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About fractal models in urban geography and planning: refuting the aesthetics and the universal norm

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Fractal models have been used in urban geography for forty years. Their main applications were for analyzing urban forms but they were also used to simulate urban growth. Research in the field has significantly contributed to better characterise the local and global shape of cities and to better understand their evolutions. Yet concomitantly, one can deplore the circulation of some myths about the interpretation of fractal analysis results and about the possible usage of fractal models for urban analysis and planning. I propose here to undermine some of these myths on the basis on some scientific publications in the field¹.

1. Cities are not fractal.

Indeed, measures of fractal dimensions vary in space: the fractal dimension estimated for a whole city differs from the fractal dimension estimated for its neighbourhoods, each having its own dimension (see e.g. (Thomas, Frankhauser, Badariotti 2012)). Moreover, considering a given built pattern, the slope of the curve that represents the number of counted elements with respect to the size of the counting window may exhibit local variations (Frankhauser 1998, 2004; Tannier & Pumain 2005; Thomas, Frankhauser, Frenay, Verleysen 2010). Very early on, pioneer works in geography have insisted on the fact that the fractal dimension is not expected to be constant in reality (Goodchild 1980); most often, it is constant over a limited range of scales but varies somewhat over successive ranges of scales (Lam & Quattrochi 1992; White & Engelen 1994).

Consequently, properties of scale-invariance and statistical self-similarity are locally specific but not universal, and concern limited scale ranges. Thus, by definition, cities are not fractal.

Nevertheless, measures of fractal dimension are interesting for geographers as they enable the characterisation of spatial distributions being highly heterogeneous. Indeed, as fractal dimension is determined via counting the elements of a spatial distribution according to several nested spatial resolutions, it informs us about the systematic variations of a given geographical fact through scales. Such variations are not proportional, not linear, and would not be detected when we use other spatial concentration indexes such as density (François, Frankhauser, Pumain 1995). In practice with fractal analysis, the starting point is to set the hypothesis that a spatial distribution is scale-invariant (or statistically self-similar). Then deviations to scale-invariance are studied. Such deviations may appear for some scale ranges but not others. Deviations may also vary in space, which allows the identification of spatial differentiations.

1 Most ideas exposed in this blog post are taken from the dissertation entitled "*Analysis and simulation of the concentration and the dispersion of human settlements from local to regional scale. Multi-scale and trans-scale models*" [In French], chap. 3 "*Variation de la concentration et de la dispersion des implantations humaines à travers les échelles : modèles mono- et multi-fractals*", pp. 114-175, C. Tannier (2017). <https://tel.archives-ouvertes.fr/tel-01668615v1>

2. Evolution of the shape of cities does not comply with a unique model that would finally end in a fractal order state.

For P. Frankhauser (2004) and N. Salingaros & B. West (1999), the emergence of fractal urban patterns originates in the combination of two types of processes:

- *bottom-up processes* resulting from individual actions (for instance, the choice of households to become owner of an individual house in a suburban area) or from collective actions (for instance, actions of local pressure groups according to the Nimby (Not In My Backyard) logic);
- *top-down processes* (i. e. urban and regional planning).

For F. Schweitzer & J. Steinbrink (2002), fractal urban patterns emerge from the interaction of contradictory actions at an individual level only, i. e. residential location choices that minimize the distance to both the city centre and the urban boundary (countryside).

Underlying those assumptions is the idea of self-organisation. In a self-organised system, a meso- or macroscopic order emerges from interactions at a microscopic level and constraints in return the future evolutions of the system².

Accordingly, F. Schweitzer & J. Steinbrink (2002) have set the hypothesis that the rank-size distribution of urban built clusters changes in the course of time toward becoming a Pareto distribution. If this hypothesis is confirmed, the conclusion would be that a Pareto exponent indicates the development stage of a city and that the deviations from a Pareto distribution indicates potentials for future urban developments. Yet some empirical research results have inquired this hypothesis. In particular, L. Benguigui, E. Blumenfeld-Lieberthal & D. Czamanski (2006) have shown that the rank-size distribution of built clusters of the city of Tel Aviv (Israel) followed a Zipf's law from 1935 to 1964 then gradually deviated from it between 1974 and 2000.

Several scholars have also studied the evolution of fractal dimensions of cities in the course of time. Although the comparison of values of fractal dimension obtained for different studies is not possible since the data used and the calculation methods involved are different, we note similar general tendencies. P. Frankhauser (1990) calculated an increase of fractal dimension of Berlin (Germany) in the course of time: 1.43 in 1875, 1.54 in 1920, 1.69 in 1945. G. Shen (2002) calculated an increase of fractal dimension of Baltimore (USA), from 1.015 in 1822 to 1.722 in 1992. An increase of fractal dimension of the built surface has also been shown for the metropolitan area of Basel (Switzerland, France, Germany) between 1882 and 1994 (Tannier & Pumain 2005) as well as for the metropolitan area of Lisbon (Portugal) between 1960 and 2004 (Encarnação, Gaudiano, Santo, Tenedório, Pacheco 2012).

Yet if the evolution of city shapes evolves according to a fractal growth process, their fractal dimension should not change in the course of time, which studies quoted above contradict. An objection can be that these studies consider each city within a spatial extent that is fixed in the course of time and that comprises on the one hand the urban area itself which expands gradually, and on the other hand, its periphery. That's why other studies have considered cities within a study area that expands according to the urbanisation process. For instance, L. Benguigui, D. Czamanski, M. Marinov et J. Portugali (2000) have analysed the evolution of Tel Aviv's metropolitan area from 1935 to 1991 taking into account three nested study areas. They have shown that the growth differed for each part of the metropolitan area: the fractal dimension increased at different speed in each part of the metropolitan area; some parts have become "fractal" (i. e. statistically self-similar for a given scale range) earlier than others; and the whole metropolitan area has become "fractal" until the mid 80s.

The fact is that a city does not evolve for centuries according to a fractal growth process that would be unique and that would go on until the achievement of a final "maturity" stage of the urban form. First, rules that determine the location and the shape of new urban developments change in the

² Additionally, scholars commonly introduce in self-organising models a limiting factor that often corresponds to a maximum city size, which can not be overcome (Schweitzer & Steinbrink 2002), or to a maximum urbanisation rate (Chen 2016).

course of time. Second, the urban sprawl process results in the gradual integration of peripheral built areas (villages, hamlets, diffuse suburban settlements/buildings) within the inner city. Third, an urban built pattern can be deeply modified through destruction and reconstruction (for instance, the re-shaping of Paris during the 19th century, the reconstruction of cities after massive destructions resulting from bombing or natural disasters, or the massive destructions of old built neighbourhoods and the construction of large buildings and skyscrapers in contemporary Chinese cities). Last, we can observe creations ex nihilo of new towns in the periphery of large cities.

3. Nothing proves that fractal urban forms are optimal by nature.

Starting from the statement that a fractal order can emerge at a meso- or macroscopic level from self-organising processes, fractality is sometimes seen as a desirable equilibrium state. « *Multifractality represents optimal structure of human geographical systems because a fractal object can occupy its space in the most efficient way. Using the ideas from multifractals to design or plan urban and rural terrain systems, we can make the best of human geographical space* » (Chen 2016)³. Thus, if self-organised fractal forms are satisfying (even optimal), urban planning becomes useless (and even annoying) because top-down constraints may engender deviations from fractality (Genre-Grandpierre 2017). Subsequently, deviations from fractality can be seen as signs of dysfunction. For Y. Chen et J. Wang (2013), for instance, deviations from a multifractal structure of Beijing's urban area denote its decline and the degeneration of the inner city. Yet we have previously seen that shapes of cities and urban built patterns are not fractal. Nonetheless they are not all in decline neither are they all degenerated.

Adopting an organicist point of view, other scholars support the idea that urban planning and design should aim at the creation of fractal forms because such forms exist in nature (in which they spontaneously emerge) and thus are "by nature" virtuous and optimal. Fractals are then raised to a universal aesthetic principle, see e. g. (Jiang & Sui, 2014). Besides the fact that such a principle falls under belief more than science, its adoption leads most often to give more importance to emerging forms than to their generative mechanisms. Resulting models are essentially structural: they take into account neither the real behaviours of individuals (as a result of a combination of aspirations, constraints and available means) nor the strong emergence that characterizes social systems⁴.

The fact is that functional advantages of realistic fractal urban developments (starting from an existing urban pattern) with respect to non fractal developments are still poorly known because they have rarely been studied until now. However, a shape is not intrinsically optimal: it is optimal only with regards to the processes (i. e. behaviours, practices) that this shape allows to optimise. Moreover, the absolute does not exist in the case of spatial distributions of human settlements because of the diversity of contexts (social, political, economic, natural, etc.) from which results a high diversity of human spatial behaviours and practices.

4. The "good" fractal dimension for urban planning does not exist.

A same value of fractal dimension can characterise very different urban shapes and can result from generative processes being qualitatively and quantitatively very different (Pumain 2017). As a

3 Y. Chen (2016) goes further as he suggests that the urbanisation process should ideally stop at the stage at which the urbanisation rate L equals 0.618 and the urban-rural ratio (called "golden ratio" in the quoted paper) equals 1.618.

4 It is possible to distinguish weak emergence, where the macroscopic structures resulting from microscopic behaviours can be observed by an external observer identifying a particular regularity in the observed process, from strong emergence, where the microscopic entities observe themselves the macroscopic structures they have produced and adapt their behaviours accordingly (Livet Müller, Phan, Sanders 2010). Social systems are characterised by a strong emergence: through their membership to a social group or to a place, individuals participate in the creation of collective references that refer to this group or place (weak emergence). In return, the adoption (or not) of these collective references by the group or the individual influences its behaviour (strong emergence).

consequence, the question of the "good" fractal dimension —the dimension that would be optimal, falls *de facto* (Genre-Grandpierre 2017). No value of fractal dimension can serve as universal norm for urban planning.

Even so, it is possible to fix a fractal dimension for the development (greenfield or brownfield development) of a given built pattern. But this fractal dimension has to be chosen and justified regarding well-defined planning goals as well as the specific characteristics of the built pattern under consideration and the nature of data used for modelling it.

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