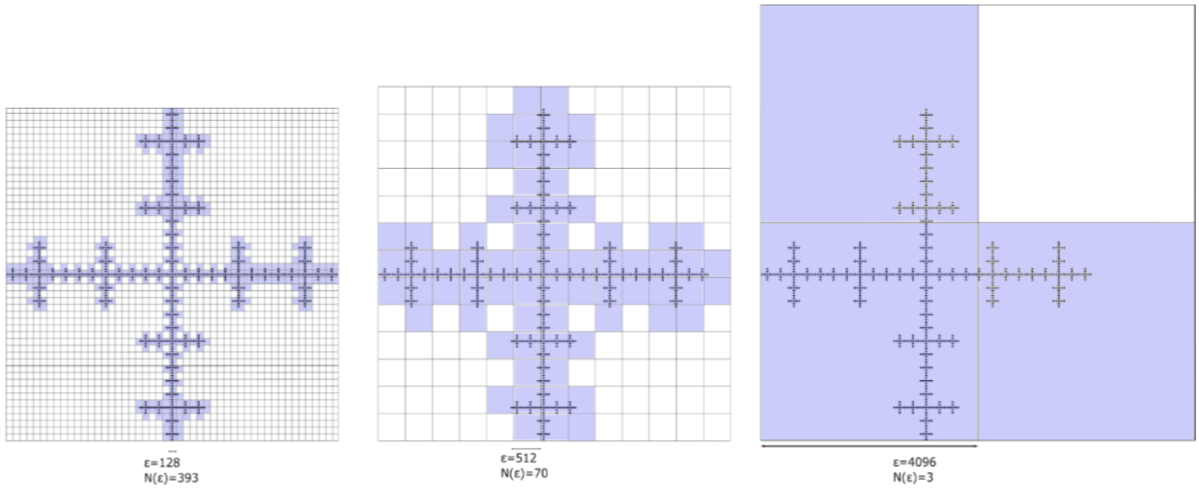


Figure 4. Box-counting technique by the grid approach.

At each iteration, a quadratic grid with boxes of size ε covers the image and the number of boxes that include part of the image is counted $N(\varepsilon)$, as shown in Figure 4. The process is repeated by increasing the size of the boxes, by an increment or coefficient (i) until a maximum size (power of i) set by the user. Usually, the minimum or the smallest grid size is 1, having:

$$\varepsilon = min \times i^p \rightarrow \varepsilon = 1 \times i^p \qquad (4)$$

where, p corresponds to the iteration step.

The empirical series of points ε and $N(\varepsilon)$, are used to fit a theoretical curve that corresponds to the fractal law, and that defines the dimension as:

$$N(\varepsilon) = \varepsilon^{-D_f} \qquad (5)$$

By means of a logarithmic approximation of this relationship, the D_f can be deduced as the slope value of the regression line. One issue of this approach is the way the grid is set over the object and the size of the box (Bouda et al., 2016; Frankhauser, 1997), which could lead to "ambiguities" or errors in the counting of boxes, affecting the real value of D_f. To deal with this issue, in Fractalyse the coefficient (i) can be tuned, adjusting the grid to cover the whole image with the lowest number of $N(\varepsilon)$.

A complement of the D_f is the lacunarity. In fact, the gaps or boxes not counted through the iteration process, also reveals information about the fractal set. The notion of lacunarity was introduced by Mandelbrot, from the Latin word Lacuna, which means lack or hole. Mandelbrot stated "Lacunarity concerns the tendency to have holes". In that sense, the lacunarity of a fractal set characterises the distribution of its gaps. Thus, two fractal sets with the same D_f could fill the space in different ways and look different.

2.3 Fractality of urban structures

The fractal geometry has been accepted as a suitable approach for describing complex forms, such as the urban spatial patterns (Jevric & Romanovich, 2016; Tannier & Pumain, 2005); as fractal objects and urban systems have similar properties, such as irregularities and fragmentation (Tannier & Pumain, 2005). Several works have recognised a hierarchical distribution of urban objects, such as the built-up structure, that fits the self-similarity feature of fractals, which generates regular spatial hierarchies at different scales (Frankhauser, 1998; Li et al., 2015; Tannier, 2009; Tannier & Pumain, 2005).

Indeed, some territorial economic approaches have found hierarchical spatial and self-similar distributions. This is the case of the centrality principle proposed by Christaller in 1933 (Chen, 2011), for which there is a nested organisation of centres of different size (Figure 5) uniformly distributed in space (Euclidean dimension of 2). Christaller's model is based on the use of certain types of services and commercial offers, according to the order of the central place (Tannier, 2009). Hence, big cities with a large catchment area offer a wide range of services, and the village hosts the few services that only ensure supply in daily needs (Frankhauser, 2012).

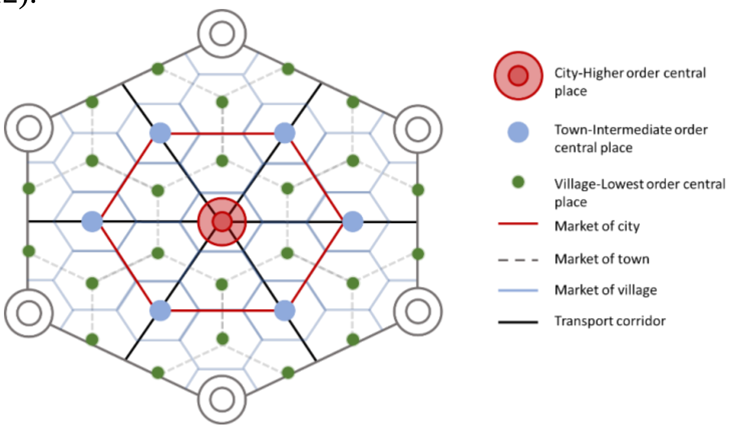


Figure 5. Central place model of Christaller.

Another spatial approach with hierarchical distribution is Zipf's law, which determines that the distribution of a system of cities follows a power law. This means, the hierarchical organisation of the cities is given by the rank-size distribution of the population, as a Pareto function. Thus, Zipf's law is an analogy with the fractal distribution.

Therefore, the fractal properties can be used to characterise the scale invariance of the urban organisation. Frankhauser (1997) highlighted the "fractal parameters characterise the degree of concentration and of non-homogeneity" of urban elements across scales. The most frequent use of fractal properties in urban geography has involved the measure of the D_f of some urban patterns, such as the built-up areas (Chen, 2011; Frankhauser, 1997, 1998; Li et al., 2015), the urban sewer networks (Gires et al., 2017), the green roofs (Versini et al., 2020), or the green spaces distribution (Juidías, 2017; Liang et al., 2013). Thus, the D_f provides information about the urban morphology and mass distribution over the plane (Tannier & Pumain, 2005).

Apart the characterisation of the scaling laws of the urban organisation, the fractal geometry, and specifically the properties of the fractal primitives make them interesting for the spatial modelling:

- The scale-invariance, which allows creating a multiscale planning scheme where the same distribution principle is repeated, for instance the diversity of densities or the proximity of built areas to green areas.
- The lengthening of the boundary of fractal primitives with scale. This means that as spatial resolution increases, the scenario increases the interface between different kinds of urban objects, such as the built-up areas and the NBS.

Then, there are always two ways of looking at a fractal 2D object: either focus on the object itself, or on the empty space that is left, this means the lacunas of the fractal. In an urban setting, we can consider that the main urban form is composed of the buildings, and that other urban objects, such as roads as well as green and blue areas are located inside the lacunas of the fractal built form.

A practical example in spatial modelling of fractal primitives is the Fournier's dust as presented by Frankhauser in Borsdorf & Zembri (2021). As shown in Figure 6.a, this fractal recreates a hierarchical organisation where the elements (i.e., buildings) are not connected and form aggregates (i.e., urban blocks). The way the elements are placed resembles a large empty space at the core of the set of blocks (i.e., neighbourhood or districts), which would be representative of a large public urban park.

Another particular case of a constructed fractal that can be useful to represent a spatial pattern organisation with highly irregular shape, is the teragon (i.e., created from a self-similar curve). Over iterations, teragon surface remains constant and homogeneous, while the boundary becomes more complex and fractal, as represented in Figure 6.b. The representation of NBS with a teragon would match the irregularity of the built-up structure and create connectivity between NBS.

Apart from the construction of spatial models that resemble the spatial organisation and urban patterns, the fractal geometry and specifically the fractal dimension, provide a measure of the heterogeneity of the way urban structures fill space across scales. This measure is convenient when modelling spatial organisation, to define the characteristics of a fractal primitive representing an actual urban settlement within one territory across a range of scales.

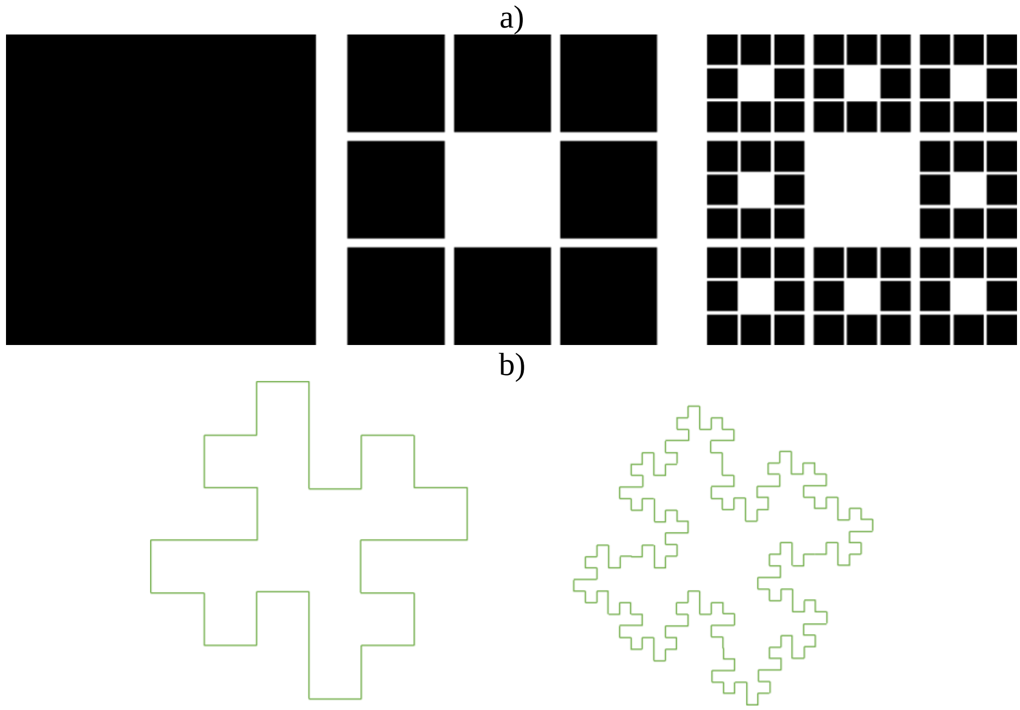


Figure 6. Fractal primitives after two iterations: a) Fournier's Dust, and b) Teragon.

In this context, we will explore a spatial multiscale simulation of NBS's location across different scales, while preserving current scaling properties of urban buildings and green spaces in the territory of Est-Ensemble. The spatial simulation software Fractalopolis, based on the scaling properties of fractal geometry, that develops self-similar scenarios of urban planning will be used for these purposes.

3. Presentation of Fractalopolis

Inspired by the usefulness of fractal geometry for analysing urban morphology, the GIS-based open-source software Fractalopolis was created (https://sourcesup.renater.fr/www/fractalopolis/) as a land planning simulation model, that aims at reinforcing a hierarchy of urban centres, with a mixture of densities at all scales, good accessibility to amenities and the preservation of green and blue infrastructures.

An iterative downscaling logic, specifically an Iterative Function System (IFS)[1] is used in Fractalopolis to create geometric fractal urban forms (e.g., urban centres) across several scales. This implies the creation of a hierarchical urban system, linked, and articulated to subsystems with social and economic interactions. One of the main advantages of this spatial modelling is the conservation principle of the urban structure that currently exists, without disrupting urban morphology and lifestyle of the inhabitants.

In Fractalopolis, the fractal form defines the “development areas” that acts as centres for urban development. The “lacunas”, which is the complementarity of the urban fractal forms, are areas where nominal urban development will continue and where other kinds of urban objects, such as NBS, can take place. Hence, two zones are created in the model: urban fractal centres for potential future development and lacunas for limited or no development. In real case studies, these “lacunas” may contain several urban structures, such as green spaces, railway networks or transport axes.

In this way, properties of self-similarity and lacunarity are used as main planning principles in Fractalopolis (see the Figure 7). Generally, the transit-oriented logic that promotes the construction of an urban settlement system linked to the transportation network is used as a principle of development too. Therefore, urban centres are preferably located near access points of the transport network, promoting the use of the public transport system, the reduction of traffic flows, and the pollution. The main objective of these principles is the creation of a resilient urban development that limits urban sprawl, conserves natural green corridors, and incorporates green facilities in built-up areas.

The iterative downscaling logic is framed in two main spatial scales in Fractalopolis: one from regional up to city scale and other from the city up to the neighbourhood scale. In given way, these scales resemble the multi-scale framework of the MAES project (https://biodiversity.europa.eu/maes), which defines the spatial scale where the impact of implementation of NBS is assessed (i.e., regional, metropolitan, and urban). Thus, Fractalopolis's scales will be summarised as regional and urban scales.

[1] The IFS is a common method to creating self-similar forms as fractals, through the iteration of one or more affine transformations.

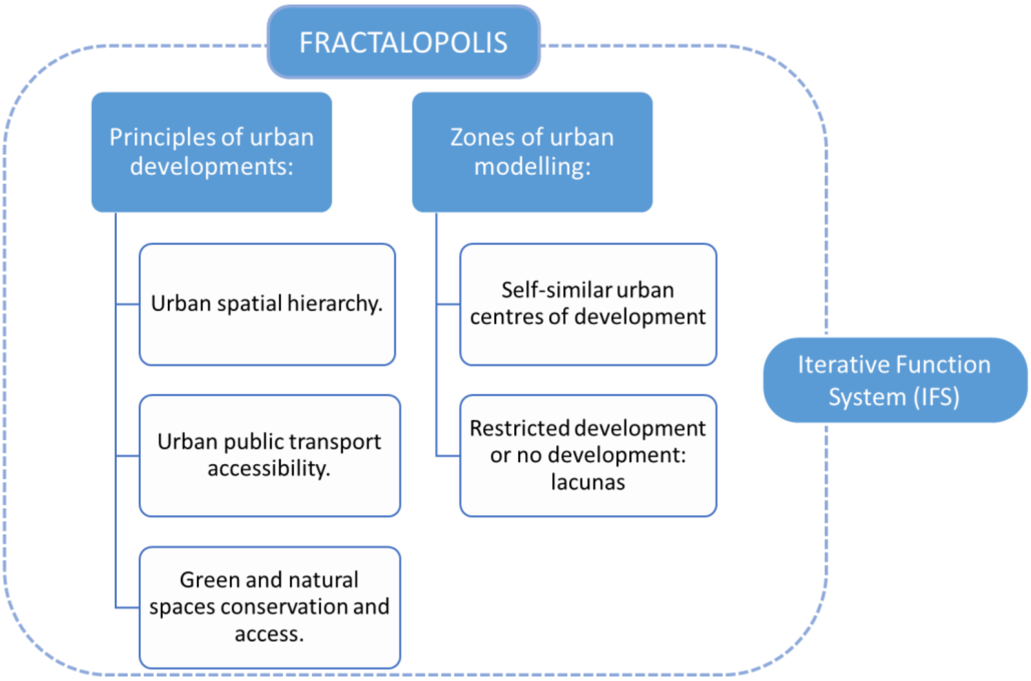


Figure 7. Working principles of Fractalopolis.

Urban spatial patterns and urban dynamics can vary between the regional and the urban scale. In fact, according to Frankhauser in Borsdorf & Zembri (2021) morphology of the built-up structure is mainly determined by phenomena occurring in both scales. Hence, a different fractal primitive can be used over every range of scales in Fractalopolis.

The creation of the fractal primitive based on an IFS implies the following process:

i) Designing a generator and defining scale or reduction factors.
ii) Placing an initiator (e.g., square, circle) over the area of analysis (e.g., area to be densified).
iii) Creating a nested iteration logic of the pre-defined generator (i.e., every feature of the generator will host a copy of itself).

The design of the generator and the location of the initiator can be inspired by existing urban patterns and driven by the interest of urban planners.

For the downscaling iteration process in Figure 8, it is necessary to define a square as initiator, and the reduction factors r_1 and r_2. Hence, the downscaling iteration process creates a hierarchy of urban centres (in white) and lacunas (in grey) of different sizes within the urban system.

It is important to note that to the extent that the Sierpinski carpet is iterated, the surface of the centres decrease whereas its perimeter length increases. This implies the mass of buildings within a centre is vanished with iterations. Then, the number of iteration steps should be selected carefully in order to keep this mass.

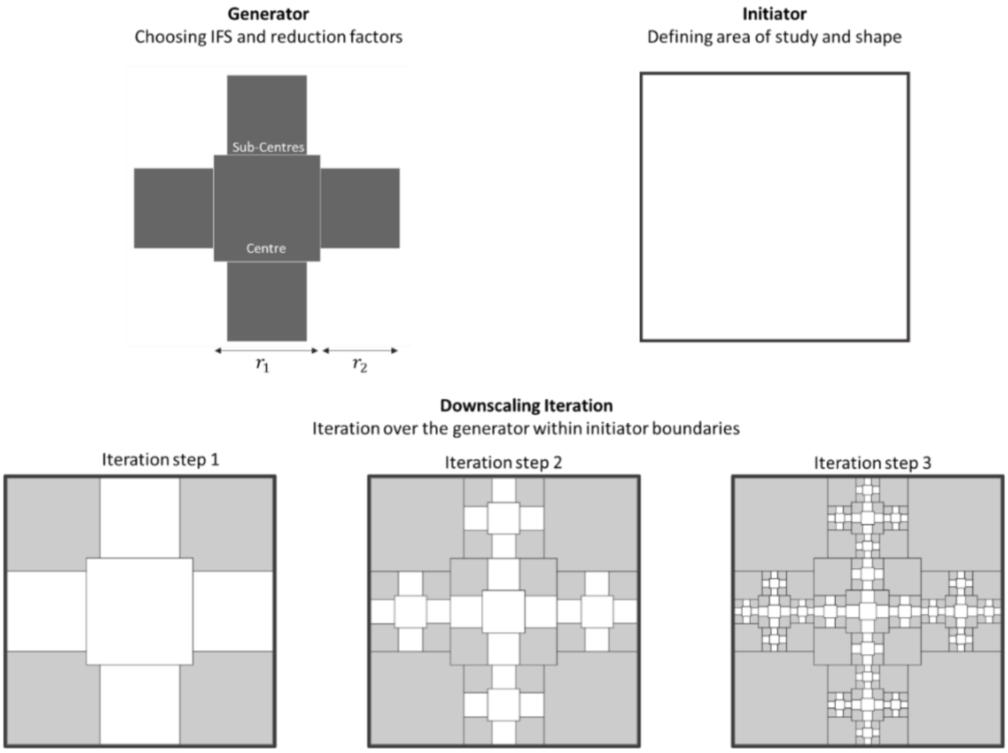


Figure 8. Development of an IFS and downscaling iteration of a Sierpinski carpet with two reduction factors. Adapted from Frankhauser et al. (2018).

To be able to fit the fractal form to an actual territory, Fractalopolis allows for displacement of squares at each scale with the limits defined by the previous scale. Thus, the fractal form obtained for is no longer strictly self-similar, but only statistically.

Because of the spatial hierarchy created in the course of the downscaling iteration process, a ranking of urban centres and lacunas is developed. A binomial coding system is introduced in the program in order to distinguish the rank of urban centres, classified between 1 and 0, and that determines their frequency of visit by residents. This logic is inspired by the Central place theory of Christaller. Therefore, main centres that are more appealing because they offer more facilities and services, are denoted by 1 and sub-centres by 0 at each iteration step.

Following the same downscaling logic of centres, the lacunas (R) are coded at every iteration step. The notation adds a digit 0 or 1 according to its embedding urban centre rank, as shown in Table 1.

Table 1. Binomial code system of spaces.

Iteration	Urban centres code								Lacuna code			
Step 1	0				1				R			
Step 2	00		01		10		11		R0		R1	
Step 3	000	001	010	011	100	101	110	111	R00	R01	R10	R11

Linked to the code system, a housing distribution model is involved in Fractalopolis (see more on Frankhauser, 2012; Frankhauser et al., 2018). At each iteration step a given number of housings is assigned to each urban centre by weighting factors, according to its hierarchical rank. By this model, scenarios that consider the increase of the housing number can be simulated and the suitability of its construction evaluated.

Fractalopolis includes a module for the assessment of accessibility to different types of amenities, such as green spaces and/or services. An indicator is used in the program to assess the accessibility to each urban centre. It varies between 0 and 1, being bad and good accessibility, respectively.

Depending on the spatial scale of analysis, the conditions of accessibility vary. The principle of accessibility assumes the distance from urban centres to green spaces is more relevant at the urban scale, as this supports a pedestrian-friendly environment. Meantime, at the region scale, the presence or not of large spaces is more significant (Czerkauer-Yamu & Frankhauser, 2013).

Moreover, accessibility to amenities depends on usage frequency by the inhabitants: daily, weekly, monthly, or occasionally. Therefore, daily amenities are the nearest to urban centres at the urban scale. Being NBS deployment the main purpose of the next sections, the rules of accessibility to green spaces are only considered. All the details of accessibly rules are described by Czerkauer-Yamu & Frankhauser (2015).

Based on the formalisation of the fractal properties of the urban organisation and their recourse for the spatial modelling with Fractalopolis, let's now deal with the characterisation of the scale invariance properties on an existing territory as well as the application of Fractalopolis to deploy NBS over the site.

4. A case study in Parisian area: Est-Ensemble

Est-Ensemble is a Public Territorial Establishment (EPT, in French) of the Metropolis of Greater Paris (MGP) located at the east of Paris. This territory is close to the Cité Descartes, where the ET campaign over the BGW was carried out. Est-Ensemble is one of the largest urban agglomerations in Ile de France region, and it concentrates 422,744 inhabitants (Insee, 2017) within 9 municipalities (communes): Bagnolet, Bobigny, Bondy, Le Pré-St-Gervais, Les Lilas, Montreuil, Noisy-le-sec, Pantin and Romanville.

The competences of the EPT include urban planning and environmental protection. According to the local urban plan of Est-Ensemble, 26,000 new housings should be created in 2030 (Est-Ensemble, 2020). Therefore, one of the main concerns of authorities is the management of potential densification areas, increasing both population and dwelling density in this Parisian-east area, while preserving natural green spaces.

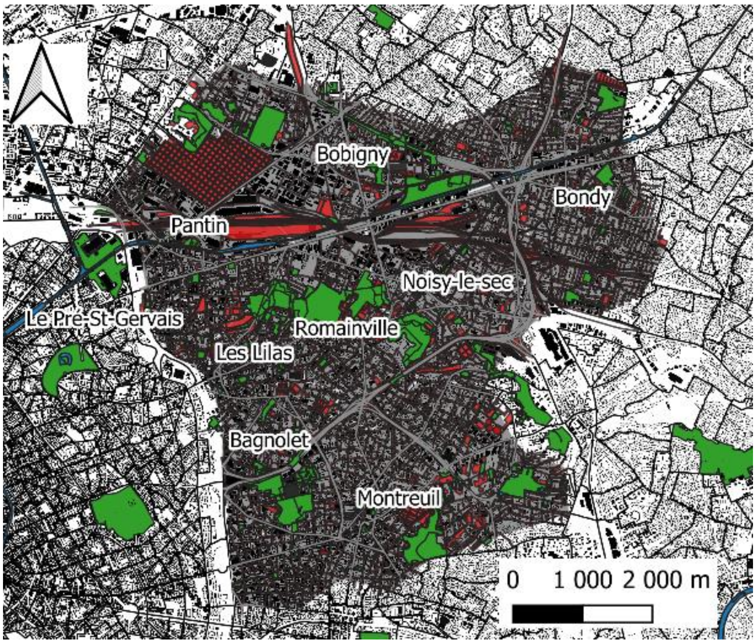


Figure 9. Communes of Est-Ensemble.

4.1 Green spaces to preserve

Because of the high pressure of building density in Est-Ensemble, and the potential impacts regarding urban resilience, it is essential to preserve the green spaces already present in the territory before simulating any scenario of urban densification or NBS installation. Therefore, green spaces recognised by urban planning and management tools, as well as those registered on the database of existing public green spaces open to the public from Paris Region Institute (L'Institut Paris Region, 2020) are listed. Missing and incomplete information of the database was completed with the Seine-St-Denis department GIS database of green spaces (Département de la Seine-Saint-Denis, 2014).

Figure 10. Urban plans of local governance and management of green spaces in Est-Ensemble.

Some green spaces and water bodies of essential importance to keep free of urban development have been declared so by local authorities, based on the recognition of their ecosystem functions and services. These spaces include the Romainville Parc and the Canal de l'Ourcq, which are inscribed in the land-use, biodiversity life and regional ecosystems equilibrium plans: "*Schema Regional de Coherence Ecologique d'Ile de France*" (SRCE) and "*Schema de Trame verte et bleue*" (TVB).

Other green spaces are included in the *local governance* and management plan of the Est-Ensemble territory, and in the future urban planning project *Parc d'hauteurs,* which connects several green spaces at the east of Paris in a loop of 32 km that pass-through Est-Ensemble. The list of urban plans and details of all green spaces that they include are summarised in Figure 10.

4.2 Fractal dimension of built-up and green areas in "Est-Ensemble"

The heterogeneity of spatial distribution of the built-up structure and the green spaces of the urban agglomeration of Est-Ensemble is analysed through the grid-counting approach in Fractalyse. This method was chosen as this adjusts the position of the grid to the image with the minimum coverage.

For this study, GIS database from the Institut Géographique National (IGN) was used to download the buildings map of Est-Ensemble, while final map of green spaces cited in the previous section was used to calculate the D_f. The size of the raster maps was 8,192x8,192 px (pixel of size 1 m). The results are presented in Figure 11 and Figure 12 :

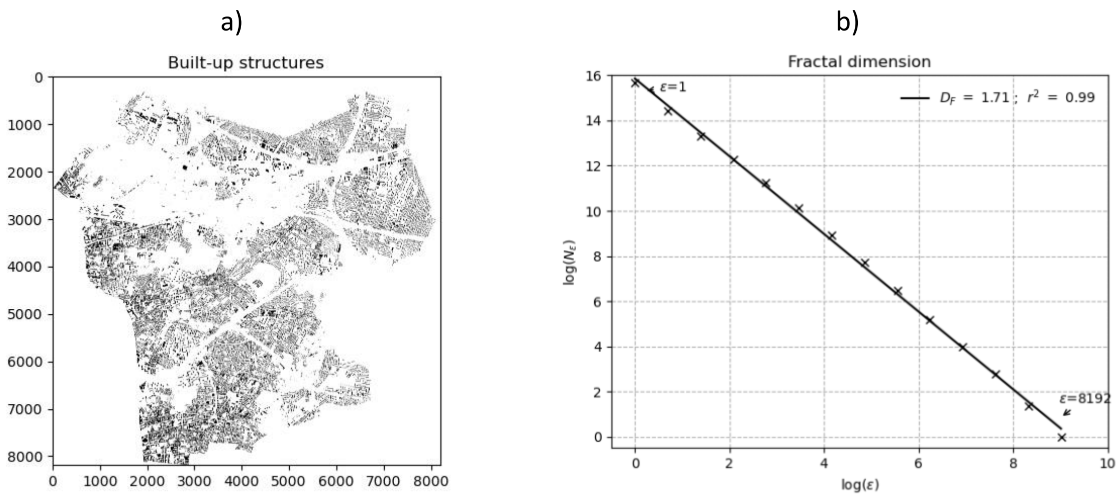


Figure 11. a) Built-up structures map and b) fractal dimension.

According to the results, the spatial organisation of the built-up structure is regular over all the agglomeration. Indeed, the D_f is approximately 1.71, which agrees with the results of Frankhauser (1997), who notes the D_f of urban form of several cities in Europe varies around 1.6.

Opposite to built-up areas, the D_f of green spaces indicated fragmentation and heterogeneity. The two breaks of the linear regression confirm a hierarchical distribution of green spaces characterised by three scaling ranges, represented by different D_f. The first and third scaling range have value of $\overline{D_f}$ close to 2 (1.9 and 1.81, respectively). In fact, the first scaling regime corresponds to a scale of observation smaller or equal to the footprint of the green spaces (1 to 16 m). Thus, the value of $\overline{D_f}$ describes a uniform distribution of green spaces with size length between 1 and 16 m. Contrary, the second regime of green spaces that characterises the middle scales (from 16 to 512 m) has a $\overline{D_f}$ of 1.4. This indicates green spaces at these scales are more concentrated as clusters. This would be related to the differences in the number and the size of green spaces per community. Finally, the $\overline{D_f}$ of the third scaling range of the larger scales (512 to 8,192m), corresponds to the Euclidean dimension of the embedding space (filled when the resolution of the image decreases).

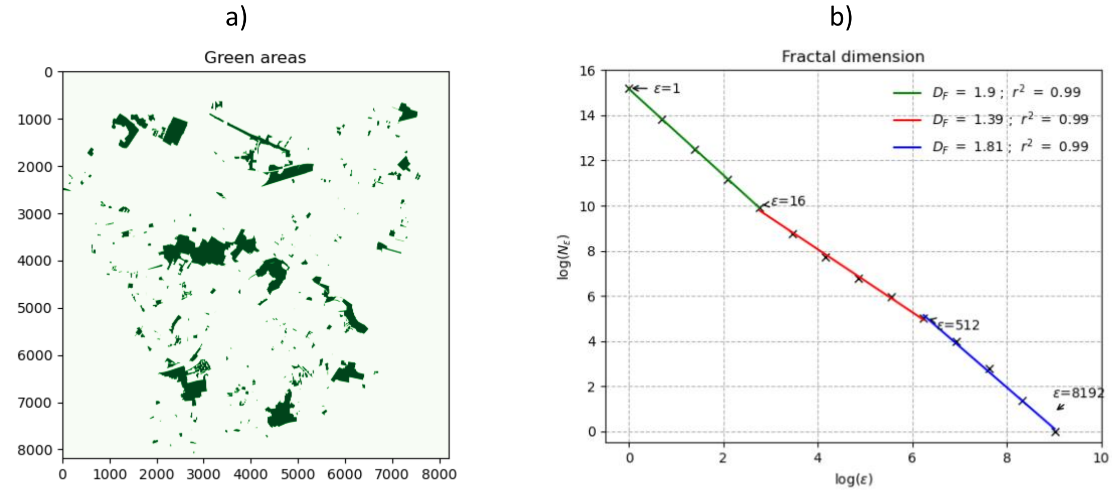


Figure 12. a) Green spaces map and b) fractal dimension.

4.3 Alignment of N4C guideline classes: classification of green spaces database by types of NBS

To avoid confusion between green spaces denominations and NBS terminology, green spaces database of Est-Ensemble was classified according to the NBS typology defined by Nature4Cities (N4C) project (Nature4Cities, 2018). The latter documented 56 types of NBS based on their urban and temporal scales, ways of intervention, thematic and land use, and local environment. The green spaces in Est-Ensemble database with no specific category, such as “autre” or “espace vert en projet” were classed as *Public Urban Green Spaces*. Table 2 summarises five main categories of NBS with ground as physical support, that includes one or several types of green spaces.

From this classification, an overview of the current distribution of NBS by class is examined. The access point to every NBS extracted and classed in Figure 13. The main type of NBS in the territory is the *Public urban green space* (in orange). This category together with *Public urban green space with specific uses* (blue) group most of NBS managed by the local authorities of Est-Ensemble.

Table 2. Classification of green spaces according to N4C classes of NBS.

N4C	Green Spaces in Est-Ensemble (FR)
Public urban green space with specific uses: including schools, playgrounds, campgrounds, sport fields, community gardens.	• Plaine de jeux • Parc sportif • Base de loisirs régionale • Base de loisirs
Public Urban Green Spaces: including parks, places, squares, green space, etc.	• Grand parc urbain • Parc de ville • Square et jardin public • Autre • Espace vert en projet
Botanical Garden: heritage garden.	• Parcs et jardins patrimoniaux • Espace naturel caractère pédagogique
Urban Forest	• Espaces bois et naturels
Vegetables Garden	• Jardin partagée • Jardin non identifié • Jardin familial • Autre jardin

Regarding the *Vegetable gardens*, most of them are concentrated in the south of the territory, in Montreuil commune where is located the historical urban agriculture project Mûrs à Peches. By contrast, less numerous are the *Botanical gardens* and *Urban Forest*, present in the communes of Bondy and Romainville respectively. In this latter is located the Romainville Parc, the larger NBS of the whole territory.

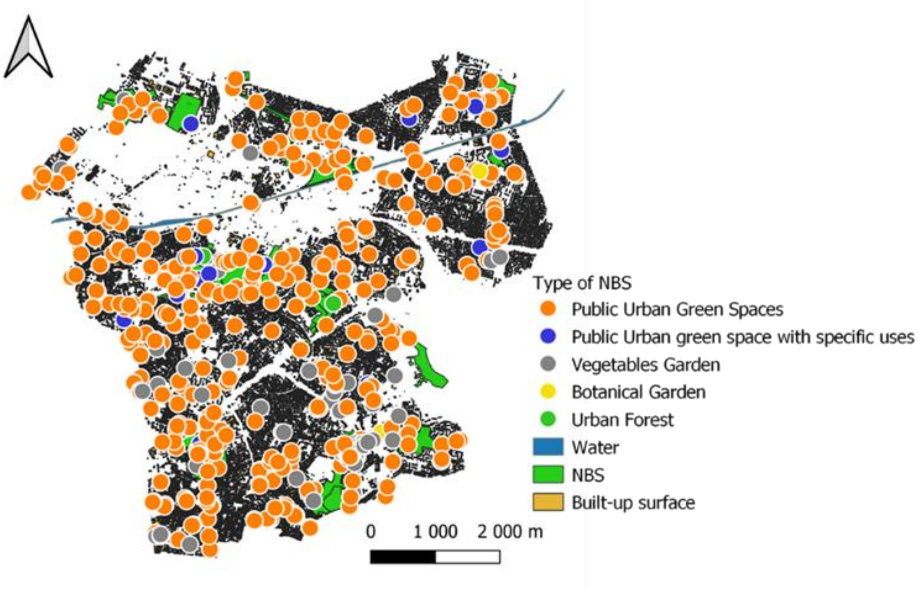


Figure 13. Distribution of NBS by typology.

This representation demonstrated in the Le Pré-St-Gervais commune there are few access points to NBS, which could be explained by the fact that this is the smaller commune in Est-Ensemble. However, these results are significantly different to Les Lillas, which is the second smallest commune, but has several *Public Urban green spaces* represented by access points to the Ile de Loisirs de Romainville.

An important feature in the distribution of NBS is their low availability at the north-west of the territory, mainly in the communes of Pantin and Bobigny. There, it is located Pantin's cemetery, the widest cemetery in the Paris region. Despite green spaces on Pantin's cemetery, which occupies 107 ha and 1/7 of the total commune surface (Pantin, 2020), those are not included in any of the original databases of green spaces.

Besides, at northern communes there is a large warehouse of the national railway company (SNCF). Hence, the urban footprint between the cemetery and the SNCF's warehouse, and water channel Canal de l'Ourcq, is not empty. Instead, there are numerous industrial buildings, as well as the national road N3.

If the total area of NBS is deduced, we found 401.97 (ha) of NBS in Est-Ensemble, which represents to 9.97 m² of NBS per individual. This is slightly higher than the minimum threshold recommended by the World Health Organization (WHO) (i.e., 9 m² per capita). Therefore, from the perspective of population growth, just as the urban planning of Est-Ensemble specifies, this indicator of availability of public NBS per capita would be easily exceeded.

The proximity to NBS from housings is evaluated following WHO recommendations too. Since this specifies NBS should be installed close to people, all housing should have access within 300 metres' linear distance to NBS of at least 0.5 – 1 ha (World Health Organization Regional Office For Europe, 2017). In the case of Est-Ensemble, this evaluation indicated 89.6% of the total number of housings are near to minimum 0.5 ha of any type of NBS. Thus, it is necessary that NBS are deployed over the territory to insure their access at different urban scales.

4.4 Design of an IFS to spatially fit the green spaces with a fractal primitive

The elaboration of a scenario of deployment of NBS based on fractal geometry in Fractalopolis requires exploring scenarios of urban development over the built-up structure, i.e., according to the classical applications of the software (Czerkauer-Yamu & Frankhauser, 2015; Frankhauser et al., 2018), in order to extract the lacunas that will serve as support where the new NBS will be located.

The simulation of both the built-up and NBS structure, consider that urban patterns follow a fractal law, that will be represented by a fractal primitive. However, the self-organising process varies for each structure. Whereas the urban centres will try to cover the built-up structure in the best possible way, the design of the new NBS is inspired by the self-similarity properties of the current distribution of green spaces.

Iteration over built-up structure

The arrangement of the IFS over the built-up areas of Est-Ensemble adopts two different approaches according to the scale of iteration: regional or urban scale.

- *At the regional scale*: The polycentric and heterogenic morphology of the Metropolis of Greater Paris (MGP).

Given the territory of the Est-Ensemble is located within Seine-St-Denis, one of Petite Couronne departments of the MGP, the design of the IFS at the regional scale is inspired by the polycentric distribution of the MGP's plan. This is composed of the city of Paris and nearby suburbs of the departments of the Petite Couronne: Hauts de Seine, Seine-St-Denis and Val de Marne. Therefore, the spatial logic of the IFS follows an adaptation of the classic Sierpinski carpet, consisting of a large centre of first rank and six smaller centres of second rank. Two reduction factors are used for the centre of each rank: $r_1 = 0.35$ and $r_2 = 0.25$, leading to find 1.46 as fractal dimension in the generator.

The main centre (of rank 1) is placed in Paris, where a wide range of facilities is provided, and two sub-centres in each of three surrounding departments, as shown in Figure 14. One sub-centres of the Seine-St-Denis department is placed over Est-Ensemble.

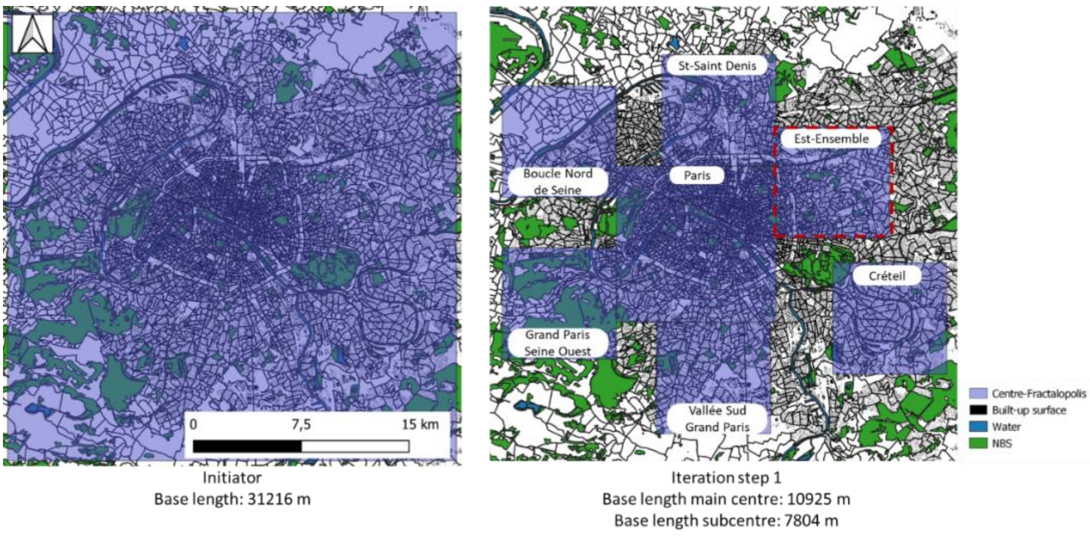


Figure 14. Simulation of urban centres at the regional scale.

The sub-centre representing Est-Ensemble is set as the initiator of the urban scale (in Figure 14). Therefore, the iterative downscaling logic is developed exclusively over this territory with the same fractal generator, keeping self-similarity properties of built-up structure across all scales.

- *At the urban scale*: The urban centres are positioned in such a way that the NBS of Est-Ensemble are free from interventions. This means that the set of existing NBS ends up located in the lacunas.

At the iteration step 2, the placement of urban centres takes into consideration the total number of housing units by communities. Hence, the main centre was placed over the communes of Montreuil and Bagnolet, with a high number of houses, whereas sub-centres are over the remaining communes. Because of Montreuil's extension, it is necessary to locate an additional sub-centre. By contrast, communes such as Le-Pré-St Gervais and Les Lillas share the same sub-centre, since they are not very large, and the housing number is lower.

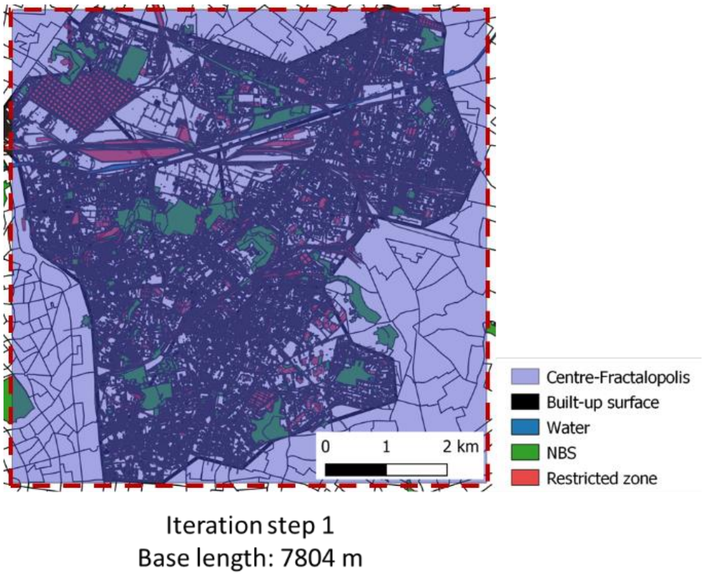


Figure 15. Sub-centre at iteration 1 and initiator at the scale of Est-Ensemble.

The iteration step 3, in the right of Figure 16, shows a good fit between the urban centres and the existing building structure, which would allow enough place for the NBS. Indeed, it can be observed how the placement of centres (in blue) attempts to leave, all NBS already existing on the territory and listed previously, free of interventions, especially the Romainville Parc and the Canal de l'Ourcq. Thus, the number of iterations is considered sufficient.

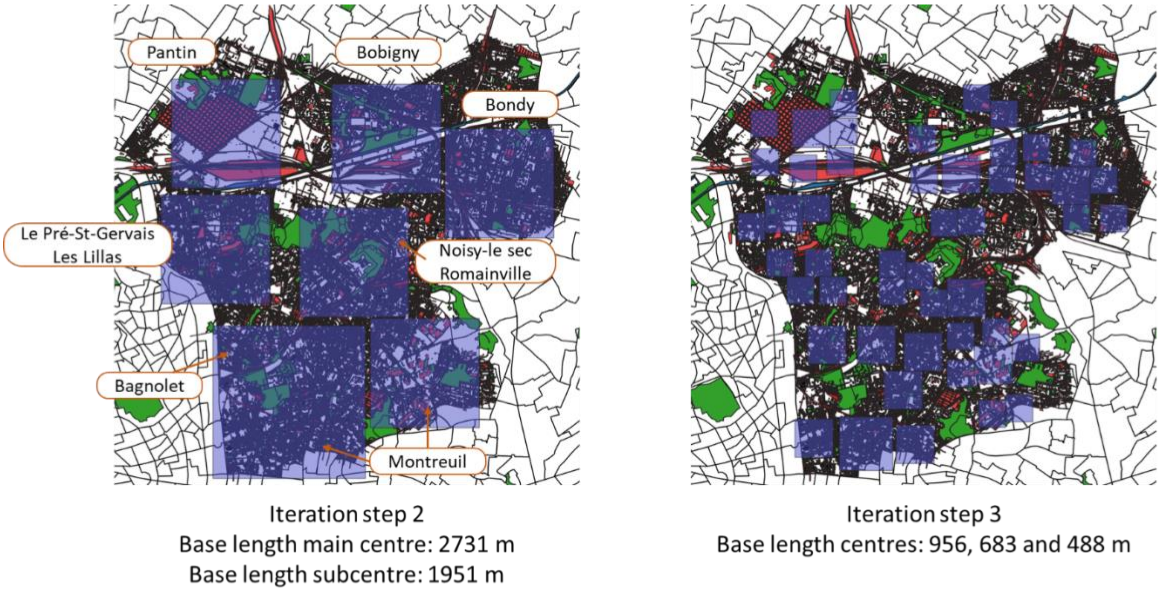


Figure 16. Scenario of development of urban centres.

If the housing density of this scenario is analysed, we found the highest values at the western of the territory centres, mainly in the communes of Le-Pré-St-Gervais and Les Lillas, as can be seen in the Figure 17. On the contrary, the number of housing units per hectare is lower in the centres located at the eastern and mainly in the north. These results confirm the deficit of NBS in communes with high housing density.

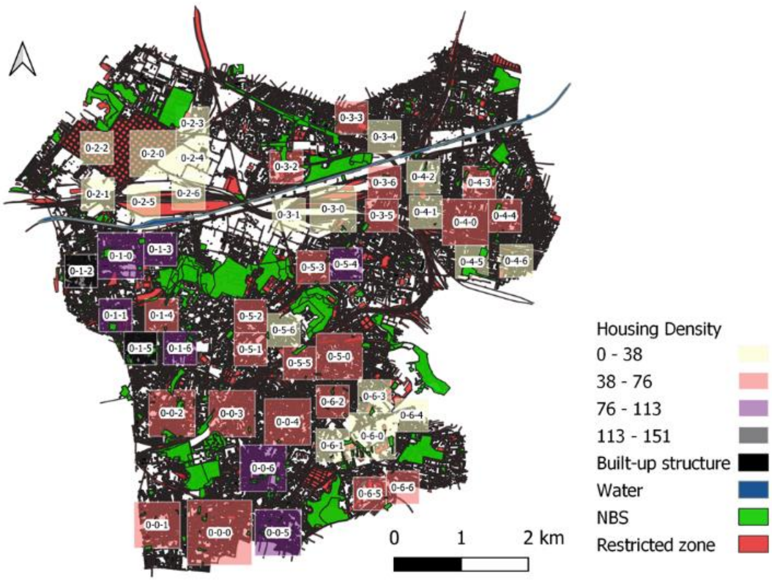


Figure 17. Housing density (housing/ha) in urban centres.

Iteration of new NBS

The unoccupied sites by urban centres, includes built-up structure, NBS, road network, transport network, etc. All the ensembles of these sub-sets of the built-up pattern comprises the lacunas. In these spaces with limited urbanisation strategy, we will develop a scenario of installation of NBS, that is based on the existing distribution of NBS.

Since the distribution of NBS in Est-Ensemble seems to follow a fractal law, we adopt the approach to define another fractal primitive for the NBS that will be deployed in the lacunas of the fractal primitive describing the built area. Lacunas of a fractal form do not constitute a fractal, but let us recall that the lacunas may contain many other urban objects, including streets, places and public infrastructure.

To preserve the self-organisation properties of NBS on the territory, the design of the fractal generator of NBS will rely on the analysis of the fractal dimension of existing NBS. This means the downscaling logic of the IFS matches the self-similar properties of the original distribution of NBS. As the results of the box-counting analysis demonstrated, the NBS are not homogeneously allocated over the urban agglomeration and its clustering distribution is described by three scaling ranges.

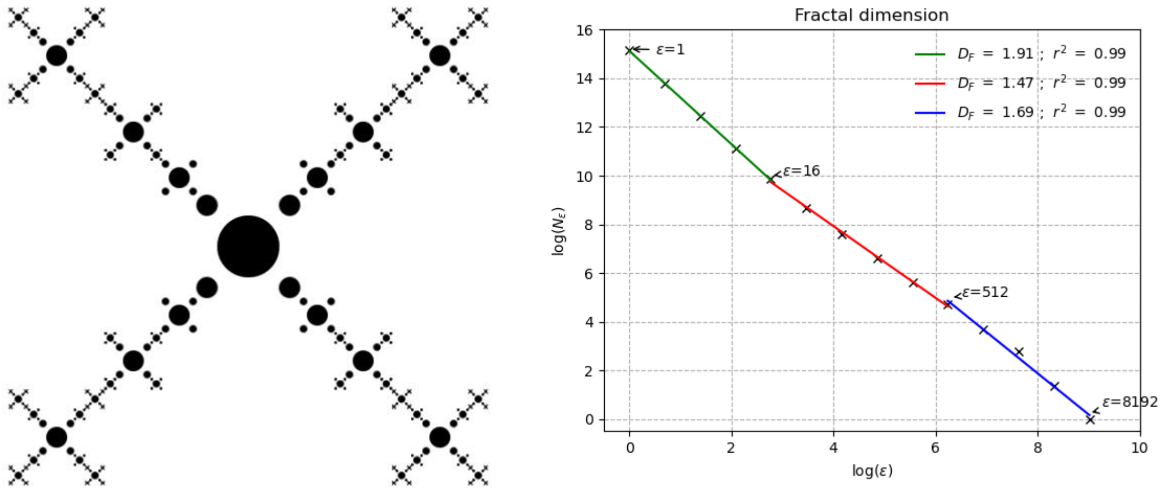


Figure 18. IFS at iteration 4 and D_f.

The open-source software GenFrac (https://sourcesup.renater.fr/www/genfrac/), devoted to the creation of fractals was used to design the IFS of new NBS, verify its fractal dimension and scaling behaviour before to use it in the spatial modelling of Fractalopolis. The generator is inspired by a Sierpinski carpet and the geometry of the initiator was chosen to be a circle (as shown in Figure 18). The generator is constructed over a grid of 10x10 with two reductions factors, $r_1 = 0.6$ and $r_2 = 0.2$, and its D_f is 1.30. The choice of the reduction factors is based on the ratio between the side-length of NBS and the horizontal extension of Est-Ensemble territory.

After four iterations of the IFS, the D_f is computed considering 8,192 m as the largest side of the box. This corresponds to the horizontal size of the distribution map of NBS. The results in Figure 18, indicated two breakups and three scaling regimes, just like the original NBS distribution. The values of the D_f are compared in Table 3.

Table 3. Fractal Dimension of NBS

Scale Range	D_f of original NBS distribution	D_f of NBS generator
8,192 – 512 m	1.81	1.69
512 – 16 m	1.39	1.47
16 – 1 m	1.9	1.91

These values demonstrated the $\overline{D_f}$ of NBS generator have quite similar scale invariance properties to the original distribution of NBS. Consequently, a self-similar scenario of NBS deployment is generated by setting the characteristics of the generator in Fractalopolis, and iteratively downscaling four times. Their location at early steps attempts to avoid centres of urban development, which leads lacunas to be partially covered.

The current distribution of NBS, called "baseline" from now, and the multiscale scenario of NBS's deployment are compared through the assessment of accessibility in the fractal scenario of urban development. For this purpose, the frequency of visits to NBS, according to the type of NBS and their area is defined by rules explained in Table 4. The area used to classify NBS are consistent with the characteristic scales of NBS side-length. This means that 16 and 512 m scales, determined an area of 256 and 262,144 m². In this way, small NBS as urban parks or squares, are busier places than a large forest.

Table 4. Frequency of visit to NBS.

Frequency	Type of NBS
Occasional (1)	• Urban Forest
Monthly (2)	• Public Urban Green Spaces, and Public Urban green space with specific uses, with area > 262,144 m² • Heritage and botanical gardens
Weekly (3)	• Public Urban Green Spaces, and Public Urban green space with specific uses, with 256 ≤ area ≤ 262,144 m² • Vegetable gardens
Daily (4)	• Public Urban Green Spaces, and Public Urban green space with specific uses, with area < 256 m²

The indicator of accessibility of each urban centre considers its proximity to NBS. The distances that should be respected according to the frequency of use of NBS, are established conforming to the characteristic scales of NBS distribution. This means proximity to daily NBS is between 1 to 16 m, weekly between 16 to 512 m, monthly between 512 to 8,192 m and occasionally NBS are less than 8,192 m.

For any frequency, in Fractalopolis the nearest distance between the centroid of the urban centre and every NBS (with corresponding frequentation of analysis) is calculated, and the rules of accessibility are applied, as described in Table 5. Thus, the final indicator of accessibility by frequency in the urban centre, corresponds to the average of accessibilities to NBS. The distance to NBS is estimated to the access point if the NBS area ≥ 5,000 m² or to the centroid for smaller NBS.

Table 5. Rule distances to NBS by frequency.

Frequency	Evaluation
Occasional (1)	$A_0 = \begin{cases} 1, & d_i \leq 8{,}192\, m \\ 1 - \frac{d_i - 8192}{10000 - 8192}, & 8192\, m < d_i \leq 10{,}000\, m \\ 0, & d_i > 10{,}000\, m \end{cases}$
Monthly (2)	$A_m = \begin{cases} 1, & d_i \leq 512m \\ 1 - \frac{d_i - 512}{8192 - 512}, & 512\, m < d_i \leq 8192\, m \\ 0, & d_i > 8{,}192\, m \end{cases}$
Weekly (3)	$A_w = \begin{cases} 1, & d_i \leq 16\, m \\ 1 - \frac{d_i - 16}{512 - 16}, & 16m < d_i \leq 512m \\ 0, & d_i > 512\, m \end{cases}$
Daily (4)	$A_d = \begin{cases} 1, & d_i \leq 1m \\ 1 - 1 - \frac{d_i - 1}{16 - 1}, & 1\, m < d_i \leq 16m \\ 0, & d_i > 16\, m \end{cases}$

4.5 Evaluation of the beneficiates of the multiscale scenario of NBS deployment with Fractalopolis

The visual outcome of the scenario of deployment of NBS following a fractal logic is presented in Figure 19. The NBS are located around almost all the territory, with the exception of the southern area. Despite their location in the first iterations aims the lacunas of the scenario of urban development, at a more local scale the local context influences the final NBS emplacement:

i) The largest element is placed in the Parc departemental de la Bergère and the Canal de L'Ourcq, as a strategy of protection of the cooling corridor in the north of the territory. Given this space represents the future construction area of new housing by 2030, in accordance with the urban management plan (Est-Ensemble, 2020), the installation of NBS would represent a strategy for the construction of urban resilience.

ii) Because of the high housing density and the low number of NBS, the deployment of small NBS is encouraged at the western of Est-Ensemble (i.e., Le Pré-St-Gervais, Bagnolet).

iii) Given Pantin' cemetery is a type of NBS according to N4C classification, but whose ESS have been unvalued by local authorities, this is included as a new NBS.

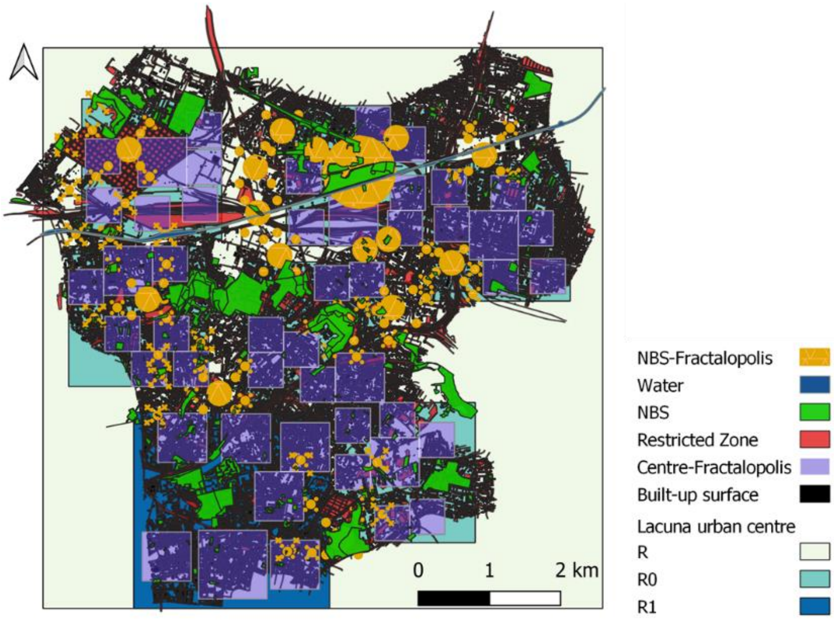


Figure 19. Fractal scenario of NBS deployment.

The location of NBS created by the fractal logic in high-density areas in the western communes, implies NBS over lacunas is not fully respected and there is an overlapping with the current distribution of the built-up structure, as can be seen in the Figure 19. For these conditions of high-density areas, the installation of a new type of NBS can be considered. According to the classification of N4C, some types of NBS can use the buildings and current urban structure as physical support. Those NBS include green roofs and green walls. As well, structures associated with urban networks on the ground, such as green tram tracks, street trees, green strips, or green parking lots. The arrangement of this kind of NBS would represent an opportunity for the installation of a new type of NBS in the areas with an extended urban footprint with low space for green.

Moreover, this scenario creates a hierarchy of spaces to the same extent as the fractal object was iterated. Thus, 625 new polygons representing new NBS with a different level were designed at the iteration step 4. The size of the fractal objects (i.e., the diameter of circles) varies between 11 and 892 m, and at a given level the objects could have different sizes (see more details in the Table 1). Thus, a hierarchy of NBS is created, just like the fractal structures.

Table 6. Level, number and size of objects representing multiscale scenario of NBS.

Level	Number of objects	Size (m)
1	1	892.44
2	4	297.48
3	20	99.16, 297.48
4	100	33.05, 99.16, 297.48
5	500	11.02, 33.05, 99.16, 297.48

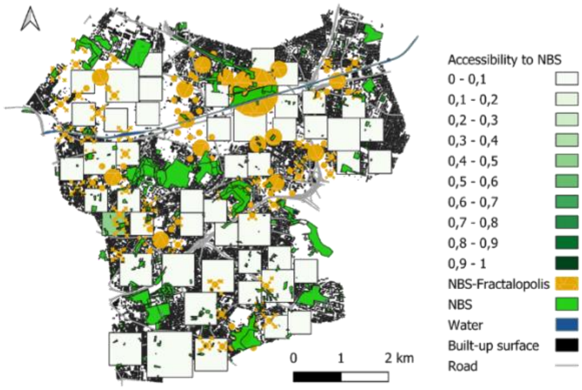
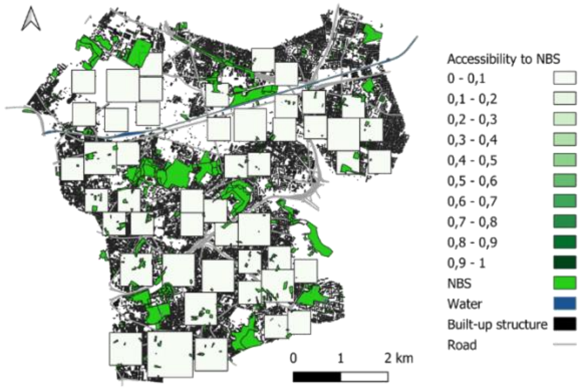
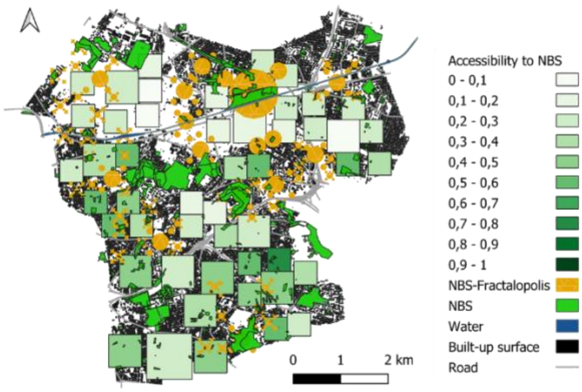
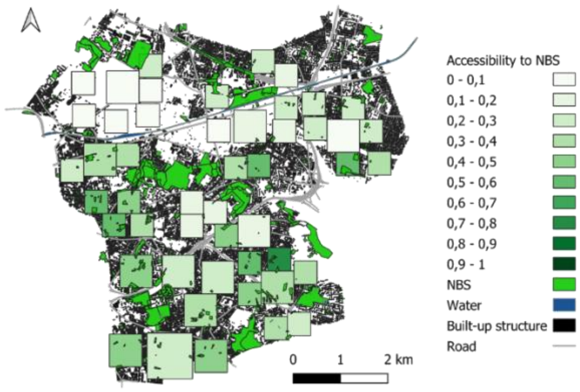
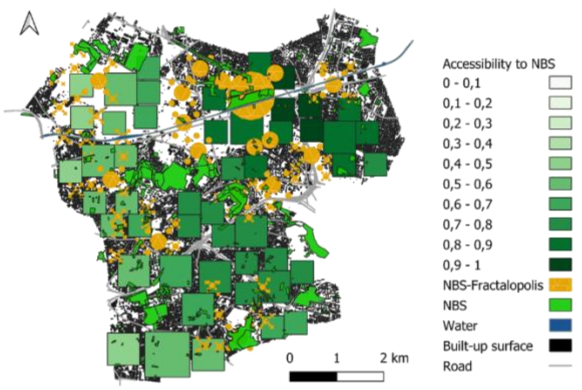
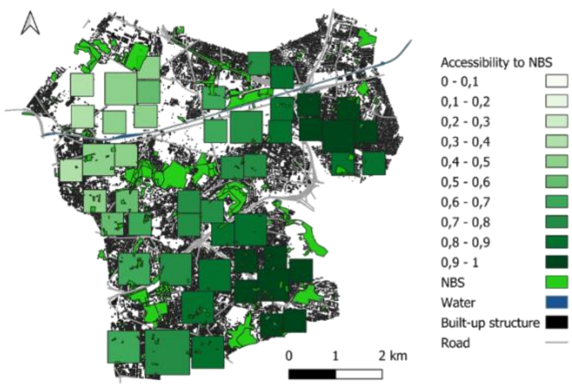
The accessibility of the baseline distribution of NBS was compared with that of the multiscale scenario of NBS' deployment. All the NBS created through NBS' fractal logic were classified as a Public Urban Green Space and its frequency is determined by their area, following conditions in Table 6. Therefore, the final classification of NBS involves those that are visited on a daily, weekly, or monthly basis. By contrast, the Romainville's Parc is the only urban forest that can be visited occasionally in both scenarios.

The results of the evaluation of accessibility at the urban scale do not highlight a significant amelioration between the multiscale scenario and the baseline. The indicator shows the overall accessibility (average of accessibilities) is 0.517 for the multiscale scenario of NBS's deployment and 0.504 for the baseline. This means access to any type of NBS is not excellent, but not extremely bad either.

Regarding every temporal scale of NBS visit from urban centres, a significant improvement of accessibility at daily and weekly frequencies was expected, since the number of NBS visited at this rate substantially increased in the multiscale scenario. However, just a slight improvement of accessibility is noticed. The maps in Figure 20.a, and Figure 20.b, show the indicator of those frequencies hardly changes. In the daily case, just one centre at the west has a value of 0.4 and in the weekly case, few squares on the west increased their access value. This would mean the distance thresholds (i.e., 16 and 512 m for daily and weekly visit, respectively) are not enough to reach the access point of NBS from the centroid of urban centres.

The higher indicator of accessibility corresponds to monthly NBS. It is superior to 0.7 for both scenarios, but it decreases in the multiscale scenario of NBS (Figure 20.c). This can be explained by the method of estimation of accessibility: In the baseline scenario, two NBS have monthly frequency of visit. In addition, both NBS have the same category or type: botanical garden, thus, only the accessibility indicator to the nearest botanical garden is estimated. The integration of a new NBS at the north (in the Parc départamental de Bergère) in the multiscale scenario, introduced a different category of NBS: Public Urban Green Space. Hence, the accessibility is estimated to the nearest NBS for each category and then all categories are combined by evaluating their average. Thus, access in urban centres on the western of the territory (close to the new NBS) improved, but in some urban centres of Montreuil was declined, as the distance from centres on south to the Parc de Bergère is long. This implies accessibility to this NBS is very low, leading to reduce the overall average.

Finally, all the urban centres have good accessibility to Romainville Parc, which is considered the only urban forest that is visited occasionally by the inhabitants of Est-Ensemble.

Multiscale scenario of NBS	Baseline scenario of NBS
a) Daily	
	
b) Weekly	
	
c) Monthly	
	
d) Occasionally	

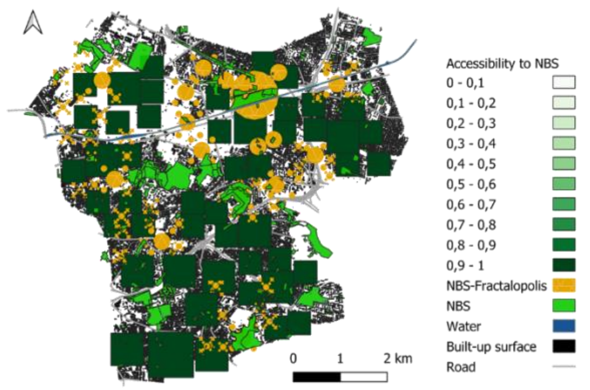
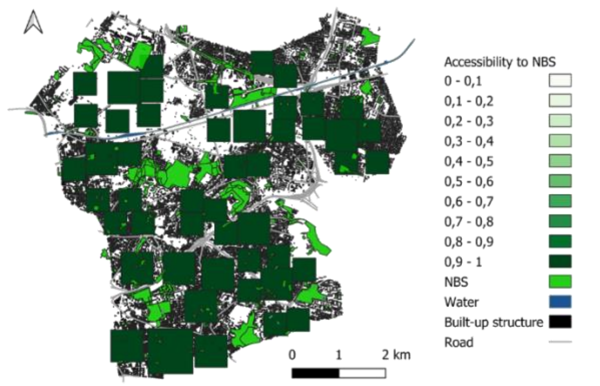
Multiscale scenario of NBS	Baseline scenario of NBS
	

Figure 20. Accessibility to NBS, multiscale (left) and baseline (right) scenario with different frequency rate of visit: a) daily, b) weekly, c) monthly, and d) occasionally.

Given that at the urban scale the proximity to one NBS is more significant than access to different categories of NBS (because of scarcity of vegetation), it was considered the evaluation of accessibility from the urban centres to the closest NBS instead of the average to all NBS. Thus, the proximity procedure is kept.

The accessibility to the nearest NBS in the multiscale and the baseline scenario were compared in Figure 21. The results of this methodology demonstrated the indicator of accessibility in the multiscale scenario is higher than the baseline, from the weekly frequency.

Most of the urban centres in the multiscale scenario have good accessibility (greater than 0.5) to at least one SNB with a weekly or monthly frequency. This weekly frequency indicator is less than 0.2 in only two centres near the Pantin cemetery (north) and in the commune of Bondy (northeast). While in the monthly frequency, the indicator is almost homogeneous and higher than 0.6, which is much better than the previous evaluation of accessibility. Regarding on a day-to-day basis, accessibility to NBS within 16 m only increase in one centre in western. Indeed, accessibility could hardly change as at small scales the distribution of NBS is almost uniform in the baseline scenario ($D_f = 1.9$).

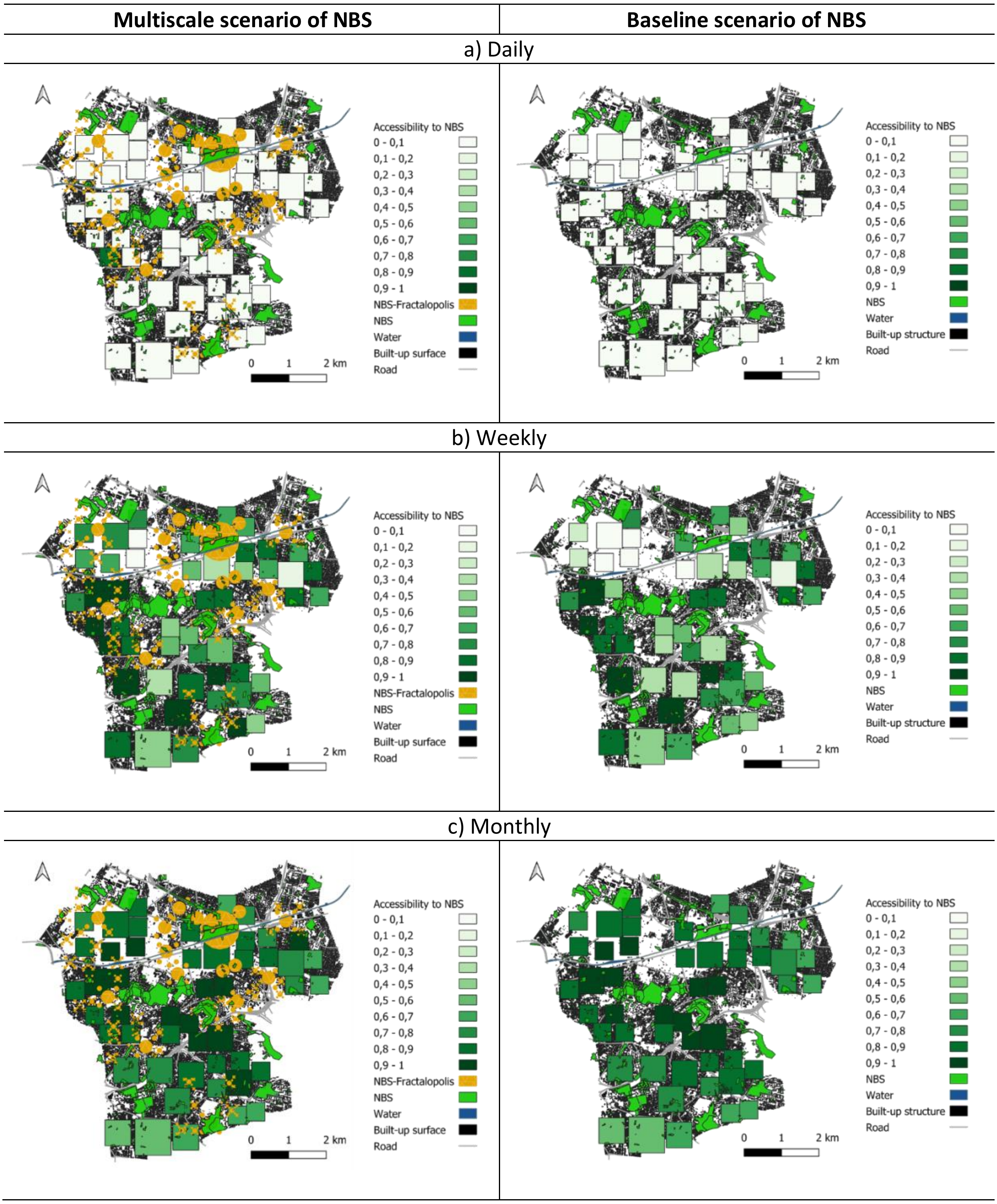


Figure 21. Accessibility to the nearest NBS, multiscale (left) and baseline (right) scenario with different frequency rate of visit: a) daily, b) weekly, and c) monthly.

5. Conclusions and perspectives

To maximise the number of beneficiates of NBS across several scales of a territory, we use the fractal geometry to simulate a scenario of NBS's deployment. By means of an iterative downscaling logic in the spatial simulation model of Fractalopolis, an urban development scenario that follows a fractal law was created. The location of planned urban centres was determined according to the conditions of urban development and planning. This allowed to obtain the lacunas of the fractal object as support for the location of new NBS.

In the case study of Est-Ensemble, the lacunas of urban development scenario comprised several urban sets, such as the NBS, the railway structure, the transport axes, etc. The complexity of such sets could be characterised by the fractal dimension, as was the case of the NBS. Because the fractal dimension results highlighted the hierarchical distribution of NBS according to a power law, they were simulated as a fractal object in the spatial modelling of Fractalopolis, just like the built-up structure. Furthermore, self-similarity properties of NBS were used to define properties of the fractal object representing NBS deployed over the territory.

This simulation allowed to create a hierarchy of NBS of different sizes over the lacunas of Est-Ensemble. However, the emplacement of NBS over the lacunas was not fully respected, because overlapping between the fractal with the zones of urbanisation, which lead to proposing the installation of a new type NBS over the existing urban structure, such as the green roof or the green parking. In this way, the original approach of Fractalopolis, where the green spaces, or NBS in this study, are represented by the lacunas or the complement of the fractal structure (i.e., the buildings) was modified.

The suitability of the multiscale scenario of NBS deployment was assessed through the accessibility from the urban centres to NBS, and the results were compared to the baseline. The evaluation of accessibility took into consideration the overall average access to all types of NBS. The proximity evaluation rules, were determined according to the characteristic horizontal scales of self-similarity distribution of NBS.

The indicator of accessibility for NBS visited occasionally was good throughout the territory. Moreover, a slight improvement of the accessibility to daily and weekly NBS was observed in the multiscale scenario. However, a significant improvement was expected as the number of NBS with these frequencies increased considerably in the multiscale scenario. The distance to reach those spaces from the centroid of urban centres was not long enough to ensure a good access. Finally, the indicator of monthly access to NBS was lower than the baseline, as a new type of NBS was included in the analysis, whose access value was low in the centres located in the south of the territory.

Given the initial way of evaluation of the indicator of accessibility did not exhibit suitability of NBS multiscale scenario, the method of evaluation only considered the accessibility to the nearest NBS. The results demonstrated high values of accessibility in the multiscale scenario for all frequencies of visit, except for NBS visited daily.

Because the installation of NBS requires considerable investment, the evaluation of the economic cost of installation and maintenance of the multiscale scenario regarding their temperature reduction performance, would be very useful. This would allow to determine the minimum number of NBS necessary to ensure the cooling effect, while respecting self-organisation of the space.

As well, under the perspective of temperature reduction because of the ET effect from the NBS, the characterisation of its scaling behaviour through statistical-based methods, such as the multifractal analysis, would enable to determine the main spatial scales of installation of NBS. To attempt this, in the next section, scaling properties of related thermal fluxes to the ET from the BGW, the ${C_n}^2$ and the air temperature will be investigated.

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