A multi-Scale (Multi-Fractal) approach for a systemic planning strategy from a regional to an architectural scale

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reviewed paper

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1 ABSTRACT

A sustainable and sustaining planning strategy is globally important for metropolitan areas. Sustainable planning addresses the development of strategies to reduce the use of resources, increase economic efficiency and improve integration of social aspects (e.g. pedestrian friendly environments, well balanced public and private transport modes, efficient street networks; land use, movement economy; access for all to jobs, retail, services, healthcare, culture, and leisure). In order to reduce urban sprawl, numerous authors recommend going back to the concept of compact cities. However, policies favoring the compact city concept turned out to be less efficient than expected. Indeed, a large number of households choosing these areas reject urban density since they prefer living in individual houses surrounded by a garden and enjoy a green and calm environment.

Hence, instead of rejecting urban sprawl it seems more reasonable to find solutions for better managing the dynamic aspects of cities, in order to reduce traffic costs and pollution, and to avoid undermining natural and agricultural resources. Frankhauser (2004) first proposed reflections onto what extent planning concepts referring to fractal geometry could be of interest for reducing negative impacts of urban sprawl. In a recent research project, financed by the French Ministry of Ecology, Energy, Sustainable Development and Sea in the framework of the PREDIT research program, a planning concept was developed concretizing this basic idea. A planning support system was developed which allows testing the efficiency of the concept (Frankhauser et al 2007, 2008).

Let us recall that fractal geometry is based on a hierarchical principle, which has been to be an essential element of urban structures. The hierarchical ordering principle is a cascade of similar elements on different levels of detail: house, block, quarter, district - or: path, residential road, side street, main road, freeway, and highway. According to Read (Read 2000), different scales of hierarchy are distinguished by scales of mobility, and are designed to convey different scales of movement. The spatio-functional pattern describes everyday space use and movement. The above-mentioned fundamental systematic of the built environment requires a structural-analytical approach on all interwoven scales (global to local) for future developments (regional, urban and architectural). The multi-scale logic allows the articulation of residential areas and leisure areas across scales, introducing different levels of service centres according to their frequency of use. These service centres are localized in the nodes of the transportation system thus improving their accessibility with respect to residential areas.

This paper addresses a further development of this theoretical model, extending it to be a holistic, comprehensive system. The idea of an "urban" hierarchy (street network, green areas, building blocks, building heights, and urban centres), generated as a multi-scale urban planning model for developing scenarios (regional, urban, architectural scale - 2D & 3D) for metropolitan areas, allows the implementation of highly efficient, functional and sustainable transport networks, masterplans and mass models.

The comprehensive system presented here can not only simulate growth scenarios but also assesses the quality of an existing area for consolidation and revitalisation (masterplan, urban fringe) or to identify areas with low overall access for a sustainable negative growth scenario (inverse model for shrinking cities and quarters).

2 INTRODUCTION

The basic principles of the built environment are the relationships between physical elements and between physical elements and dynamic components. These can be described as "spatial packing" (Franck 2005). They aggregate on different scales through interactions of dense and separated spaces created by fluctuations. Hence, two major architectural definitions emerge as the basis of cities' spatial nature: buildings and movement channels.

The constitution of space (e.g. the aspect of accessibility and centrality) is determined by its spatial organisation. The term organisation refers to Hillier's terminology *spatial configuration* (Hillier 1996) - a set of relationships. Configuration can be analysed and understood on all scales - from regional planning to urban planning and design, and further to architecture itself. The geometric pattern of spatial configuration of dense and separated spaces is accomplished by a system of piling and accessibility. Every space connects other spaces as well as itself. This scheme repeats itself on all scales to such an extend that we can speak of it as a fractal structure (fragmented, self-similar, multi-scale). Research has shown that a hierarchically structured ordering principle of urban agglomeration are self-organising and exists everywhere where people have to share limited amount of space. Self-organisation structures the space in traditional European towns as well as in synthetically ones (Batty and Longley 1994, Frankhauser 1994, Frankhauser 2008, Franck 2005).

The characteristic of a city (fractal structure) demands a structure-analytical approach on all interacting scales (regional scale, urban scale, and architectural scale). The idea of hierarchy as a foundation for developing an urban growth model allows an efficient usage of space by using the law of all living systems. The combination of configuration and accessibility (individual transport, public transport) combined with plot sizes, free spaces, building volumes and building heights (population density) puts the built environment in the context of ecological and socio-economic aspects. Regional and urban models which take these factors in consideration represent a holistic strategy for sustainable and sustaining planning. Visionary scenarios demand an interdisciplinary approach from architecture, regional planning and geography. In the course of urban and regional development in Europe over the last decade, sustainable strategies have become the focal point of planning strategies on all scales.

2.1 Sustainable and Sustaining Development

The Brundtland Report of the United Nations defines sustainability as "[…] development that meets the needs of the present without comprising the ability of future generations to meet their own needs". The report also comments on the availability of non- renewable resources "as their use reduces the stock availability for future generations. […] But this does not mean that such resources should not be used. In general, the rate of depletion should take into account the criticality of the resource, the availability of technologies for minimizing depletion, and the likelihood of substitutes being available." (Brundtland Report, Our Common Future, Chapter II, 1987).

Transport and network strategies play a key role in this context as high accessibility (pedestrians, public and individual transport) is a major aspect in reducing the use of resources (fossil fuels) and at the same time minimizing a community's carbon foot print of which, in the developed world, 13% is contributed by transport an 7% by car manufacture. The figure below shows the main elements which make up the total of a person's carbon footprint in the developed world.

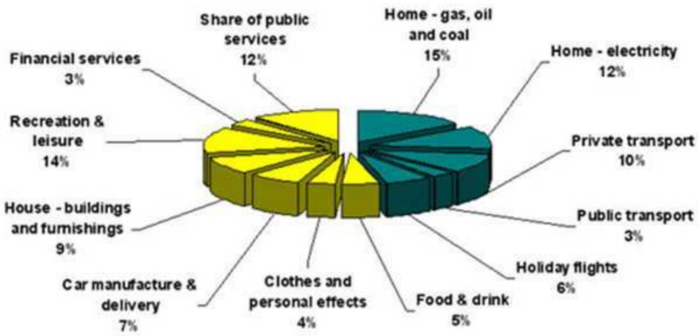

Fig. 1: A carbon footprint is made up of the primary foot print (blue slices) and the secondary foot print (yellow slices). The primary footprint is a measure of direct emissions of CO_2 from the burning of fossils (a person is in direct control of these). The secondary foot print is a measure of indirect emissions of CO_2 from the whole life circle of products (www.uhv.edu, accessed 2010).

Highly efficient transport and network strategies support users when using the car to produce less carbon dioxide, and give the opportunity to use public transport on more occasions or simply walk or ride the bicycle to the aimed location. Therefore, sustainable planning strategies not only influence the usage pattern (primary carbon foot print), but also reduce production and consumption (secondary carbon foot print), and the depletion of no-renewable resources.

To make a built environment work sustainable we also need to take into account the aspect of density. This complex dynamic between density and transport infrastructure must not be a reactive process. The choice of transport mode influences land use, this, in turn, influences the transport mode (individual transport, public transport, pedestrian). In general, sustainable transport strategies can only function on the basis of an efficient network with high accessibility, connectivity, centrality and potential through movement (preferred for pedestrians within an urban system). Further, on different scales the whole network needs to be distinguished into a pedestrian network, bicycle network, private vehicle network, bus and rail network, freight network, transit network, and green network. For all these networks the same rules apply as to the system as a whole.

The reduction of consumption of resources does not only take into consideration the three areas of sustainable development - ecology, economy and social aspects - but also allows cities and regions to act independently from international and political decisions.

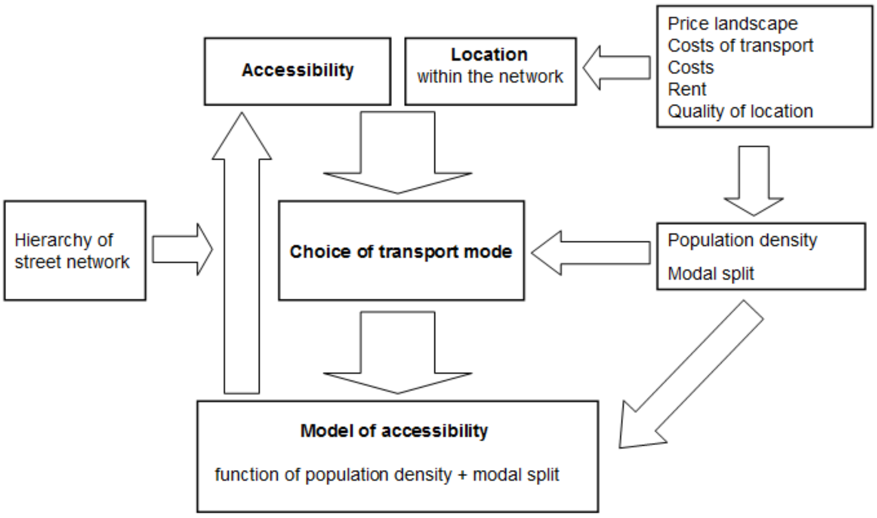

Fig. 3: Interdependency of accessibility and socio-economic factors (Czerkauer 2009)

Let us recall that since the critique of Newman and Kenworthy (1989), many authors have seen in the compact city, a solution for reducing individual transport (Dantzig et Saaty 1973). Experience shows however, that policies favoring the compact city turn out to be less efficient than expected, not least, because the affected population has a critical view of a high-density approach (Garcia et Riera 2003, Remy 1994). In reality, surveys made evident that a moderate to high percentage of people prefer households close to green areas, low density developments and quiet living areas which are important factors in location choice (eg. Guénaëlle Gault / Laurence Bedeau 2007). Hence it seems difficult to convince such households to come back to density (e.g. Owens 1992, Breheny 1997, Garcia et Riera 2003). Schwanen et al. (2004) argue that households tend to minimize the distance or the travel time not only with respect to work, as also shown by Brun and Fagnani (1994) and McDowell (1997), but they optimize their residential location with respect to different kinds of spatial amenities that they frequent as well. This holds, e.g., for commercial areas (Lerman 1976) or even leisure areas (Guo and Bhat 2002). It reinforces the risk that households relocate to a lower-density environment, which risks increasing the costs of housing, traffic congestion and reduces the accessibility of leisure areas (Breheny 1997).

3 MULTI-SCALE PLANNING MODEL

3.1 Theory and Methodology

3.1.1 The Basic Ideas

As pointed out, simple models referring to monocentrism and densification of residential areas seem not to be realistic alternatives for managing urban sprawl. The concept presented by this paper refers to a hierarchical organization of metropolitan areas. The hierarchical structure of an agglomeration, developed based on social and economic interaction and interdependency between the locations (e.g. villages), has been investigated in urban geography for a long time. These observations served Christaller as foundation for his Central Place Theory (Christaller 1933). He was able to explain the hierarchy of centres, namely, that the catchment areas of different services are dependent on how often the services are used. That is why the services for everyday life (e.g. supermarket) are close to housing, whereas weekly or monthly services require bigger catchment areas. By this characteristic services can be distinguished, leading to a centre-hierarchy (global centre, intermediate centre, local centre) with diverse catchment areas (Figure 3). However, Christaller's theory is constrained to only concerning a functional hierarchy, not reflecting the spatial structure. This explains why in Christaller's theory locations are evenly distributed across the spatial surface plane. The accessibility of such a distribution is disadvantageous for several reasons. On one hand it demands a pseudo-homogeneous traffic infrastructure, on the other hand all of the remaining free spaces are approximately the same size.

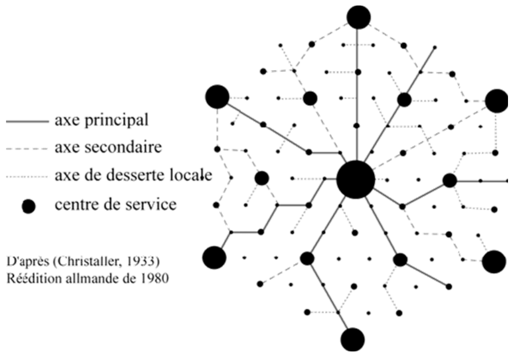

Figure 4: Christaller's net of central places including traffic infrastructure (Christaller 1933, reprint 1980)

In the framework of the PREDIT research program, financed by the French Ministry of Ecology, Energy, Sustainable Development and Sea, a planning concept was developed at the ThéMA institute (Université de Franche-Comté) featuring Christaller's centre-hierarchy, in which spatial distributions are linked to the hierarchy of the traffic infrastructure, equating to a multi-fractal structure (Frankhauser et al. 2007, 2008).

In doing so, the agglomerations are pushed closer to the main traffic axes, decreasing distances and increasing accessibility from and to services. The structured services in Christaller's centre-hierarchy are localised in traffic nodes and have different sized catchment areas. The designed traffic system, using a radio-concentric principle, offers high accessibility with regard to its functional impact (global centre, intermediate centre, local centre). This axes-oriented concept concentrates and lumps traffic flows and therefore allows public transport to be prioritised. In addition, a hierarchically organised system of linked free spaces allows small green areas to be obtained next to housing estates as well as nature resorts and vast woodlands. Therefore, the green corridor principle is expanded as not only non-built-up surfaces and corridors are kept free, but also the interweavement of urban space and free space on all scales becomes the leading concept. On purpose, the urban edge and agglomeration fringes are not chamfered, but linked to green spaces on all scales in order to reduce traffic flow and minimize travel distance to leisure areas.

The linked spatial system of free spaces and agglomeration avoids uncontrolled and splinter developments. Ergo, this concept addresses all postulations of sustainability without propagandising a mono-centric, compact city model.

The concept presented allows the integration of the above described needs reducing environmental pollution at the same time. In summary, the model is a further development of Ebenezer Howard's garden city in combination with Christaller's Central Place Theory. Green areas are prioritised (grey wedges - figure far right).

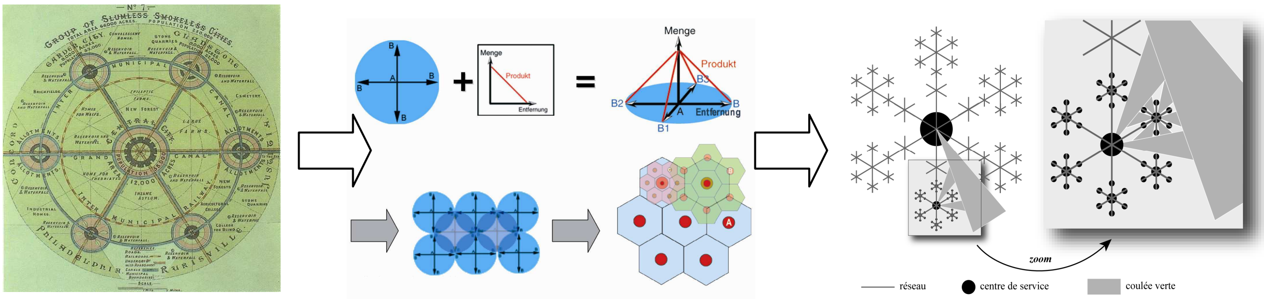

Fig. 5: Theoretical model derivation – far left: Ebenezer Howard's garden city (Wikipedia 2009), middle: Christaller's model (Czerkauer 2007), far right: Frankhauser's fractal model (Frankhauser et al 2007)

An important feature of the concept consists of distinguishing different levels of services according to their frequency of use. For the reduction of pollution, it seems crucial to localize services for daily needs next to residential areas. Services or malls frequented once a week can be placed at a greater distance. Hence, according to frequency of use, the concept distinguishes at least three levels of services and commerce. The goal is to develop planning scenarios respecting the multiscale logic of the concept. For this aim, a given situation is first analysed. Then, predefined standards are applied for developing planning scenarios. The standards refer to the following topics:

- the multi-scale soil occupation index, which corresponds to fractal dimension measures;
- morphological aspects like the articulation of built-up space and open landscape across scales;
- the accessibility of urban amenities (retail centers, services) and green amenities (leisure areas);
- the potential of city-size development (rank-size distribution of cities);
- natural and environmental constraints or recommendations.

These rules are implemented in a planning support system allowing the conception of scenarios for future development in an interactive way starting from a cartographic representation of the considered area.

In the framework of the French research project, a particular method, fractal decomposition, and a software package (MUP-city) has been developed which intergrates fractal, morphological and accessibility rules for services (Frankhauser et al 2007, 2008; Tannier et al 2010). This tool is particularly adapted for working on an urban scale (see below). In the framework of the project Fractalopolis, it is intended that an application concept that allows us to go even further will be developed, taking into account the regional level and including the 3rd dimension, i.e. the height of buildings.

3.1.2 Regional Model

Before applying the regional model, a region's qualitative and quantitative generic (growth) potential is identified by geometry, demographic data sets and morphology. From the present situation of a region, a variety of geometric and demographic analyses (agglomeration sizes, agglomeration hierarchies, cluster, population, distances and many others) are carried out to generate the model's scaling factors (reduction factors for a multi-fractal approach) for the best fit (structure-function model).

Based on an algorithm (including buffers for non-potential zones such as water areas, natural parks, etc.) the model will then be adjusted to the existing network and agglomerations. The simulated scenarios undergo an assessment (accessibility, services, etc.) to identify the advantages and disadvantages of each scenario.

In particular, the interface between existing urban morphology and new potential development (from the simulation) is an interesting challenge, as we have to deal with a non-linear urban fringe, with underlying characteristics of self-organisation paired with former planning and building interventions. The strategy of merging simulated and existing networks is of major importance as the urban development and extension has to be continuous, without any noticeable phase transition, neither for the urban structure nor for the residents of the area. Standards have to be developed corresponding to a city's population, ranking different levels of central places.

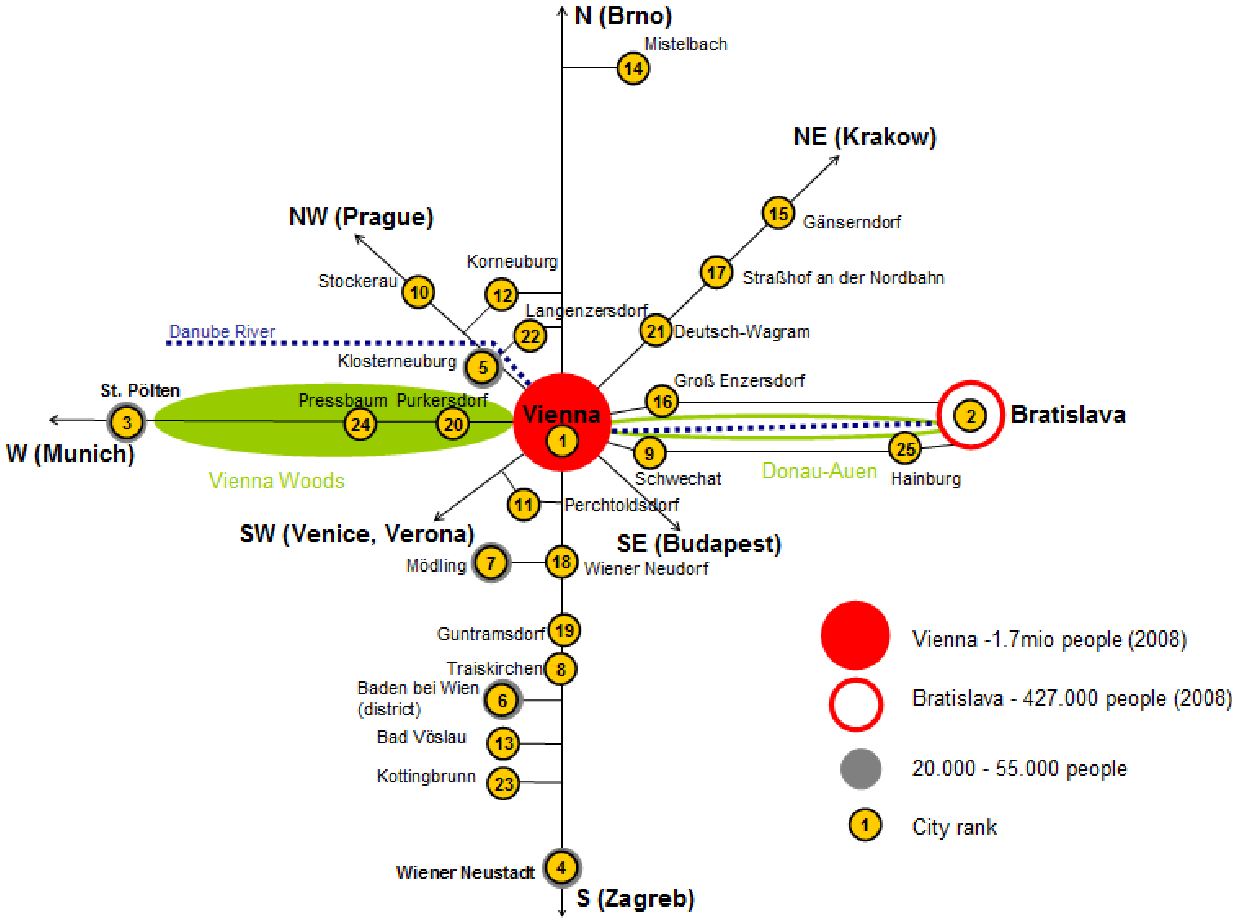

Figure 6: Schemata - City ranking by population of the Vienna-Bratislava metropolitan region (Czerkauer 2010)

In the framework of the fractalopolis-project, it is intended that a decision support system will be developed, which allows the evaluation of development scenarios on the regional scale. With this tool, rules and standards will be implemented referring to the situation on the regional scale. However, we must be aware that on this scale the logic will be different from that of the urban scale, since the pre-existing settlement network comes into play. Indeed, it is easier to develop sites (or not) within a city than to build new cities or urban districts.

3.1.3 Urban Model

In order to apply the planning concept on an urban scale the method of "fractal decomposition" was developed, which is similar to that of grid analysis currently used in fractal analysis (Mandelbrot 1983). The area under consideration is covered by a grid of square-like cells, their size being large in the first step (e.g. 540 m). We identify the "occupied" cells, i.e. those containing buildings. In the next step, each of these cells is cut into nine smaller squares, i.e. the size of the squares is a third of the initial one (fig. 7). In each of the occupied cells identified, we look again for those containing buildings. Of course, since our cells are smaller, we will again find empty ones within the occupied larger cells of the previous step. Hence the total ratio of occupied cells decreases from one step to the other, which corresponds to a decrease in intensity. This procedure is reiterated up to the size of the cells corresponding approximately to that of plots (e.g. 20 m). One of the decomposition steps for a real world pattern is illustrated in figure 8.

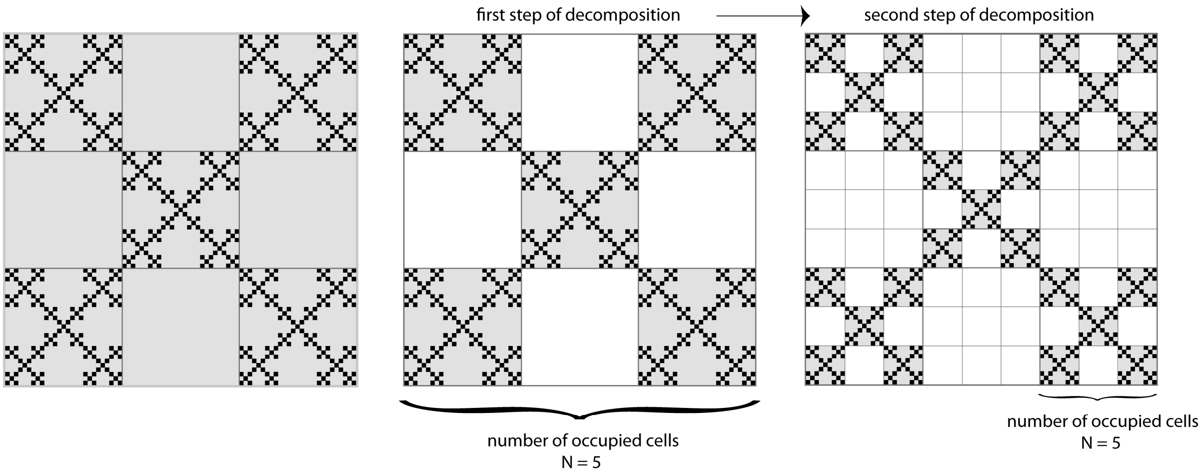

Figure 7: Fractal planning scheme (Frankhauser et al 2008)

In order to avoid fragmentation for urbanized areas as well as for open landscape, the concept demands topological rules of interconnectedness of free space and built up surfaces and a multi-scale hierarchical configuration.

On an urban scale, accessibility to jobs, services, leisure, etc. is of major importance. For a sustainable settlement, service clusters and facilities have to function on different levels (daily, weekly, monthly) indicating a certain catchment area (150-250m, 400-600m, 2-6km, 4-10km radius) linked to a catchment population. Hence, MUP-city evaluates the overall accessibility of each cell with regard to the existing network as well as accessibility to diverse services (Tannier et al 2010). Based on these criteria, MUP-city provides, at each decomposition step, global information for each cell about its suitability for future development. This is shown for one decomposition step in figure 8. By selecting a specific selected cell (surrounded in blue) detailed information are shown in the box. We must be aware that the number of cells which can be urbanized is constrained by fractal law. With this in mind, the larger meshes surrounded by a dark yellow line are introduced. Each of these larger meshes contains nine small meshes but, according to the chosen fractal law only Nmax of these cells can be urbanized. This holds for all meshes and for all decomposition steps.

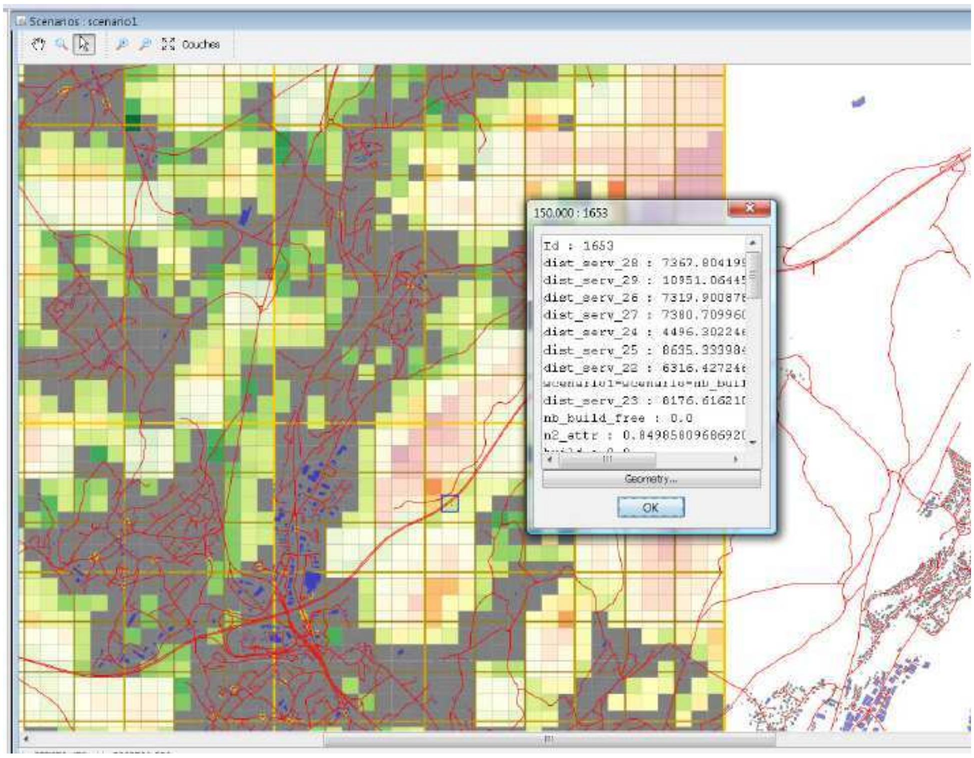

Figure 8: Example MUP-city: Evaluating a scenario based on the accessibility to services

This model not only simulates growth potential, but can also be used as an inverse model to identify areas with low accessibility for consolidation, revitalisation and demolition (e.g. shrinking cities and quarters).

In the present research context a more generalized approach has been developed. Instead of using a unique size of elements at each scale - the square-like meshes of a grid - we introduce the possibility to combine different sizes of squares, according to a multi-fractal logic. This multi-fractal decomposition allows the development of a more architectural approach, taking into account the different sizes of buildings. From a fractal point of view, it is then possible to have a kind of gradient from the centre to the periphery, where larger buildings tend to be localized in the centre. However, fractality allows buildings of different size to be combined in the different zones, thus avoiding monotony. Figure 9 illustrates this possibility, which shows, moreover, how in a multi-fractal approach, built-up areas and free spaces may be combined with regard to the different hierarchy level (centre, sub-centre). From this strategic multi-fractal decomposition, a masterplan is generated. The planning support system will take into account such tools.

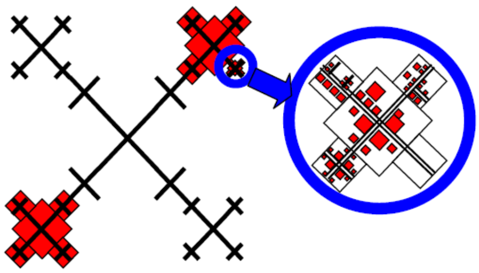

Figure 9: Strategic multi-fractal urban planning scheme (Frankhauser et al. 2005)

3.1.4 Architectural Model

Intensity of land use can be established by a) the morphology of built-up areas and b) a building height scheme (mass model). Intensity of land use regulates a plot’s/block’s/quarter’s/agglomeration’s population rank within a system (local to global, neighbourhood to region) and therefore has an impact on important economic and social forces.

A multi-fractal approach allows us not only to modify the size of buildings but also to take into account the intensity of land use, i.e. introducing the height of buildings. Hence, we can expect to develop a highly efficient distribution of built-up mass throughout the urban system, which can then link to a well balanced application of economic theories such as industrial location theories and their impacts on the built environment (centrality, accessibility, rent, landscape prise, capital, and costs). Figure 10 illustrates by means of a rather simple multi-fractal model how the intensity of land use can be modelled with a multi-fractal concept. We may imagine that the bars correspond to the spatial distribution of land use intensity along a street axis going from the city centre to the periphery. Figure 11 shows how different land use intensity factors (p1, p2 etc.) may be applied to different meshes of a grid for which we have chosen, for simplicity, the same size of meshes. These factors correspond to different heights. In further steps of decomposition, these factors are combined and hence a great diversity of intensity factors occur, respecting, however, the hierarchical logic which appears in figure 10 where only two intensity factors are combined.

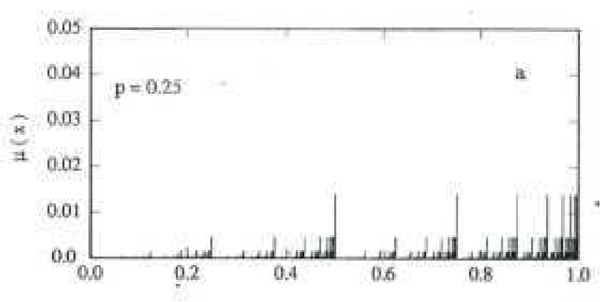

Figure10: A binominal multiplicative process is used for global height development (Feder 1988)

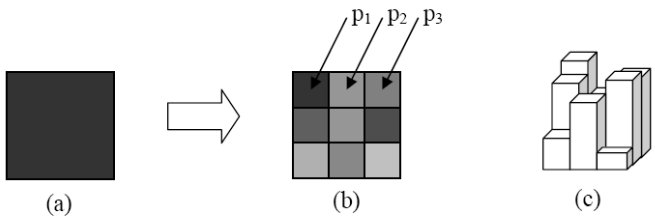

Figure 11: Schematic local height development based on a fractal operation (Frankhauser 2009)

The masterplan serves as the basis for an architectural mass model (3D). Based on its indicators (accessibility, centre hierarchy, closeness to services), each plot (of a cell) is multiplied by a certain height-factor retrieved from the present situation as well as demographic forecasts of the area under scrutiny. The planning support system will take into account this enlarged concept.

4 CONCLUSION

The multi-scale expert system supports regional planners, town planners and architects in developing sustainable scenarios (2D & 3D) for potential developments.

In addition, the multi-scale approach is used to control the intensity and density of land use and therefore economic forces. The new invention of this expert system is not only to use a multi-fractal approach for 3D modelling, but also to create stable and therefore sustainable and sustaining scenarios. This is only possible by addressing consistency through all scales based on functional geometric aspects:

- regional scale: agglomeration classification, street network including green and water areas, topography (2D)
- urban scale: masterplanning (2D + 3D)
- architectural scale: mass model (3D)

Only with an understanding of the interrelation of all interwoven scales on different zoom levels can thriving and sustainable communities, cities and regions be developed. According to requirements, the model is flexible enough to implement individual strategies in greater detail, without destroying the holistic and overall strategy. The expert system addresses the approach of new urbanism: walkability, connectivity, mixed-used-density, mixed housing, increased density where useful, green transportation and sustainability.

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