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An integrated multifractal modelling to urban and regional planning

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ABSTRACT

In this paper, we propose a conceptual framework for the design of multifractal urban or regional development plans that adhere to five planning principles: hierarchical polycentric urban development; transit-oriented development; locally dense residential development; penetration of green areas into built-up areas across several nested scales; preservation of interconnected networks of natural and green areas having various sizes. This conceptual planning framework is based on multifractal spatial modelling, which is intrinsically multiscalar. The GIS-based software application Fractalopolis (current version 1.0) is used to apply this conceptual framework to real-world case studies. Fractalopolis helps to define where to create new housing units and new facilities in accordance with the planning principles set out above. We use Fractalopolis to create a multifractal development plan for a medium-sized French metropolitan area, namely Besançon, for the year 2026. This plan allows a realistic "soft" transformation the Besançon metropolitan area in keeping with the five planning principles set out above and makes the region more multifractal.

1. Introduction

The consequences of urban sprawl have been at the heart of planning concerns for several decades now. The construction of residential areas far from jobs and facilities is considered to have caused an increase in the number and length of trips by car as well as increased congestion and pollution. This is mainly due to greater distances to be covered to accede to jobs and facilities as well as the inefficiency of public transport along peripheral routes (Cervero, 1996; Cervero & Kockelman, 1997; Franck & Pivo, 1994). Moreover, individual housing, which prevails in city outskirts, is seen as a source of excessive and worrying consumption of space, especially because the scattered spatial distribution of residential areas entails the construction of new roads which fragment natural areas and agricultural land. Land consumption for residential development and the associated construction of transport facilities, as well as the traffic induced and other human disturbances, all threaten biodiversity.

Classically, planning recommendations for limiting the negative effects of urban sprawl are: compact urban development, polycentric developement, New Urbanism and Transit-Oriented Development, Concentrated Decentralization, greenways and green corridors. Yet, when designing urban development plans, these recommendations can hardly been applied jointly, mainly because of the absence of a formal integrative framework.

In this paper, we propose a multifractal modelling, which is intrinsically multiscale and aims to combine these planning principles within a single coherent framework. The value of fractal urban development on a local or an intermediate scale has already been pointed out, e.g. by Frankhauser (1994, 2008) and Salingaros (2004). Fractal residential development, which allows intra-urban non-built areas to be preserved, meets the expectations of the population better than a uniformly dense urban form (Cavailhès, Frankhauser, Peeters, & Thomas, 2004; Tannier, Vuidel, Houot, & Frankhauser, 2012). Moreover, if the local fractal dimension of residential development is high enough, it averts the loss of ecological habitats and concomitantly avoids the barrier effect of built areas (Tannier, Bourgeois, Houot, & Foltête, 2016). Multifractal modelling extends the idea of fractal urban development up to the regional scale. It also introduces greater diversity in the sizes of both urban and non-urban areas (Cavailhès, Frankhauser, Peeters, & Thomas, 2010; Frankhauser, 2015).

In order to create multifractal plans for real-world situations, the multifractal modelling process has been integrated into a GIS-based software application named Fractalopolis. The preliminary stage in the design of this application (version 0.6.1) is described in Yamu and Frankhauser (2015). Here we present the completed version 1.0 of Fractalopolis.

The paper is organized as follows. Section 2 provides an overview of planning recommendations classically advocated to limit the negative effects of urban sprawl. From these recommendations, we take on five key planning principles. Section 3 sets out the theoretical basis of

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multifractal modelling for planning purposes. Section 4 describes how it can be applied using Fractalopolis 1.0 in the case of the urban region of Besançon (eastern France). Section 5 concludes the paper.

2. Overview of planning recommendations classically advocated to limit the negative effects of urban sprawl

Compact urban development is usually seen as the most efficient solution for limiting urban sprawl (see e.g. Duany, Plater-Zyberk, & Speck, 2001; Krier, 1998). It is characterized by high built densities, uniformity, and sharply contrasting boundaries (Geurs & van Wee, 2006). Yet the impact of density on car use is not straightforward and may sometimes be contradictory, especially with respect to trip frequencies (Hall, 1997; Neuman, 2005). Moreover, as pointed out by Schwanen, Dijst, and Dieleman (2004), increasing density in residential zones may prompt households to move to lower density areas. Hence a compact city policy may actually encourage urban sprawl in the long term. Neuman (2005) reports that residents show no long-run preference for dense centres as in Boston, Baltimore, or San Francisco. The shrinking city phenomenon in eastern Germany (Bontje, 2005) or the exodus from the Corbusier skyscrapers in France show that density cannot be imposed – at least in countries where places of residence can be freely chosen. Planners tend to favour urban renewal and apply urban containment strategies to produce compact cities. Common planning tools for urban containment strategies include Urban Growth Boundaries and greenbelts. Yet such strategies may cause leapfrogging in urban development (Peeters et al., 2015; Vyn, 2012). Siedentop, Fina, and Krehl (2016) claim this undesirable phenomenon is likely to occur if growth restrictions are limited to core areas of city regions. In such cases, higher land prices may cause urbanization to spread to communities where no such regulations apply. Consequently, less dense suburban or exurban areas should be incorporated into growth control schemes.

In conjunction with urban containment strategies, polycentrism may limit urban sprawl through non-uniform spatial distribution of new urban developments (Camagni & Gibelli, 1997). A comparison of several French metropolitan areas shows that commuting distances are held down more effectively in polycentric agglomerations than in monocentric ones (Aguilera & Mignot, 2004). However, polycentric urban configurations are usually the outcome not of strategic planning but of market-driven dynamics. Fujita and Ogawa (1982) first demonstrated that, for a growing population, urban sub-centres emerge when transport costs exceed a critical threshold. This was confirmed by empirical investigations by McMillen and Smith (2003). Very early on, Christaller (1933) proposed a deductive explanation for the emergence of a hierarchy of sub-centres by linking service and commercial offers, market areas, and frequency of recourse to them. In Christaller's system, a hexagonal spatial distribution of central places ensures that consumers living in urban centres of a low hierarchical level can obtain goods and products they do not often need from one of the three higher-level neighbouring centres. Central place theory is often thought of as a descriptive scheme with no micro-economic foundation (Krugman, 1995). A crucial point for debate is price elasticity, which varies with distance in spatial price theory whereas central place theory assumes that the substitutability of goods and thus price elasticity is constant (Fittkau, 2004; Fujita & Thisse, 2002).

Other urban planning models have been proposed with a focus on the use of public transport networks and the attractiveness of intra-urban space, especially New Urbanism and Transport-Oriented Development (Calthorpe, 1993), and Concentrated Decentralization (Schwanen et al., 2004). In Transit-Oriented Development, transit nodes serve a predominant function in the urban system; they concentrate all kinds of facilities as well as public spaces offering green amenities. The urban system is organized hierarchically, combining urban centres of various functional levels, which is reminiscent of Christaller's central place system. In each urban centre, density decreases from the centre outwards. New Urbanism supplements the TOD planning strategy by focusing on intra-urban design. The traditional design of old centres of European cities is the benchmark. In the Netherlands, the development plans of a couple of new towns located in the Randstad, Holland and encompassing ancient villages provides a good illustration of the application of TOD and New Urbanism planning concepts. Almere is one of those two towns; it now has 196,290 inhabitants. Its urban area consists of three main centres. A railway station is located in each centre and is the starting point of a pedestrian boulevard with shops and restaurants on the ground level and apartments and multi-family housing in the upper storeys. The public bus system benefits from separate bus lanes. A segregated system of bike lanes generally passes under the roads. A green network is accessible for residents within a radius of 500 m and includes large forested and natural areas located a few minutes' bike-ride away (Beatley, 2012).

Greenways policy is another planning concept applied quite early on in northern European countries. Inspired by the spatial development of Berlin, which was linked to the construction of an efficient suburban railway, Eberstadt, Möhring, and Petersen (1910) suggested concentrating urban development in radial sectors along public transport routes. In-between these urbanized sectors, green sectors penetrate into the city providing residents with easy access to green areas. Similarly, the development plan proposed by Schmidt (1912) for the Ruhr region separates the different towns of the region by a network of green areas providing recreational areas. Another well-known example is Copenhagen's finger plan, which features development routes served by public transport and green lanes in-between these routes. The climatic relevance of greenways has been emphasized in many articles. As intra-urban parks and squares are mainly beneficial to microclimates (Kong, Yin, James, Hutyra, & He, 2014), they should ideally be connected to outlying rural zones via ventilation corridors providing cool air at night (Kuttler, 2011; Sachsen, Ketzler, Knörchen, & Schneider, 2013; von Haaren & Reich, 2006).

As pointed out by Bryant (2006), greenways can prevent landscape fragmentation and preserve biodiversity if they are not designed in a “piecemeal fashion”. Borgström, Elmqvist, Angelstam, and Alfsen-Norodom (2006) have suggested that the efficient management of green areas in an urban setting requires a multiscale strategy ranging from local up to regional level. Urban landscape management should ideally combine land-use policy with nature conservation across scales. Yet urban and ecological processes intertwine in a complex manner. Gaining in one characteristic on a given scale, e.g., meeting demand for housing by increasing housing density, comes partly at the expense of other characteristics, e.g. the local availability of open space and biodiversity on the regional scale (Wissen Hayek et al., 2015). Moreover, allowing wildlife into residential neighborhoods generates negative externalities, and it is unclear to what extent these externalities affect urban spatial dynamics (Toger, Malkinson, Benenson, & Czamanski, 2016). Soga et al. (2015) have also identified a potential conflict in the design of cities between the urban form that is most desirable for the direct protection of regional biodiversity (i.e. land sparing) and the form that best promotes people's experience of nature and so their support for its wider protection (i.e. land sharing).

In general, small ecological patches, long inter-patch distances, and lack of ecological connectivity make for poor conditions for preserving biodiversity (Collinge, 1996; Forman, 1995). On the scale of an urban region, urban sprawl may entail increased traffic induced by daily trips between the centre(s) and the outskirts and consequently a barrier effect of transport networks (Fu, Liu, Degloria, Dong, & Beazley, 2010; Gurrutxaga, Lozano, & Del Barrio, 2010). On a local scale, dense urban development may avert the loss of ecological habitats (Conway, 2009) but concomitantly increase the barrier effect of built areas (Aguilera, Valenzuela, & Botequilha-Leitão, 2011). Conversely, loose urban development increases landscape fragmentation but the barrier effect of built areas may be reduced if the urban boundary remains comparatively fuzzy (Czamanski et al., 2008) and/or if urban patterns are