A multifractal framework to create sustainable development scenarios for metropolitan areas

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1. Context

By improving car accessibility, motorization is at the origin of urban sprawl which affects rural areas. The new residential zones lie often far away from jobs, services and shopping facilities. As a consequence, the number and length of trips by car increase considerably over time. The environmental consequences like air and noise pollution, or weakening of natural areas have widely been discussed.

To counter this tendency, numerous scholars recommend a return to compact cities in order to limit urban sprawl and to favor the use of public transports. However, simply rejecting urban sprawl by promoting compact urban development turned out to be less efficient as expected. Households who choose their residence in periurban areas often flee urban density since they prefer living in individual houses surrounded by a garden and enjoying a green and calm environment and hence will reject densifying (Breheny 1997, Gordon and Richardson 1997). Additionally, individuals frequent nowadays a numerous places, like shopping centers, cultural centers, green amenities, sports grounds etc., which makes trip patterns complex. This increases the tendency of households to optimize their residential location with respect to different kinds of spatial amenities. As a consequence, the densification of residential zones may incite households to move to less dense areas (Schwanen et al. 2004).

Considering this, several authors suggest the restructuration of metropolitan areas by introducing subcenters close to residential areas in reference to a central place hierarchy. Such subcenters have to provide facilities for daily and weekly needs as well as offering jobs (Fouchier1995).Other planning concepts have been proposed to reduce car reliance and promoting the use of public transport and soft modes, like cycling or walking, in periurban areas. In particular the concept of Transit Oriented Development introduces a multi-level central place system where everyday facilities are present in all residential units whereas high level facilities are only located in high level centers, which can be reached by public transportation (Calthorpe1993).

In order to avoid weakening animals' habitat and threatening biodiversity induced by the fragmentation of open landscape, it seems also important to maintain a large-scaled well-connected network of greenways. The greenway strategy of Northern European countries, like Copenhagen's finger plan or the palm plan of Schumacher for Hamburg, is here interesting. Moreover these greenways provide fresh air flows in direction to the city centers.

2. Formal concept: multifractal urban development

In the frame of the research program PREDIT supported by the French Ministry for Sustainable Development we developed a formal multifractal planning concept, which is intrinsically multiscale. This formal planning concept ensures jointly:

- a good access to different types of daily frequented shopping and leisure facilities,
- reducing the travel length to access higher order facilities,
- respecting the diversity of social wishes through taking into account the fact that some households prefer living in low dense environment,
- avoiding urban leapfrogging that lengthens the distances to urban centers,
- preserving the connectivity of natural and agricultural areas.

The underlying logic of this formal concept is an iterative mapping procedure similar to that used for generating multifractal Sierpinski carpets (Frankhauser 2008). This mapping procedure allows generating a hierarchical system of central places that offer different levels of services and shopping facilities according to how often they are attended by households. Contrarily to the Christallers' model, however, the centers are not uniformly distributed in space, but concentrated close to transit stops. Besides the multifractal location of new residential areas, the formal concept sets also a principle to spatially distribute the population within a metropolitan area (Frankhauser 2012). This principle takes into account the decrease of population density for increasing distances from the main center(s). Hence urban centers of a given hierarchical level and located close to a higher-ranked center concentrate more population than urban centers of the same hierarchical level but located in the vicinity of lower-ranked centers. The location of facilities near transit stops and the development of residential areas close to these stops remind the concept of Transit Oriented Development.

The road network follows a strong hierarchical logic consisting of main axes, secondary axes etc. up to ways used for soft modes of transport.

Last but not least, the multifractal logic allows preserving a hierarchically and strongly connected system of agricultural and natural areas consisting of large patches, which are connected to a number of smaller patches. Urbanized areas and natural and agricultural areas are interrelated at all scales. Hence the quality of suburban lifestyle is preserved by a good accessibility to open landscape, but traffic flows are reduced and natural areas prevented from fragmentation. Moreover, this system of greenways helps improving local climate in urban centers.

3. Method

The application of the proposed formal concept is based on a multifractal decomposition method. The multifractal decomposition rules, completed by additional morphological and accessibility constraints, have been implemented into a GIS-based software application entitled Fractalopolis, which allows developing planning scenarios by starting from an existing urban pattern.

First a square-like zone is chosen which includes the existing urban pattern as well as the future development zones. Then a size ratio is fixed between a square covering the main center of the zone and smaller squares, which are placed on the most important subcenters. The number of subcenters can be chosen freely. Their position within the initially defined zone is also free; however, they must not intersect. For each of the squares, the multifractal decomposition is reiterated several times. The decomposition rules are completed by complementary morphological rules in order to avoid greenways to be cut by new urban developments. At the final decomposition step, developed zones and development zones are identified and located on the map. The mapping procedure also takes into account the "rural" zones lying outside of the development zones.

The population model allows affecting a higher amount of population to the central places i.e. to have higher densities in these squares. In order to ensure some flexibility, the population distribution parameters can be modified when passing from one iteration step to the next one. Moreover, a small amount of population can be affected to the "rural" zones.

Besides these strong rules, other soft rules take into account the accessibility to services, shops and leisure areas (forests, parks, sports fields, playgrounds) (Tannier et al. 2012). Services and facilities are classified into different levels corresponding to their frequency of attendance. Each service and facility level is affected to a hierarchical central place level defined by iteration. A specific aggregation procedure allows identifying commercial clusters consisting of shops lying close together by taking account the variety of the offer. On this basis, the accessibility to the different kind of services is measured for each urban center. Notice here that Fractalopolis takes into account car accessibility as well as the accessibility by public transportation systems or soft modes. Accessibility measures are then summarized using a multiscale rating aggregation.

The creation of an urban development scenario consists in moving the squares identified through the multifractal decomposition in order to choose the position, which allows a good compromise between the different criteria taken into account (amount of population and accessibility to services and facilities). After simulation, the scenario can be evaluated regarding global accessibility indicators integrated into Fractalopolis software.

An example of the creation of urban development scenarios with Fractalopolis is given in the case of the agglomeration of Besançon, a medium-sized agglomeration in the East of France.

4. Conclusion

The presentation describes a coherent multiscale formal concept for planning purposes based on fractal geometry. This concept allows taking into account social wishes as well as environmental objectives, in particular the reduction of car dependence and the preservation of the connectivity of green areas. It also integrates existing planning concepts like greenway preservation, Transit-Oriented Development, and central place theory. Thanks to the introduction of multifractal rules, the proposed concept, although being quantitative and strictly formalized, is more flexible and less reductive than existing planning concepts. It allows the creation of a large variety of urban development scenarios with respect to different initial spatial configurations. The software application Fractalopolis supports efficiently the conception and the evaluation of urban development developing scenarios and to evaluate them according to predefined criteria.

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