UNIVERSITÉ DE FRANCHE-COMTÉ
École Doctorale, Langages, Espaces, Temps, Societes
Laboratoire ThéMA - Théoriser et Modéliser pour Aménager
(UMR 6049) CNRS

Thèse en vue de l’obtention du titre de docteur en
GÉOGRAPHIE et AMÉNAGEMENT DES TERRITOIRES

Strategic Planning for the Development of Sustainable Metropolitan Areas using a Multi-Scale Decision Support System – The Vienna Case –

Présentée et soutenue publiquement par

Claudia Hedwig CZERKAUER-YAMU

Le 21 décembre 2012

Sous la direction de Pierre FRANKHAUSER,
professeur de géographie

Devant un jury composé de:

Denise PUMAIN	Professeur, Université Paris I - Sorbonne	Examinateur
Bernd SCHOLL	Professeur, École polytechnique fédérale de Zurich	Examinateur
Gérard BRUN	Ministère de l‘Écologie, du Développement durable et de l‘Énergie	Examinateur
Cécile TANNIER	Chargée de recherche CNRS, Université de Franche-Comté	Examinateur
Isabelle THOMAS	Professeur, Université catholique de Louvain	Rapporteur
Andreas VOIGT	Professeur, Université technologique de Vienne	Rapporteur
Pierre FRANKHAUSER	Professeur, Université de Franche-Comté	Directeur de thèse

Strategic Planning for the Development of Sustainable Metropolitan Areas using a Multi-Scale Decision Support System – The Vienna Case –

Reform the *environment*,
stop trying to reform people.
They will reform themselves
if the environment is right.
(Buckminster Fuller 1960s)

Fractal geometry will make you
see everything differently […].
You risk the loss of your childhood vision
of clouds, forests, galaxies, leaves,
feathers, flowers, rocks, […]
and much else beside.
Never again will your interpretation
of these things be quite the same.
(Michael Barnsley 1988)

I am indebted to many people who supported this research with their expertise, feedback, and discussions.
I would like to thank my supervisor, Pierre Frankhauser, who has not only sharpened my vista of the world in the sense of Humboldt's ideal, but has also allowed me a new holistic and systemic insight into planning questions. Particular thanks also go to Andreas Voigt for providing me with a stimulating research environment. I owe both a great deal – this research work was only possible with their support and expertise.

I would especially like to thank Mme. Isabelle Thomas and M. Andreas Voigt for agreeing to be the rapporteurs of this research.
I thank Mme. Denise Pumain, M. Gérard Brun, Mme. Cécile Tannier and M. Bernd Scholl for participating in my jury and as examiners.

For programming the software I owe a debt of thanks to Gilles Vuidel of ThéMA. The scientific works of Cécile Tannier and discussions on accessibility rules were important for the formalisation of the model.
Special thanks also go to my colleagues Thomas Brus and Fabian Dembski of Vienna University of Technology for their support. I further thank my PhD fellows Kawtar Najib and Stephan T.P. Kamps for their friendly cooperation.

Finally, I want to express my deepest thanks and appreciation to my family, who always tread the paths with me. Thank you.

GENERAL INTRODUCTION

PART ONE: NATURAL PHENOMENA and THEIR APPLICATION

PART TWO: SUSTAINABILITY

CHAPTER EIGHT: CASE STUDY

CHAPTER NINE: CONCLUSION

GENERAL INTRODUCTION

Global and Local Challenges

The world's total population is constantly growing. According to the United Nations (2011) the world's population is projected to surpass 9 billion people by 2050 and exceed 10 billion in 2100. Mostly, the population of developing countries will enlarge[1]. More developed countries see a minimal change[2] (United Nations Report 2011: xiv).

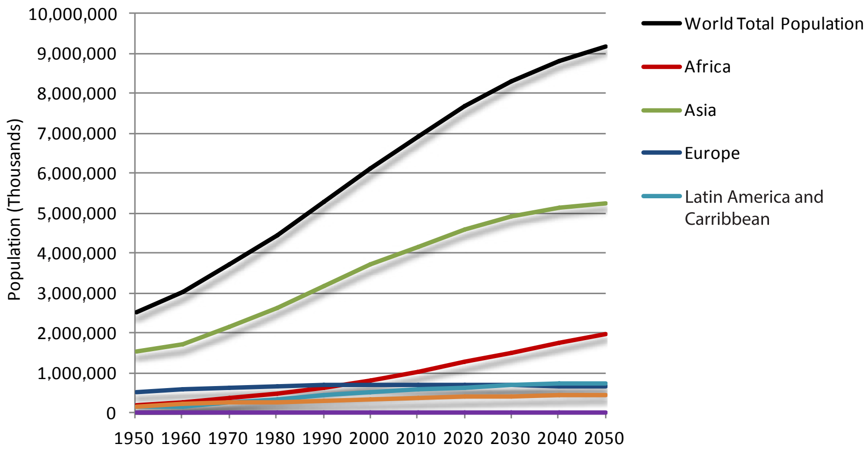


Figure I: Estimated and projected population by major areas 1950-2050.

Asia will remain the most populous major area in the world during the 21st century, but Africa will gain ground as its population more than triples.

(data: World Urbanisation Prospect - The 2007 Revision Population Database; accessed 2012-02-10)

Even if Europe's population does not grow dramatically, global population growth, increasing constraints on resources (if not substitutable) and environmental pollution (air and water pollution, lack of infrastructure, homelessness, unemployment, and traffic congestion) call for sustainable metropolitan regions worldwide.

It is not only global population growth that will give rise to new strategies in spatial planning in order to avoid energy and cost intensive settlements, but also the constantly growing "urban population". We are confronted with an influx of population into urban hubs (megapolis[3], megacity[4]). Girardet is referring to this problem when he says that the human species is turning itself into an *urban species.* Larger cities, rather than towns and villages are becoming our primary habitat (Girardet 1996). He thus addresses the inherently modern problem of a non-efficient regional distribution of settlements on a wide range of scales. It has an illicit effect when a prime city is anomalously

[1] A rise from 5.7 billion in 2011 to 8 billion in 2050 and 8.8 billion in 2100 is projected (United Nations 2011)

[2] Forecasted from 1.24 billion in 2011 to 1.34 billion in 2100, with a decline to 1.1 billion without projected net migration of 2.2 million persons annually from 2011 to 2050 and 0.7. million from 2050 to 2100 (United Nations 2011)

United Nations 2011:
In 2011, 60 per cent of the world population lived in Asia and 15 per cent in Africa. Until the early 1990s, Europe had been the second most populous region of the world, but in 1996 the population of Africa surpassed that of Europe for the first time. Africa's population is growing very rapidly, at 2.3 per cent per year from 2010-2015, a rate more than double that of Asia's population (1.0 per cent per year). The population of Africa first surpassed one billion in 2009 and is expected to add another billion in just 35 years (by 2044).

[3] *Megapolis (megalopolis, megaregion)*: Extensive urbanised zones with amorphous dispersal[...]. A megapolis is typically defined as a chain of roughly adjacent metropolitan areas (cf. Spengler 1918; Mumford 1938). Interlocking economic systems, shared natural resources and ecosystems, and common transportation systems link these population centers together.

Gabler Wirtschaftslexikon, Springer online, www.america2050.org 2012-10-07

Girardet 1996

bigger in size than cities and towns in their embedded regional context ("vacuum effect", depletion of hinterland, cf. Prigogine 1980). Why? The size of cities has an economic impact on them as they depend on energy to power their industries, households and transport systems (mainly fossil fuel and nuclear power). Nowadays megacities are longer part of their local environment; due to globalisation they have become part of the wider world. As a result, transport costs and energy use have risen enormously.

[4] *Megacity*
Economic and political centre with subglobal surplus meaning and a focal point of information and transport. According to the United Nations, a megacity has a minimum of 8 m inhabitants. A megacity has to be distinguished from the term *megalopolis*, a regional concentration of several large towns and major cities.

Gabler Wirtschaftslexikon, Springer online, www.wirtschaftslexikon.gabler.de 2012-10-07

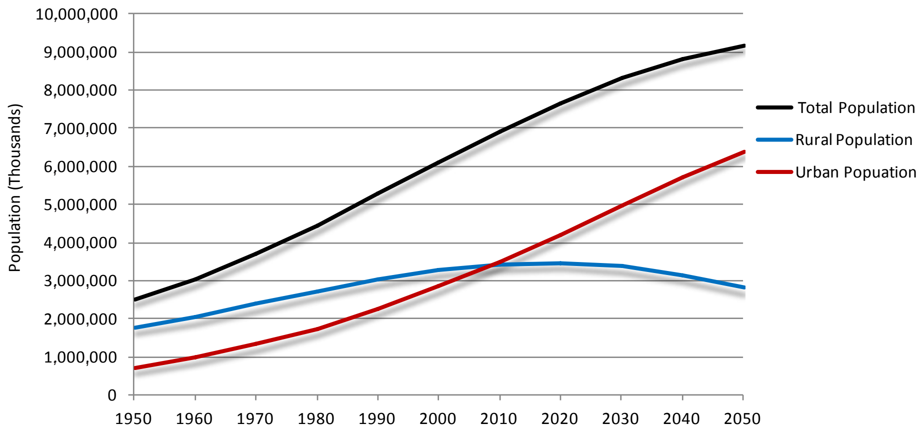


Figure II: Urban versus rural population worldwide: trend 1950-2050
(data: World Urbanisation Prospect - The 2007 Revision Population Database; accessed 2012-02-10)

Further, petrol consumption is affected by the urban pattern (morphology, road network) and land use (Kenworthy and Newman 1989) of modern cities, which are becoming more and more unaffordable in terms of energy consumption (Voigt 2011). The malaise of post-modern American cities in this context is well known, and nowadays traditional European cities can no longer hide behind Newman and Kenworthy analysis either.

Prigogine 1980

Kenworthy, Newman 1989

Voigt 2011

The hyberbolic curve (Figure III) demonstrates that with more and more effort in planning strategies the use of gasoline can be reduced. Especially for American cities the possible change (tolerance range) is large, whereas for Asian cities the possible change compared to the input effort is small. European cities are a compromise between the two extremes, which feeds into to the debate on environmental and social sustainability. In this context, most Asian cities are environmentally sustainable but socially not; American cities in this context are mostly socially sustainable, but not environmentally.

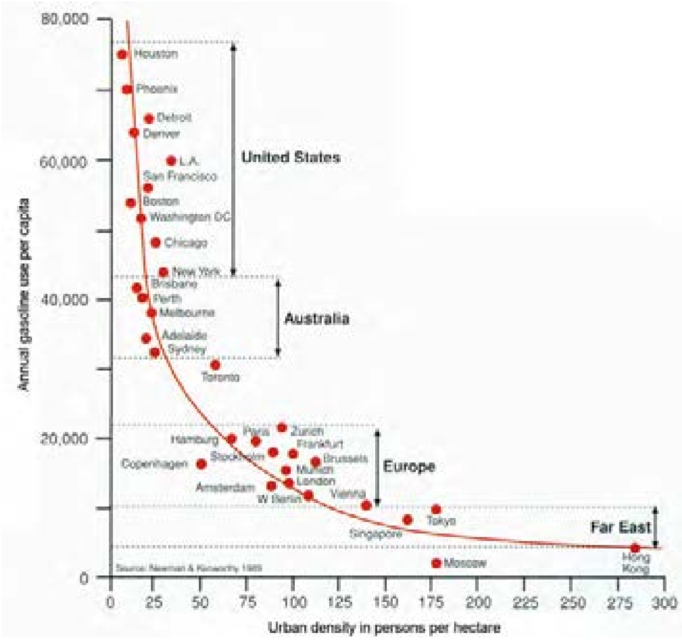


Figure III: Gasoline use per capita (gallons[5]) versus population density - adjusted to US MJ 1980 (from Newman and Kenworthy 1989, revised version from Andrew Right Associates in:Towards an Urban Renaissance 1999:103).

[5] 1 U.S. gallon = 3.79 litres

Kenworthy and Newman 1989

A further twofold problem arises: the dispersal of population (cost of land and the wish for single-family houses[6]) with simultaneous centralisation of services and faciltites[7], according to Stead leads to a number of impacts on transport and the environment. Many of the impacts on transport have resulted in a vicious circle of decline in which land use changes have increased the need to travel and discouraged more sustainable modes. At the same time, high rates of travel and car ownership have led to unsustainable patterns of development (Stead, 2000, 32). Beyond environmental problems, we also have to face the social problems thus created. Society splits into those who can afford and those who cannot (a car, fuel, education, etc.) and all important spheres of life are affected – the economic, the ecological and the socio-cultural.

[6] Perception de la densité et des formes d'habitat, Observatoire de la villes, TNS Sofres 2007.

[7] This results from statistics collected for England and Wales between 1971 and 1991. However, this trend can be found in various degrees of intensity in European towns and cities.

Stead 2000

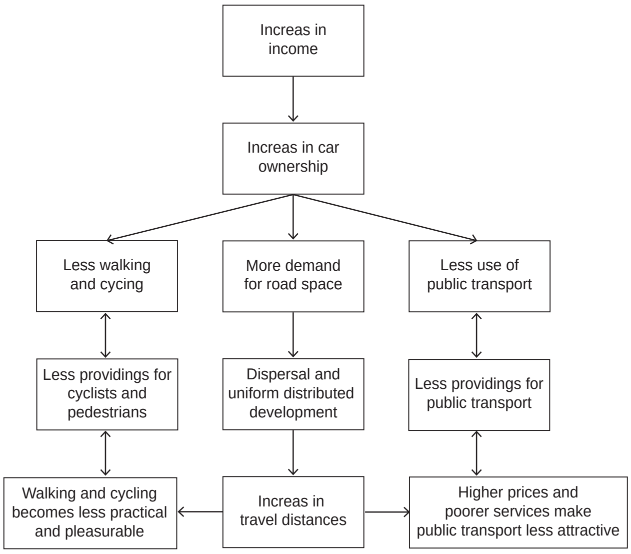


Figure IV: Driving forces for land use trends (Czerkauer-Yamu 2012; adapted from Royal Town Planning Insitute 1991 and Pharoah 1992 in: Barton 2000: 33)

As a result of the gasoline and energy consumption (growth in transport energy consumption, industry and commerce, domestic sector) we are facing global pollution that contributes to the greenhouse effect and further global warming. The most important greenhouse gas is carbon dioxide (CO_2). Beside nitrogen oxides (NO_x) emissions of which are mainly reduced due to catalytic converters for cars, particulates remain a major problem for the urban microclimate. Nowadays they mostly originate from road transport. In this context, the domestic sector has decreased due to the change from coal to gas and other sustainable technologies such as wind, water and solar power (Stead 2002).

Barton 2000

Stead 2002

In summary, there are seven main constraints planning has to deal with:

- Worldwide population growth
- Growing urban population; smaller rural population
- Unaffordable urban patterns in terms of energy and costs
- Greenhouse effect and climate change
- Dispersal of population with simultaneous centralisation of services and facilities, causing longer travel distances
- Uniform distribution of agglomerations due to a carbonerfiourious society (urban sprawl)
- Space consumption by transport networks

Objectives of Research addressing a Sustainable Planning Strategy

From a world-wide perspective globalisation produces different needs and demands on the part of every individual. In medias res, this is exactly where today's problem lies - the various infrastructures are inefficient and serve the needs of neither people nor economies. This links us back to the above mentioned challenges we are facing. Nowadays cities are confronted with urban growth, shrinking (the "donut city"), consolidation and management of agglomerations on all scales.

Thus, 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 create *sustainable and sustaining regions and cities*, we agree with Calthorpe and Fulton's idea (2001) that a regional order has to work more as a constellation, focusing neither towards or away from a city, as the latter leads to great problems such as those that can be observed in megacities. The concept is not a new one, though. In order to create more justice in supply and living conditions for the urban population, the concept of a *regional town* was developed: New Towns, Villes Nouvelles, Stockholm's Finger Plan, the Marcelius Plan.

Calthorpe, Fulton 2001

Villes Nouvelles, for example, were planned as overspill towns for Paris with places of employment in order to reduce commuting, whereas the Finger Plan contains and buffer new agglomerations and infrustructure such as railways and roads. The suburbs developed around main railway stations to ensure high accessibility for all citizens; see als TOD.

Let us recall that *cities are complex system*s; therefore every inconsistency on a smaller scale influences the bigger scale and vice versa (see also multi-level interactions; Pumain 2006, Johnson 2007, Salingaros 2005). Thus, problems such as urban sprawl must be addressed both on a regional and local scale in order to make a metropolitan system work.

Pumain 2006

Johnson 2007

Salingaros 2005

Splinter development (e.g. urban sprawl) involves damage to nature and generation of an increasing volume of traffic (these are the main criticisms following a study by Newman and Kenworthy 1989 on the relationship between settlement density and energy consumption). Interestingly, the *overly* compact

Newman, Kenworthy 1989

and leisure areas, or changes of residence due to a favouring of sites that lie farther away from the centre than the inhabitants' current places of residence. Households not only consume urban amenities integrated into densely populated areas, but also aspire to have access to green and leisure areas. Schwanen et al. (2004) showed that households usually optimize their residential choice with respect to accessibility to various types of amenities, which is inherently linked to the frequentation rate of these amenities (daily, weekly, monthly, and occasional) (c.f. spatial practice of people; Hägerstrand 1953, 1967). Moreover, on an urban scale, over-compactness causes ecological problems such as a lack of green wedges for supplying the city with fresh air (urban microclimate).

Schwanen et al. 2004

Hägerstrand 1953, 1967

With reference to the stated problems, two central research questions are defined as the basis for this research project:

Q1: How can we find a solution for managing dispersed development which marries the twin elements of green and built-up space in a highly efficient (non-homogeneous) manner from a region-wide to an neighbourhood scale?

Q1a: How can we fulfill a highly efficient management of urban sprawl by at the same time incorporating dynamic aspects of a city in a sustainable way?

Q2: How can we minimize traffic costs and emissions by taking into account a highly efficient management of urban sprawl linked to dynamic aspects of a city in a sustainable way?

For the research questions following spatial charactaristics as frame conditions are incorporated:

- The homogeneous distribution of agglomerations creates urban sprawl in metropolitan areas;
- People wish to live in close proximity to service and leisure facilities (including green areas). Fractal geometry allows us to marry the contradictory elements of built-up zones and green areas;
- View of open landscape
- Reduction of car dependency and fuel consuming strategies in the context of location choice.

With reference to the stated problems and research questions this leads us to explore to what extent fractal geometry (as the geometry of all living systems) may be drawn upon for resolving the spatial antagonism of compactness and urban sprawl (interweaving of various spatial systems; cf. biophilic planning).

Fractal geometry is thus the central theoretical and methodological foundation underlying this research. Following Frankhauser 2008 and others, this is predicated on the finding that since "urban space is founded on the principle of fractal geometry, it seems interesting to explore to what extent fractal geometry may be drawn upon for solving the spatial antagonism of compactness and urban sprawl.

Frankhauser 2008

Objectives

Corresponding to the stated problems and research questions we consequently defines three objectives to be pursued in the course of the research:

1. To find a solution for managing dispersed development which marries the twin elements of green and built-up space in a highly efficient manner. This solution also needs to incorporate dynamic aspects of a city as well as minimizing traffic costs and emissions and avoiding the appropriation of agricultural land.

2. The development of a simulation tool (software) which is able to support government and planners in developing sustainable and sustaining scenarios for transport and masterplanning for metropolitan areas and cities.

3. The outline of a decision support system a planning support system (strategic masterplanning with Space Syntax).

In the context of strategic planning the model (decision support system Fractalopolis) and the planning support system faciliates the idea of *informed decision-making*.

Method(ology)

As already mentioned above, the principles of fractal geometry constitute the central theoretical and methodological foundation underlying the research project. The evidence for the application of these principles in the context of urban structure and urban development is derived from morphological analyses of urban structures and growth patterns in which a “fractal structural principle“ can be discerned.

The key assumptions regarding the use of fractal geometry in the context of urban planning and development can be set out as follows: Fractality corresponds to underlying optimization criteria, as is supposed to be the case in natural structures. Fractal surfaces seem to be optimal for spatial systems requiring a high articulation between subsystems. Then, hierarchical structures seem very efficient. This holds true for many natural networks.

Hence we posit a “multi-scale approach to urban planning“ for discussion and systematically link this back to the objective and appropriate selection, formulation and further development of “planning approaches“ (cf. inter alia Schönwandt-Voigt 2005), which are of particular importance in connection with the solving of complex spatial problems.

Schönwandt, Voigt 2005

Furthermore, we integrate multi-scale planning approaches into the contemporary discourse on strategic planning. According to Scholl (2005), strategies can be viewed as signposts into the future, and the research foci of this research make precise reference to this point. Robust methodological innovations integrated into strategies and planning approaches are conducive to solving complex spatial problems.

Scholl 2005

Decision Support System Fractalopolis

The herein developed decision support system *"Fractalopolis" – a cell based multi-scale multi-fractal approac*h – allows an articulation of green areas and urbanised space based on the underlying hierarchical concept, thus providing leisure areas in the neighbourhood of urbanised space but avoiding fragmentation of open landscape. In addition, this concept introduces hierarchy of centres and sub-centres on a metropolitan scale, allowing accessibility to daily, weekly, monthly and occasionally frequented facilities to be improved. Larger distances are accepted for less frequented amenities.

Based on the spatial characteristics, the concept incorporates following principles:

- Development along main transit axes (public and individual transport) with urban nodes on all major scales (see also TOD);
- High accessibility to services within their catchment areas (frequentation);
- High accessibility to leisure and green areas within their catchment areas (frequentation);
- Implementation of a spatial configuration which integrates high physical and visual accessibility;
- Consistent articulation of open space and built-up zones across all scales; maintenance of the landscape diversity and a system of green open space as well as agricultural areas;
- Prevention of fragmentation of agglomerations;
- Restricted areas for landscape landscapes with protected status.

Accordingly, *Fractalopolis* incorporates following standards in order to respond to nowadays challenges:

	Challenge	*Rule*
Morphological standards	Multi-scale intensity of occupation	Fractal iteration rule
	No fragmentation of construction	Neighbourhood rules
	Environmental quality	Lacunarity rule including landscape view
Accessibility standards	Access to services and facilties of different levels	Distance rules on the network; diversity rules, cluster rules
	Access to leisure and sports faciltiesof different levels	Distance rules on the network; diversity rules
	Access to open green space of different levels	Distance rule on the network; size rule (ANGSt)
Development standards	Central place hierarchy	Distance rules on the network; diversity rules
Preservation standards	Avoid fragmentation of green areas; protected zones	Neighbourhood rules
	Respect hierarchy of green areas	Fractal logic
Density standards	Moderate density according to intensity of occupation	Ponderation rule (population)

Table I: Standards and rule set for the decision support system Fractalopolis.

The *decision support system* can be linked with other GIS and cell-based analyses to form a *planning support system* (PSS). In addition, the approach offers 3D visualizations.

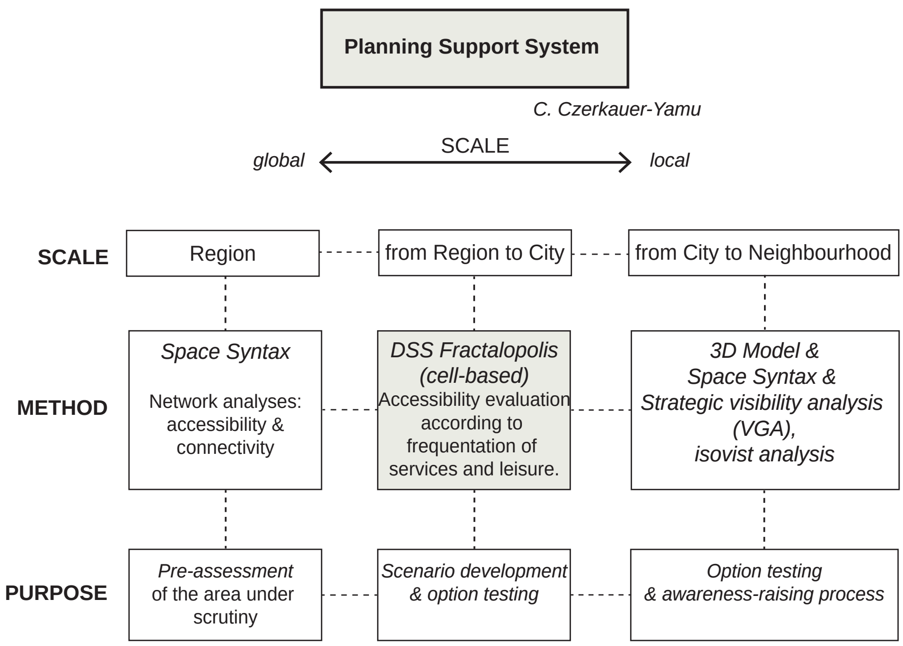


Diagram I: From the decision support system to a planning support system.

For scenario development processes the herein developed decision support system is used in a top-down manner, but giving at the same time the possibility to readjust scenarios in a bottom-up process. Fractalopolis software allows to develop scenarios according to following planning types: new development, inner development, extension of existing developments.

The generic process for a cell based multi-scale fractal modelling is as follows:

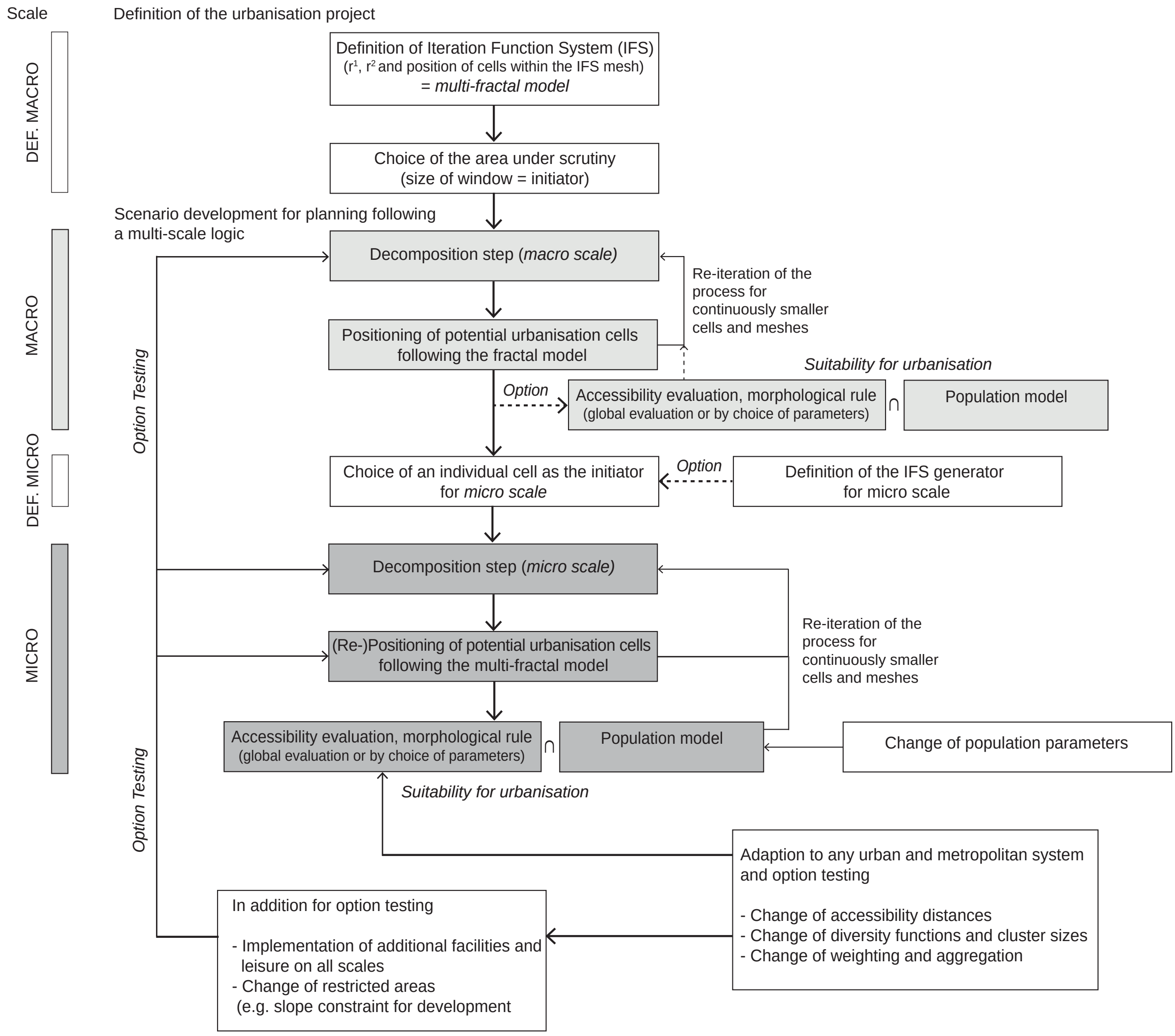


Diagram II: Generic process flow chart for the multi-scale decision support system.

From a Decision Support System to a Planning Support System

Fractalopolis, the multi-scale decision support system (DSS) is the basis for the strategic planning approach; combined with other GIS based analyses it becomes part of a planning support system (PSS) in the context of PSS research (cf. Geertman 2013, for identification of a PSS-related research agendas see Nevodic-Budic 2000).

Geertman 2013

Nevodic-Budic 2000

The combination of developed and presented herein methods follows the idea of spatial models that are consistent across scales with defined levels of details (LoD) corresponding to the respective scale. In addition the method and analyses set of *Space Syntax, isovist, serial vision* and *3D visualization* is used to answer questions which are not covered by Fractalopolis.

- *Identifying the centre for the starting point of Fractalopolis.*
  Space Syntax centrality analyses offers to identify on a global scale a centre hierarchy which in turn supports to define the starting point for the decision support system Fractalopolis.

- *Further, the regional Space Syntax analysis (potential through movement) identifies local centres for potential development.*

- *Network adjustments from a planning point of view*
  On a neighbourhood scale the graph-theoretical approach evaluates the network itself, which Fractalopolis does not (cell-based approach). By doing this an optimisation process for the network and the potential additional services and facilities can be identified. Fractalopolis software is based on the idea of accessibility, but does not take into account the role of the network itself (network segment analysis).

- *Optimisation evaluation*
  By adding network links and services based on the Space Syntax analyses, the Fractalopolis cell (chosen neighbourhood area for the network analyses with Space Syntax) can be re-evaluated and potential optimisation identified.

- *Strategic visibility, isovists and serial vision*
  Fractalopolis does not include the idea of wayfinding and orientation based on visibility aspects of the built environment. Thus, these analyses support to position possible developments (buildings) in such a way that it supports the approach of simple and direct links (see master planning principles). The visual graph analyses identifies potential places for stationary activities (e.g. facilities like a café with outdoor seating). Route and wayfinding based on visibility is further linked to the constuction of mental maps (perceptual information).

- *3D visualization*

  3D models and visualizations are commonly used to overcome lack of communication between different parties (e.g. laypeople, general public and planners) as they can translate convential analyses and drawings into a format that is more easily understood. Thus, a 3D visualization often works as as a communication tool and can be seen as a supporting tool for a decision-making process (cf. Roupé, Johansson 2010).

Roupé, Johansson 2010

The generic process of the *Planning Support System* is as follows:

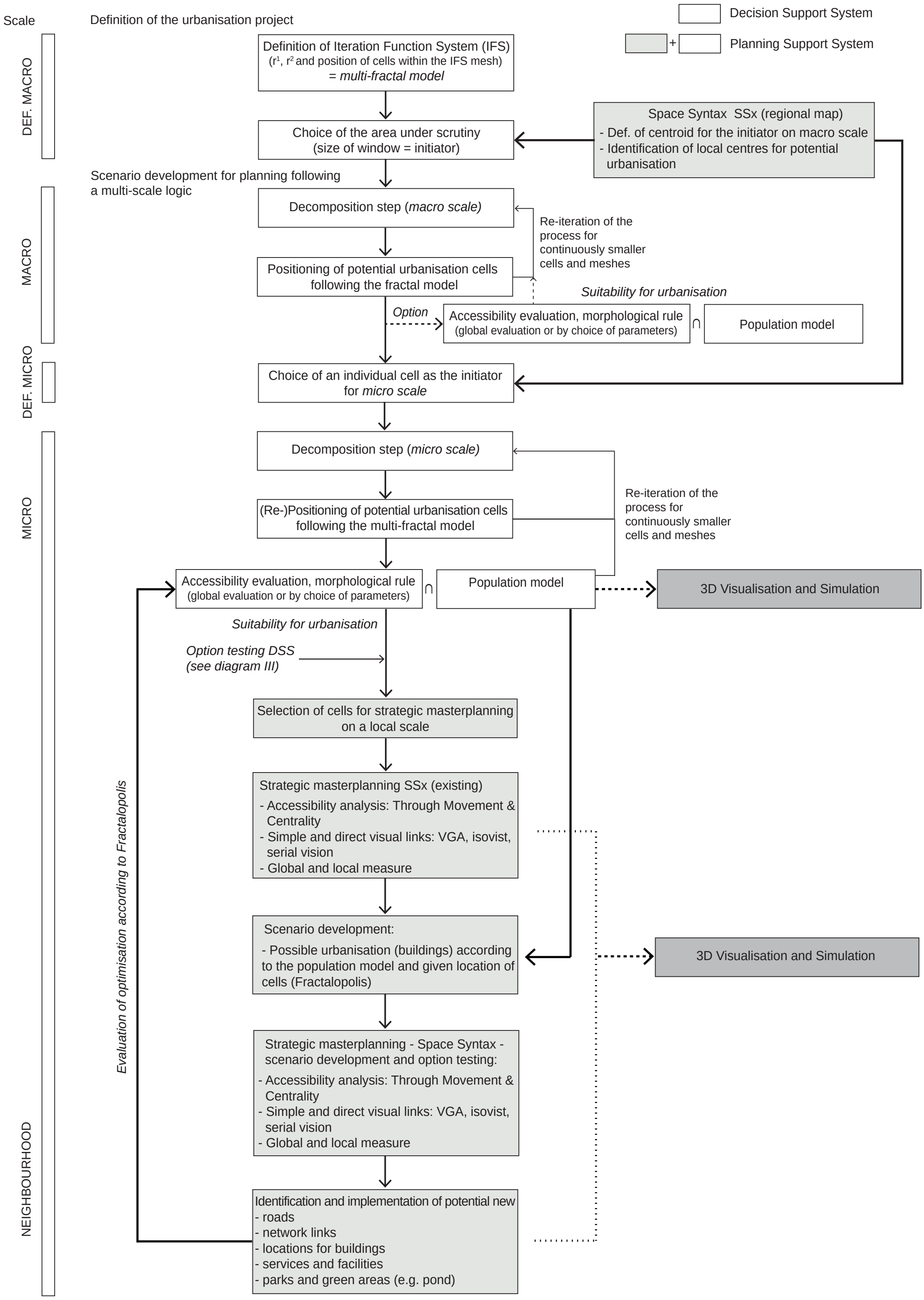


Diagram III: Generic process flow chart for the multi-scale planning support system.

The herein developed decision support system is inspired by MUP-City (Tannier, Frankhauser 2010, 2012) and was developed within the framework of the research project "Vilmodes". Below, the research cooperations are diagramed.

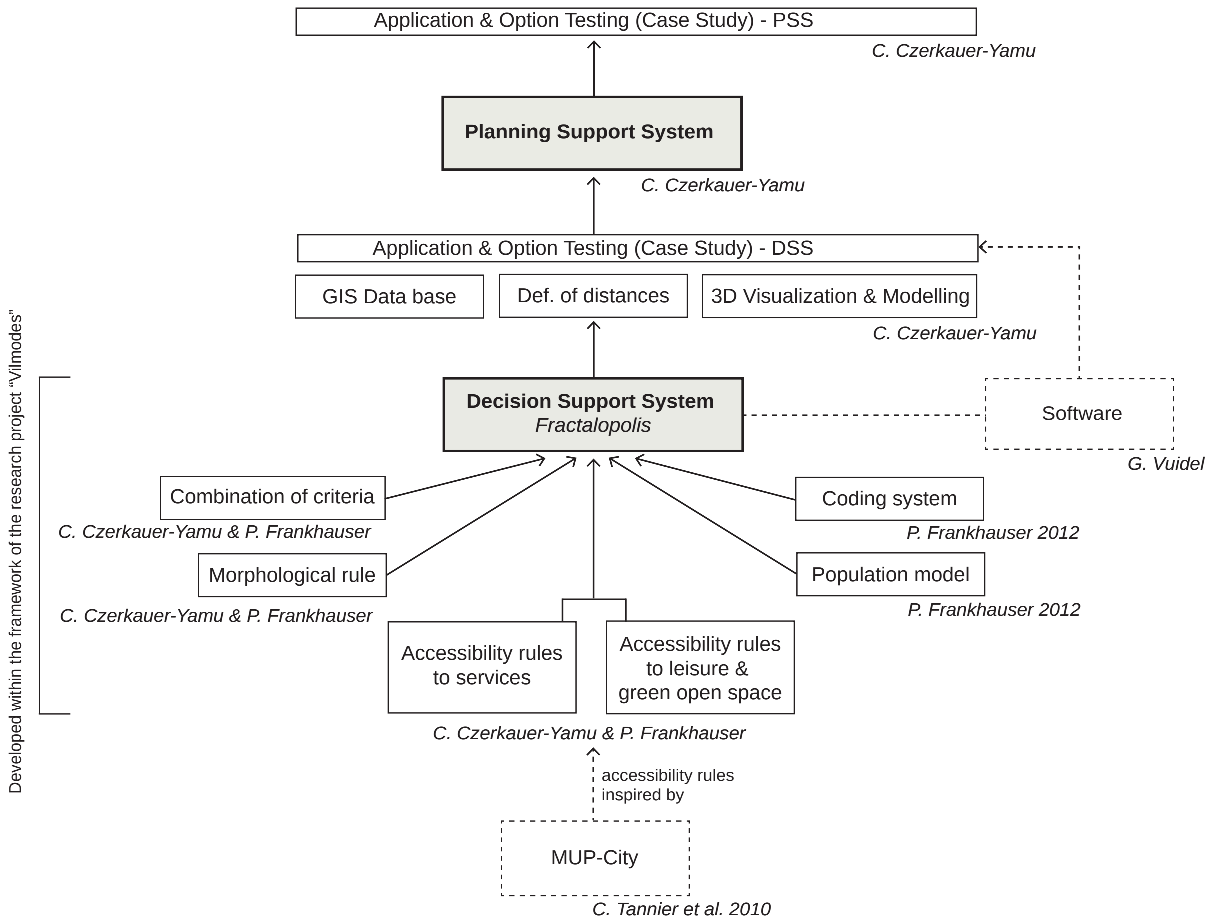


Diagram IV: Research cooperations

Structure of the Work based on the Objectives of Research

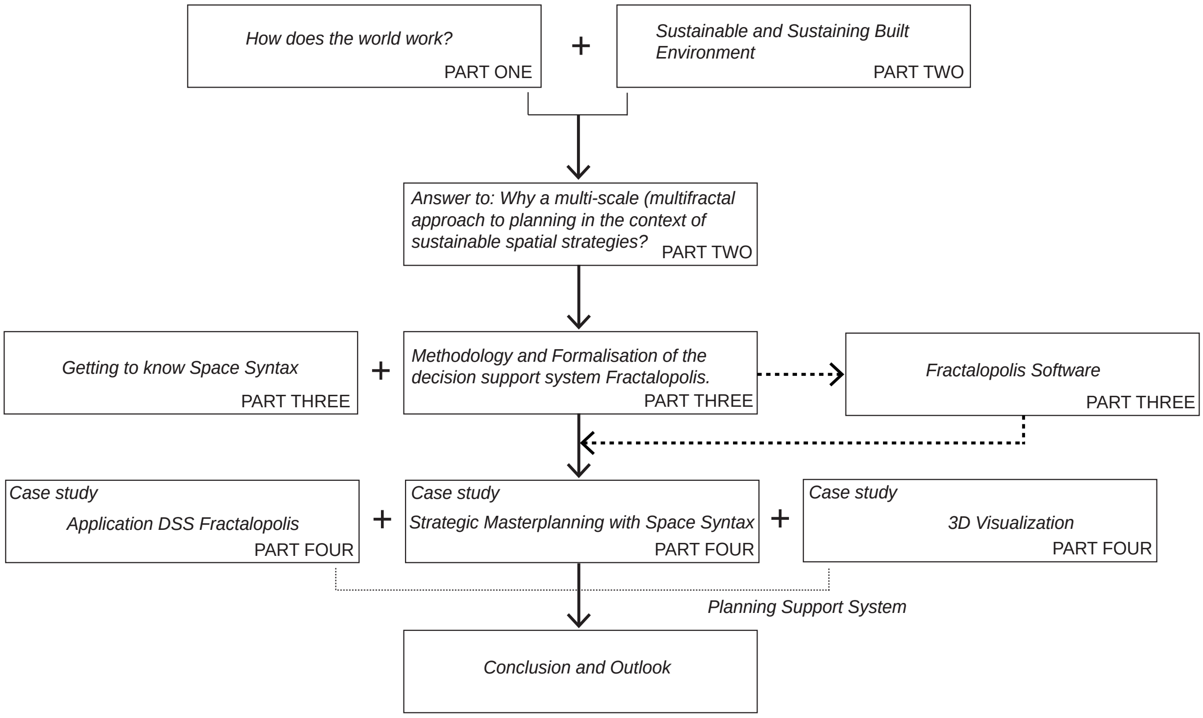


Diagram V: The golden thread

Part One: Natural Phenomena and Their Application

The built environment can be described as complex as its geographical structure is dynamically produced through a high number of different societal spatial interactions. Generally speaking, natural and social systems are usually organized into several levels which are linked by interaction (multi-level interactions, cf. Pumain 2006). Thus, when dealing with the built environment we face complex spatial problems. In order to find adequate strategies for approaching and solving these problems we need to understand the built environment in all its complexity. Hence, we need to try to answer the question “*How does the world work?*” in order to be capable of approaching complex problems.

This part discusses the subject areas of complexity, hierarchy, emergence and self-organisation with associated sub-topics (bell curves, power laws, small world). We will additionally proof take into account the fact that human visual perception of the built environment is also subject to a fractal decoding logic.

Part Two: Towards a Sustainable and Sustaining Built Environment

In part two we identify sustainable and sustaining strategies for the built environment in order to link the two approaches (*nature's strategy and sustainable strategies*) combined in the decision support system (DSS) Fractalopolis. We also discuss the problem of urban sprawl and outline an approach to a spatial solution for metropolitan areas.

Further we answer the question "*Why a multi-scale multi-fractal approach for a sustainable and sustaining planning strategy?*", underpinning our arguments with ideas, thoughts and conclusions from parts one and two. From this discussion we derive important features for the DSS.

Part Three: Spatial Modelling and Simulation

This part deals with the approach, methodology and formalization of the decision support system, as well as explaining how it can be linked to other sets of analyses to become part of a spatial planning support system (PSS) in the context of a strategic planning approach from a metropolitan to an urban scale (global to local). The additional methods used for the PSS are also described in this part. Finally, the added value of a 3D visualization and a 3D virtual reality (VR) environment is briefly introduced.

Part Four: Case Study, Scenario Development and Option Testing

In part four we deal with the application, scenario development and option testing (from a metropolitan to an urban neighbourhood scale) of the DSS Fractalopolis, including 3D visualizations (and modelling) for two selected planning scenarios. Further, the analyses derived from the decision support system are linked to other GIS analyses forming a PSS.

The case study is divided into four major parts:

- Historical context of forecasted population growth of the Vienna-Bratislava metropolitan region;
- Pre-assessment of the metropolitan area (global scale)
- Scenario development and option testing incl. 3D visualization (global to local scale)
- Strategic masterplanning incl. 3D visualization (local scale)

The Vienna-Bratislava metropolitan region was selected as the test case as it offers the two capital cities in close proximity. This region is an urban and economic core of the Centrope region and has been strongly influenced by the restructuring of the former Eastern Bloc countries.

PART ONE:

NATURAL PHENOMENA and THEIR APPLICATION

About this Part

The built environment can be described as complex as its geographical structure is dynamically produced through societal spatial interactions. Generally speaking, natural and social systems are usually organised into several levels which are linked by interaction (multi-level interactions, cf. Pumain 2006). In many cases, the various levels are linked by a hierarchical logic (Auerbach 1913; Zipf 1949; Mandelbrot 1977; Batty 1994, 2006; Pumain 1997, 2006; Frankhauser 1994; Gaibax 1999; Thomas 2004, 2007, 2008).
Thus, when dealing with the built environment we face complex problems. In order to find adequate strategies for approaching and solving these problems, we need to understand the built environment in all its complexity. Hence, we need to try to answer the question "*How does the world work?*" in order to be capable of approaching complex problems.

Pumain 2006

Auerbach 1913

Zipf 1949

Mandelbrot 1977

Batty 1994, 2006

Pumain 1997, 2006

Frankhauser 1994

Gaibax 1999

Thomas 2004, 2007, 2008

This leads us to discuss the ideas of complexity and hierarchy, small world, bell curves and power laws (including scale-free networks and Zipf's law) in the context of their appearance in society (Granovetter's approach 1973) and the built environment (cf. Humpert's morphology of footpaths).
The hierarchical structures observed in social systems, such as e.g. street networks, administrations, etc. are in part planned in accordance with optimization criteria as outlined in Christaller's Central Place theory. In many cases, however, they ultimately result from self-organisation processes which are also at work in the city system. Following on from this, we look at the concepts developed for describing the organisation process of nature - emergence and self-organisation - and link them to bottom-up and top-down processes and a discussion of natural fractals and mathematical fractals. Here we look at Alan Turing's ideas (1952) as the cornerstone of self-organisation – genotype and phenotype – which attempt to explain the beginning of shape with all its intricacies (but do not fully resolve the problem). In this context we briefly discuss Haken (1982, 1986), Weidlich et al. (1986), Prigogine's non-equilibrium thermodynamics (1980) and Krugman's idea of a self-organising economy for cities (1996).

Granovetter 1973

Humpert 1997

Turing 1952

Haken 1982, 1986

Reiner, Munz, Haag,
Weidlich 1986

Prigogine 1980

Krugman 1996

In a next step we look at cities and metropolitan areas having scaling properties as found in fractals. Herein we distinguish two kinds of fractals: uni-fractals and multi-fractals. We link multi-fractals to the idea of urban growth along radial axes as identified in historically evolved cities and towns – the so-called deformed wheel – and present some initial thoughts as to how fractals can support sustainable planning strategies.

Hilbersheimer 1957

Batty 1994

Haller 1968

From the built-up area we go one step further and look at street and road networks as fractal entities. Herein we discuss Hilbersheimer's development plan for Seattle (1957) and Batty's idea (1994) of a space-filling curve for traffic systems, as well as Haller's "Totale Stadt" (1968), and link the hierarchy of a road network to simultaneously parallel and hierarchical processes. The fractal dimension D and the Lipschitz-Hölder exponent are presented.

Moving from cities to human visual perception of the built environment, we answer the questions "*How do we perceive the world?"* and "*Does visual perception also follow an inherent pattern like a power law distribution or Gaussian distribution?*" Based on the perception of Japanese Zen gardens we can prove that fractals are a natural visual pattern for decoding the built environment (cf. Van Tonder, Lyons 2005). Not only do we decode natural phenomena using a fractal approach, but also artificial objects.

Van Tonder, Lyons 2005

Cooper, Oskrochi 2008

Building on the discussion of visual perception we identify what makes the built environment aesthetically pleasing in the context of street vistas (cf. Cooper & Oskrochi 2008), showing how the fractal dimension D can support information related to the perception of urban quality and visual variety.

CHAPTE ONE:
COMPLEXITY, BELL CURVES AND POWER LAWS

1.1. Small World

In 1973 Mark Granovetter in his paper *The Strength of Weak Ties* proposed a new way of linking micro and macro levels of sociological theory: the translation of small-scale interactions into large-scale patterns and its rebound effect. Granovetter suggests that when it comes to interaction with the outside world, our weak social ties (acquaintances) are more important than strong friendship ones.

Granovetter 1973

As Granovetter explains it, this means that whatever is to be diffused can reach a larger number of people, and traverse greater social distance (i.e. path length), when passing through weak ties rather than strong. If someone passes on a rumour to all his close friends, and they do likewise, many will hear the rumour a second and third time, since those linked by strong ties tend to share friends. The rumour moving through strong ties is much more likely to be limited to a few cliques (Granovetter 1973, 1366) whereas weak ties provide and obtain information from all kind of sources. He postulates a theory of internally highly connected small-scale clusters (cf. Humpert 1997) with a few links to other small-scale clusters. Highly connected clusters form dense networks, weak ties less dense ones. He unifies patterns of social networks on a micro and macro scale (approach to consistency through scales)[8].

Humpert 1997

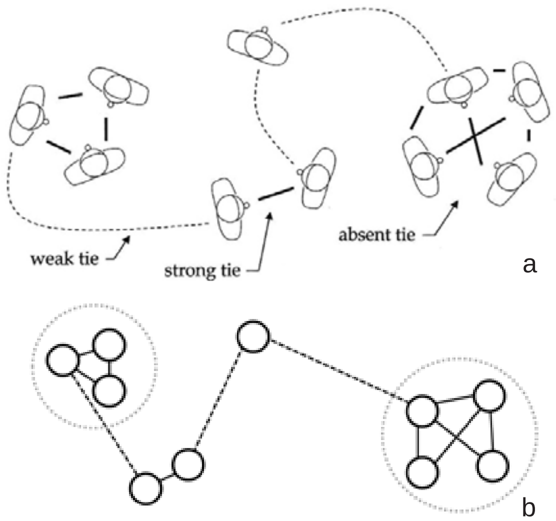


Figure 1: a) Granovetter's idea of strong and weak ties (from Granovetter 1973; modified Brabási 2003:15).

b) Transposition of Granovetter's idea of strong and weak ties into a none justified graph. Granovetter's approach partly follows the rules of gravity theory.

[8] This links to *diffusion-limited aggregation* (DLA) where particles in random motion (Brownian motion) cluster together to form aggregates of such particles (cf. Sander, Witten 1981) This is one of the simplest mechanisms for constructing fractals (cf. dendritic growth simulation from the Diffusion-Limited Aggregation Model, Batty 1994, plate 7.3 to 8.3,8.4, 8.6)

Salingaros summarises that a *small-world network* is one where nodes are connected by both long and short links (Barabási 2001; Salingaros 2005). Starting from a set of nodes with only nearest-neighbour interactions, add a few longer links at random (cf. Watts and Strogatz 1998). The result is a drastically improved overall connectivity. This is measured by how many links it takes to get from node A to node B for any two nodes chosen at random. If the nodes are connected only via nearest neighbours, then one is required to go through all the intermediate nodes between A and B. Just a few longer connections provide sufficient shortcuts to improve the connectivity. What has happened is that a system with only nearest-neighbour (shortest) connections has been transformed into one that is closer to having an inverse-power distribution of paths.

Barabási 2001

Salingaros 2005

Watts, Strogatz 1998

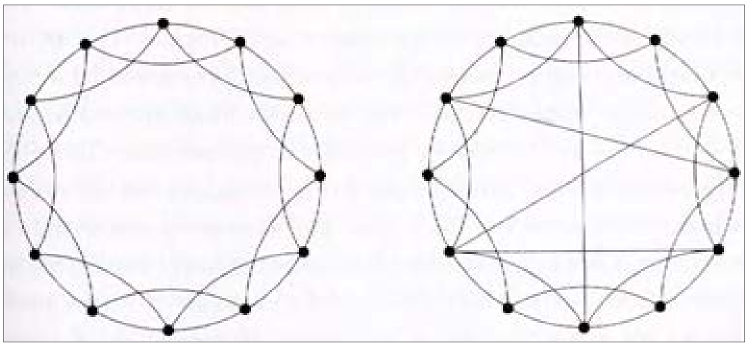


Figure 2: A small and clustered world. Due to a few extra long links the world becomes a small one (from Barabási 2003:51).

Barabási 2003

Although it is a powerful theory, Granovetter's approach has been criticised for portraying a static system in which no flows (dynamics) are represented. Thus, it is a descriptive approach that focuses on morphology (form follows function; descriptive morphological and structural approach)[9].

Barabasi states the important fact that it only works with complete graphs, in which each node is connected to all other nodes (Barabási 2003, 42). What is true about Granovetter's argument is that our social organisation functions on the basis of small-world clusters (friends, work, leisure) communicating with each other.

However, Granovetter depicts a certain image of society in which a structural principle of metropolitan areas is hidden. If we interpret Granovetter's ties as roads and the nodes as road intersections, the image transforms into clusters of agglomerations with highways connecting them. Also, the mainly hierarchical structure of road networks can be inversely assumed. Highways are weak social ties (distance), but superordinate to roads (with,

[9] We have to be aware that all planning strategies – from a regional scale to an architectural scale – have an inherent problem: the need to incoporate the idea of dynamic flux in planners' working concepts. Moves in this direction in the scientific field include e.g. cellular automata models and traffic flow models (von Neumann 1951, Wolfram 1986, Toffoli and Margolus 1987, White 1998 , Portugali and Beneson 1995, White and Engelen 1993).

high speed), whereas inner-city streets (narrow, limited speed) as strong links of the cluster are subordinated.

As mentioned before, we can also interpret Figure 1 as a strategic metropolitan model. For this simple illustration to function as a spatial model we need to consider at least one basic parameter: population density, as it has an immanent impact on the function of a system (Newman and Kenworthy 1989, Schwanen et al. 2004, Rogers 1999) in economic, ecological and social terms. This links back to the question of sustainable and sustaining systems. A highly connected cluster forms a dense network, the density being the level of connectivity (ties, links, streets).

Newman, Kenworthy 1989

Schwanen et al. 2004

Rogers 1999

Continuing this line of thought, Watts and Strogatz (1998) developed the *clustering coefficient*[10]. Watts and Strogatz found that if only a few extra "global" links were sufficient to increase the to effectively increase the clustering coefficient. Ergo, a system can be highly effective even if it consists of a variety of small clusters as long as a few global links are maintained.

What is missing in the Watts and Strogatz model is the idea of hubs. We are very familiar with the term hub as it has found its way into a variety of scientific disciplines from microbiology to IT and economics. In general, for planners, hubs are connectors and distributors such as major public transport hubs (a place such as a railway station joining several public transport modes). Hubs are nodes with a number of links that is above the system average (centralisation effect).

Hubs dominate the structure of all networks in which they are present, making them look like small worlds. Indeed, with links to an unusually high number of nodes, hubs create short paths between any two nodes in the system (Barabási 2003, 64).

The constellation and composition of bigger and smaller hubs as well as the inner relationship (system boundary) between different-sized hubs (or e.g. agglomerations) orbits the terminology of *centrality* and *hierarchy*. Humpert's sketch derived from arbitrary footpaths can be interpreted as a regional order or hierarchy (Figure 3).

[10] In graph theory, a clustering coefficient is a measure of degree to which nodes in a graph tend to cluster together. Evidence suggests that in most real-world networks, and in particular social networks, nodes tend to create tightly knit groups characterised by a relatively high density of ties (Holland and Leinhardt, 1971;Watts and Strogatz, 1998). In real-world networks, this likelihood tends to be greater than the average probability of a tie randomly established between two nodes (Holland and Leinhardt, 1971; Watts and Strogatz, 1998).
Wikipedia, 11.10.2011

Barabási 2003

It links the ideas of Christaller's Central Place Theory (Christaller 1933) and further Hillier's Space Syntax theory (Hillier 1996). Both work with the conception of space as a hierarchically ordered structure.

At the very beginning of all these considerations stands the *morphology of footpaths* [11] after Humpert, depicting the idea of a power law through the logic of hierarchy and hubs (Humpert 1997, 2007) – a *scale-free network*. Further, Humpert's illustration (Figure 3) hints at the idea of *Lévy flights* – random walks (cf. Mandelbrot 1977) whose step lengths are not constant but rather chosen from a probability distribution with a power-law tail[12].

Christaller 1933

Hillier 1996

Humpert 1997, 2007

Mandelbrot 1977

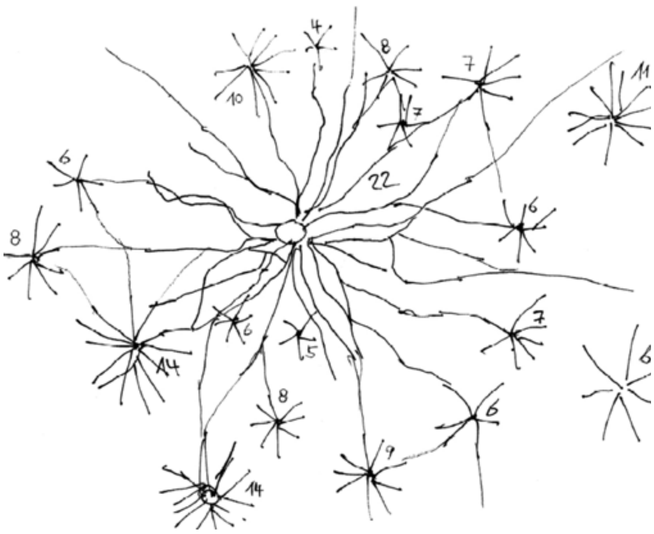


Figure 3: Humpert's morphology of footpaths (from Gangler, Esefeld (eds) 2007: 82). The structure shows similarities to Baran's decentralised network for computer and web network structures (Baran 1964). People's wayfinding follows certain navigation rules (cf. Humpert 1997) which are the same for all locomotion modes. Walking is based on an optimisation process. One optimisation parameter is speed, as the latter strongly affects the network and its users.

[11] People's walking and navigation behaviour is crucial for biophilic planning strategies. Incoporating natural human behaviour into urban planning decisions is the most efficient and sustainable way of forming the built environment.

[12] Lévy flights occur in a diverse range of physical phenomena, examples including fluid dynamics, dynamic systems and micelles (Viswanathan, Afanasyev et al. 1997, 413). In summary, Lévy flights are walk trajectories which are composed of self-similar jumps (cf. Lévy distribution). The jumps are distributed according to a power law. Lévy flights are stochastic processes. There has been growing interest in the study of Lévy flights observed in the movements of biological organisms performing random walks while searching for other organisms (Viswanathan, Bartumeus et al. 2002, 208). The interesting thing about the Lévy flights is its explicative approach (heuristic-descriptive) for biological systems and economic systems.

1.2. Hierarchy

A hierarchy[13] is a descrete gradient as it represents levels of interaction. Pumain offers an explanation when she says that a hierarchy is "a type of systemic organisation into levels that are ordered with reference to criteria of a normative character, and fully or partially subordinated by relationships of power, influence, or control." (Pumain 2006,1). Cities and regions are also organised on the basis of hierarchies (population, markets, society, etc.). According to Batty, is an urban hierarchy established by the growth of agglomerations ("from hamlets and villages into small towns thence into larger forms […]"; Batty 2006, 143). Thus, cities follow a rank-size distribution (Strogatz 2009). Rank-size distribution links to power laws and further to fractals[14].

[13] According to Verdier the word hierarchy is made up of hieros "sacred" and arkhia "rule". The first clear meaning arises from this etymology, since hierarchy at that time (6th century AD; author's note) is "the governance of things sacred". As a theological term, it is used to refer to the "subordination that exists between the different choruses of angels" (Verdier 2006, 13).

Pumain 2006
Batty 2006
Strogatz 2009

[14] This points us to the concept of scaling laws as they "typically reflect, and often reveal, the general principles" (West 2006) of underlying (physical) structures. West further adds that the „conceptual role of scaling in fundamental problems in physics and biology have their origins in hierarchical fractal-like structures" (West 2006, 71).

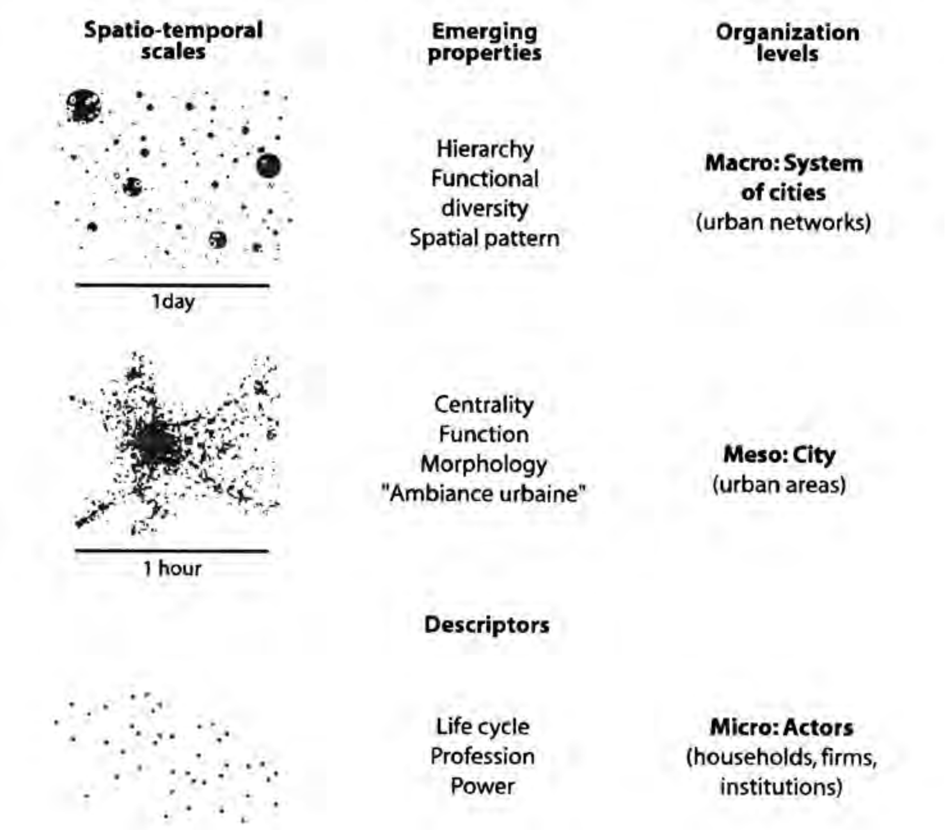


Figure 4: Scale of an urban hierarchy (from Pumain 2006:172)

But why are we interested in hierarchies?

N.F. Johnson 2007

Hierarchies are part of complex systems. Complexity depends on how individual objects interact and how interconnected they are (N.F. Johnson 2007). We find the idea of complex systems in many fields, including computer networks, human economies, social structures, climate, all living systems, and cities and regions. Pumain points out that "we think that the analysis of the hierarchical organisation of complex systems can provide deep insight for understanding their emergence and evolution" (Pumain 2006, 1) and goes on to posit three hypotheses why hierarchical organisations are so frequent in natural and social systems (Pumain 2006, 3): First, hierarchies are just our way of perceiving and understanding our environment; second, hierarchies are spontaneous attractors in unconstrained dynamic random processes; and third, hierarchies represent the best solution for many optimisation problems.

Pumain 2006

Lane distinguishes four kinds of hierarchies based on the idea that hierarchy is a polysemous term (Lane 2006, 83):

1. *Order hierarchy:*

Lane 2006

"In various technical contexts, hierarchy is sometimes taken to be equivalent to an ordering induced by the values of a variable defined on some sets of elements (e.g. population for cities, author‘s note)". Self-similar levels exist.
For Lane this concept has the advantages of clarity and abstraction, but at the same time weakens "the richness and depth of the concept by reducing hierarchy to an ordered set". He points out that order alone is not important for complex systems.

2. *Inclusion hierarchy*:
"Hierarchy refers to a recursive organisation of entities".
Lane illustrates this kind of hierarchy with the example of Simon's Chinese boxes (Simon 1962), where opening a box not only discloses a new box, but a whole subset of boxes. He further gives the example of an urban hierarchy, where explaining that a collection of cities contains forms, households, institutions and organisations, which further in turn contain people, and can thus be regarded as an inclusion hierarchy. In contrast, an urban hierarchy (system of cities) measured by population is not an inclusion hierarchy, but an order hierarchy.

Simon 1962

3. *Control hierarchy*:
"Particularly in reference to social organisations, has to do with who gives orders to whom. In this context, hierarchy refers to a control system in which every entity has an assigned rank, and all power is concentrated in

the (usually) single entity with the highest rank . […] Orders flow rank-downwards […] information and requests rank-upwards (e.g. church, political party, army, etc.)”.

Lane adds that we have to distinguish a control hierarchy from an inclusive hierarchy, although some systems (e.g. army) can be described either way: “Soldiers ordered by rank form a control hierarchy, while the command units (platoon, company, regiment, corps, etc.) comprise an inclusion hierarchy”.

4. *Level hierarchy*:

“Each level is characterized by a particular spatio-temporal scale for its associated entities and for the processes through which the entities at this level interact with one another: the higher the level, the more extended the associated spatio-temporal scale. Entities at a given level may, through their interactions, construct and maintain entities at higher levels, and higher level entities may, at least in part, be composed of lower-level entities: these are often described by the term upward causation. […] However, hierarchies are also characterized by downward causation: incorporation into a higher-level entity can change the properties and interaction modalities of lower-level entities.”

Lane illustrates this kind of hierarchy by the example of biological systems (cells – organs – individuals – species) and economic systems (individuals – working groups or departments – firms) adding that a level hierarchy can also be an inclusion hierarchy. Further, he points out that the entities at any level can be seen as autonomous.

When we think of hierarchies we mostly depict the image of an evenly distributed system. In contrast, real-world phenomena and coherences are not evenly distributed. Hubs led us to the idea of hierarchy, but we have to be aware that they are not evenly distributed.

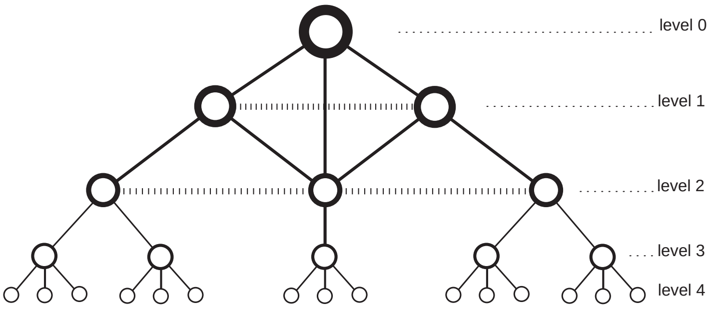


Figure 5: Hierarchy with weighted nodes representing centrality.

1.3. Does Nature have a distinct Preference for Bell Curves?

If we come back to hubs, they pointus to Vilfredo Pareto[15] and his 80/20 rule. Pareto's principle states that for many phenomena 20% of causes will have 80% of consequences. Thus, he found an uneven distribution of real-life coherences. This phenomenon is woven into complex networks, e.g. in social networks there are always a few who know many more people than the average person – they are the social hubs. Pareto's long-tailed curve leads us to *power laws*. Power laws demonstrate the coexistence of a very few major events with a large number of small events. Their exponent shows the degree of distribution of events. The size of human settlements when ranked by population follows a power law distribution (Auerbach 1913, Zipf 1949).

Further classic examples are the frequency of word use, distribution of internet traffic, and intensity of earthquakes and hurricanes. Power laws indicate a *continuous hierarchy* of nodes and abandon the idea of a scale; therefore they are defined as *scale-free*.

The idea of scale-free networks links us to the geometry of nature – fractals (Mandelbrot 1977). They are power laws which in reverse - based on the coexistence of various scales - are defined as *multi-scale* [16]; an essential attribute. Fractals are known as the geometry of nature and all living systems as they appear as the ordering principle in e.g. trees, clouds, the human vascular system (3D fractal), brain cells (stochastic fractals), and cities (Batty and Longley 1994; Frankhauser 1994, 2004; Frankhauser et al. 2007; Salingaros 2005; Tannier, Vuidel et al. 2010; Thomas et al. 2007). A fractal's shape lies between order and disorder and therefore corresponds to the human sense of proportion. That is why we find fractals very interesting and perceive their iteration steps as being harmonious (a bit like a universal pattern of life).

Common examples in nature using fractal logic are phase transition, for example, the *Rayleigh-Bénard convection* in thermodynamics (Bénard cells). Due to the nature's striving for efficiency the highly heated thin oil layer has to change its inherent structure in order to evacuate the heat from the bottom to the top. The system undergoes self-organisation, a natural regulator of efficiency. Order enters the state of chaos to enter the state of order. The temporary state of order is the *equilibrium* [17].

[15] Born as Fritz Wilfried Pareto, 1848-1923 (Graß, 1996)

Zipf 1949

Mandelbrot 1977

Batty, Longley 1994
Frankhauser 1994, 2004,
Frankhauser et al. 2007
Salingaros 2005
Tannier, Vuidel et al. 2010
Thomas et al. 2007

[16] In general a fractal can be defined as rugged, self-similar and multi-scale. In other words, a fractal is nowhere smooth; different particles appear throughout their whole body structure as a whole and their transformation is iterative, depending on their starting conditions. Any part of a fractal can be repeatedly magnified, with each magnification resembling all or part of the original fractal. On the one hand a fractal is a complex structure, but it is also interwoven with a hierarchical order that can be described and applied by means of an algorithm (Czerkauer 2007, 90).

[17] The idea of equilibrium is also found in social, strategic interaction of people as part of the game theory. The Nash Equilibrium defines the adjustment of strategies in a group of players. If player A changes his strategy, player B has to integrate this into his own strategy, and so on.

An interesting side step in this context is Le Corbusier's *Modulor*, the average height of a (male) person: firstly 1.75m, later, from 1950 onwards, 1.83m. Interestingly enough, that Le Corbusier calculation is based on the Golden Section, which itself is related to the field of fractals. The *Modulor* was a paradigm of his architecture, manifested, for example, in the monastery of Sainte-Marie de la Tourette, Éveux, France (1956-1960). Actually, Le Corbusier was not too far away from the standard European height.

Le Corbusier 1950

In nature we a find a parallel to the idea of power laws in that many biological, social and psychological phenomena in the distribution of population follow a normal distribution (Gaußian distribution or bell curve). The latter is another way of characterising the probability of events (cf. Lévy flights, Wiener process); the height of the population, for example, has a normal distribution. However, normal distribution and power laws are two different ways of viewing the world, with some events following a Gaußian distribution and some a power law.

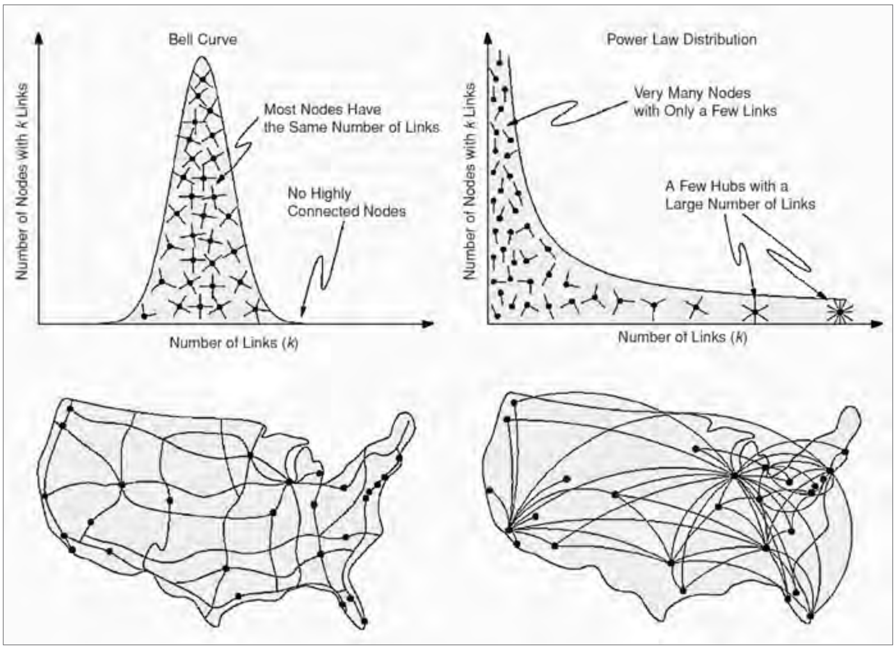


Figure 6: US highways versus US air routes (from Barabási 2003:71)

US highways on the left show a normal distribution, with most nodes having the same number of links. On the right, the American air traffic system is an excellent illustration of a power law. From a functional perspective we can argue that the air traffic map tells us the need to exchange between certain links (hubs) from a socio-economic perspective (number of flight passengers). Flight routes are regulated by customer demand. They are an interdependent, self-regulating dynamic system (growing and shrinking). The duty of the road network is to connect every city with every other city. The US highway map does not reflect a weighted graph which takes traffic volume into consideration.

Andriani et al. state that the fundamental difference between power laws and Gaussian distributions lies in the assumptions about the correlation among the events. In a Gaussian distribution the data points are assumed to be independent and additive. Independent events generate normal distributions. When events are interdependent, Paretian distributions dominate because positive feedback processes (cf. Wiener process, Lévy flights, author's note) leading to extreme events occur more frequently than "normal", bell-shaped Gaussian-based statistics lead us to expect; normality in distributions is not the norm (Andriani and McKelvey 2011, 3). Thus, the advantage of power laws is that they refer to a *functional, interrelated efficiency*. This can be said to be a *structure-function model* of nature as it incorporates a dynamic cause feeding in to the structural attributes on all scales.

Andriani, McKelvey 2011

Nature works with the concepts of bell curves and power laws. Power laws demonstrate the coexistence of a very few events with a large number of small events. Their exponent shows the degree of distribution of events.
The Size of human settlements when ranked by population follows a power law.

Zipf's Law

The sequence of city sizes forms a hierarchical organisation following a rank-size rule (Batty 2006). Parallel to the formulation of the Central Place Theory (supply of services) a more global approach to hierachy (macro scale) – the city size distribution – was established.
The German geographer F. Auerbach (1913) was the first to define the mathematical relationship that the product of the rank of a city and its population is constant (Pumain 2006). Zipf (1949) later formulated the following formula, known as Zipf's law – a systematic form of the Auerbach distribution. Stragatz points out that amazingly Zipf's law has apparently held for the last 100 years, even given different social conditions from country to country, different patterns of migration and many other variables (Strogatz 2009/05/19).

Zipf 1949

Batty 2006

Auerbach 1913

Pumain 2006

Strogatz 2009

1.4. The Organisational Process of Nature - Emergence and Self-Organisation

S. Johnson 2001

N.F. Johnson 2007

Pumain 1997, 2006, 2011

Emergence is a local behaviour of individual objects (agents) resulting in discernible macrobehaviour (a higher-level pattern) suited to its environment (S. Johnson 2001). Within this definition lies a multiple terminology (and field), which helps to understand emergence in its degree of impact: *self-organisation* [18] *and complexity (organised complexity)*. N.F. Johnson adds an important feature when he says that complex phenomena (as the umbrella science of emergence and self-organisation) depend on how the individual objects interact and how interconnected they are. In the view of N.F. Johnson (2007), deducing complexity solely from an individual object's properties is difficult, if not impossible. In this context Pumain (1997) describes urban systems as complex systems, as their geographical structure is dynamically produced through societal spatial interactions. The evolution theory of urban systems (Pumain 2006, 2011) combines a specific history of settlements in a territory with a generic dynamics that is inherent to settlements: stylised facts at macro-level generated by interactions between individual settlements differentiated by size and functions.

[18] Complexity Science can be seen as the study of the phenomena which emerge from a collection of interacting objects. At the heart of most real-world examples of Complexity, is the situation of limited resource – for example, food, space, energy, power, wealth. In such situations, the emergence of a crowd can have very important practical consequences. For example, in a financial market, or the housing market, the spontaneous formation of a crowd of people who wish to sell – and hence are effectively competing for buyers – can lead to a market crash in which the price falls dramatically in a short time. A related crowd phenomenon occurs among commuters who are competing for space on a particular road at the same time (N.F. Johnson 2007, 3f).

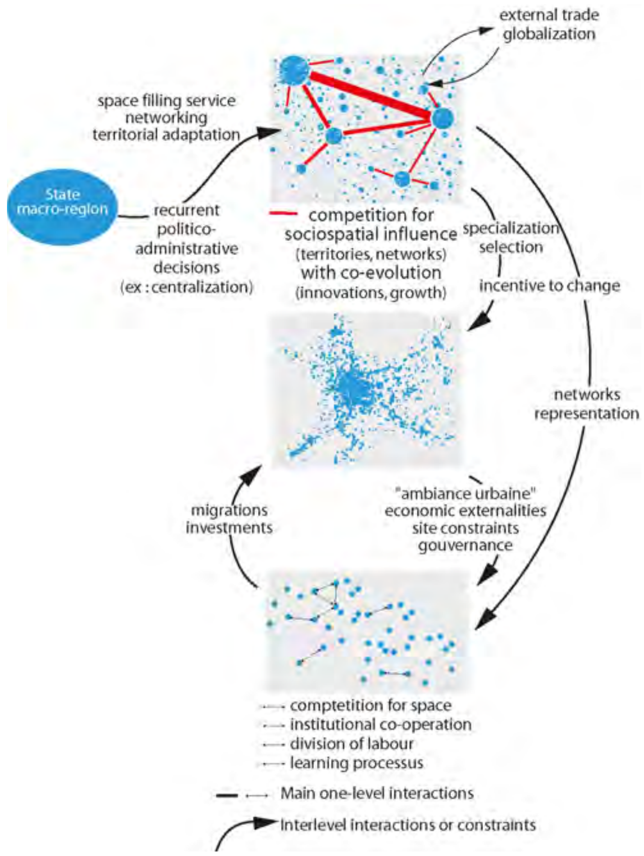


Figure 7: Multi-level interactions (from Pumain 2006:173)

However, the cornerstone of self-organisation is Alan Turing's brilliant and seminal 1952 paper on *"The chemical basis of morphogenesis",* which attempts to explain the beginning of shape with all its intricacies (but does not fully resolve it). Turing tried to provide an accessible chemical mechanism to explain how self-organisation works. His paper embeds the idea of:

Alan Turing 1952

- how the morphogenesis process could be used to describe biological systems;
- how a simple mathematical description could be used for the process es that take place in an embryo;
- and how cells with no thoughts and no sensual coordination could form skin or parts of an eye. Trying to explain the phenomena of *self-organisation*, Turing was in the search of *genotype and phenotype* [19] phenomena. He was convinced that mathematics could describe human systems.

[19] Genotype is the DNA in our cells, the basic cell code, whereas phenotype is the higher-level form of behaviour of this code.

Salingaros describes self-organisation as a property of a system that uses internal forces to influence its own structure and growth. That is, it is generated by some algorithm which causes it to develop internal coherence. We may not understand entirely how self-organisation works but it is seen in many natural systems. For example, snowflakes, spider webs, cauliflowers, eddies and whorls in fluids, etc. exhibit self-organisation (Salingaros 2005, 232).

Prigogine's non-equilibrium thermodynamics (1950s) can also be categorised within the context of self-organisation. It provides an insight into where the laws of entropy are temporarily overcome and higher order emerges out of chaos (author's note: see also transition phase and Bénard cells). Phrasing it in Wiener's terms, it can be described as a self-regulatory power of feedback (Wiener 1948).

At this point mention should also be made of Haken's theory of synergetics (1982, 1986). Synergetics deals with the spontaeously formation of components in complex open systems. It describes aspects of self-organisation of spatial and functional structures and patterns. Haken proved that only a few order parameters are enough to force a structure upon a system (open systems far from thermodynamic equilibrium) (c.f. Reiner, Munz, Haag, Weidlich 1986).

Salingaros 2005

Prigogine 1950s

Wiener 1948

Haken 1982, 1986

Reiner, Munz, Haag, Weidlich 1986

Self-organisation requires a system (open or closed) with manifold non-linear subsystems. Thus, the foundation of complexity is that *local interactions produce globally ordered patterns*. Prigogine's thermodynamic findings (organised complexity) tell us that complex systems are a mix of stability and change.

Starting from Turing's paper this leads us to five principles (S. Johnson 2001) of complex systems for a *bottom-up system* where macrointelligence derives from local actions:

S. Johnson 2001

A. A critical mass of individual component parts is required to assess its global state.

B. Emergent systems can grow unwieldy when their component parts are become excessively complicated. A densely interconnected system with simple elements will exhibit more sophisticated behaviour on a macrolevel. Having individual agents capable of directly assessing the overall state of the system can be a liability in swarm logic.

C. Decentralised systems rely heavily on the random interactions of individual agents exploring a given space without any predefined orders. Encounters with other individuals are arbitrary, but because of the critical mass of encounters and agents, those encounters allow individual agents to gauge and alter the system itself on a macrostate[20].

[20] see agent-based modelling in planning

D. Simple communication signs (forces) provide information for diverse patterns (e.g. semiochemicals with ants for leading them to a food source; high ratio of nest-builders encourage to change the task). The density of signs provides important information about the global state of a system.

E. Swarm mechanism acts on neighbouring information. The individual agents react and act with regard to their neighbours (swarm logic). Interaction with neighbours supports efficient problem-solving.

Let us recall that fractals are part of self-organising processes. Emergent systems are bottom-up systems. Natural fractals like the human vascular system (3D fractal) or stochastic fractals (brain cells, settlements) emerge in a *bottom-up logic*, whereas mathematical fractals only follow this logic with regard to their construction (hierachy, form). If we construct (draw) a mathematical fractal like a snowflake curve or Cantor dust we notice that this is done by *top-down iteration steps* (from a global to a local scale). The construction is top-down, but its inherent logic is still a bottom-up logic, as with all emergent living systems. (At this point we need to distinguish random fractals from deterministic fractals. A snowflake curve is a deterministic fractal, thus not a self-organising process, whereas random fractals use stochastic rules, e.g. Lévy flights.)

This insight provides us with an important feature for the multi-scale strategic planning approach. Using the fractal logic from a global to a local scale (decomposition or iteration steps) we start with a top-down logic for planning simulations as a first approach. However, because the approach features emergence (the fractal's self-similarity) and is multi-scale (the fractal is scale-free) it incorporates a bottom-up logic as well. The final construction (form, pattern) of a fractal is the same whether it is natural or mathematical.

Both natural and mathematical processes generating fractals are subject to a positive feedback loop (see also Norbert Wiener's work on cybernetics, 1948). This is a causal loop, where small change creates an effect that causes even bigger change. Fractals are produced when the slightly modified output (e.g. reduction factor r = 1/3 of an initiator) is fed back over and over again (iteration steps).

Wiener 1948

For planning processes we also need to define start and end modalities (practical applications). From the viewpoint of human perception a cloud or a tree (as a fractal example) does not seem to be infinitely complex on larger and smaller scales. Thus, a geometric form indefinitely recurring at every scale, including an inexact repetition, is known as *pre-fractal* or statistical pseudo-fractal (thus reducing the complexity, as a pre-fractal drops the intricacies that are not distinguishable to the human eye) (see also Peitgen, Jürgens, Saupe 1992, 2004).

This opens up the discussion of scaling ranges (start and end modalities). In planning strategies the scaling range is on the one hand determined by the complex problem to be solved and the associated planning question(s), and on the other hand by human perception.

Peitgen, Jürgens, Saupe 1992, 2004

Prigogine 1980

However, Prigogine outlined self-organisation for urban settlements in his concept of dissipative structures, as the structure of a city can only be understood with regards to its economic exchange with its hinterland (Prigogine 1980, 12 in: Czerkauer 2007, 52). This means that open systems with a feedback mechanism are adaptive. *Adaptivity* generates efficiency;

the best fit within a system's embedded environment.
A city can only be adaptive and therefore sustainable if it is planned as an open system. Metropolitan, urban and neighbourhood scale needs to be planned synchronously (parallel planning process). Consistency through scales enables efficiency and adaptivity, and hence a simultaneously sustainable and sustaining global and local system.
Based on these premises we can identify the general guidelines for complex systems (N.F. Johnson 2007, 143ff):

N.F. Johnson 2007

A. The system contains a collection of many interacting objects or agents;
B. These objects' behaviour is affected by memory or feedback;
C. The objects can adapt their strategies according to their history;
D. The system is typically open;
E. The system exhibits emergent phenomena which are generally surprising, and may be extreme;
F. The emergent phenomena typically arise in the absence of any sort of central controller;
G. The system shows a complicated mix of ordered and disordered behaviour.

However, in cities we find both *bottom-up* and *top-down processes*. Cities are shaped by top-down planning processes in the form of zoning laws, planning commissions and self-organising bottom-up forces like the activity of every individual actor within the city, forming neighbourhoods and unplanned demographic clusters (see also Humpert's morphology of foot paths depicting the idea of a power law through the logic of hierarchies and hubs, 1997, 2007). This in turn feeds back to the morphological pattern of a city. Morphology and dynamics are interwoven, interdependent entities.

Humpert 1997, 2007

Dynamics leads us to the question of self-organising economy for cities and metropolitan areas. Krugman offers two principles: First, order from instability, explaining that in terms of a system's constitution a flat or disordered structure is unstable, so order spontaneously emerges (cf. global atmospheric circulation spontaneously organising itself into weather patterns). In this theory Krugman rightly sees an indication of how metropolitan areas evolve their far from uniform structure. The second principle is that of order from random growth, which obeys a power law size distribution (see also Zipf‘s law). With regard to Krugman the best explanation is that these objects are formed by a growth process in which the expected rate of growth is approximately independent of scale, but the actual rate of growth is random. The size distribution of cities exhibits sustained empirical regularities that are every bit as striking and consistent as those of the physical process (Krugman 1996, 99f).

Krugman 1996

Overall, we should take account of Krugman’s statement that self-organisation is something we observe and try to understand, but not necessarily something we want: he cites the example of urban racially integrated communities which unravel, producing segregated domains, which subsequently become more spatially organised – but not better (Krugman 1996, 6).

CHAPTER TWO:
CITIES AND METROPOLITAN AREAS HAVE FRACTAL PROPERTIES

2.1. Fractal Cities and Metropolitan Areas

Many objects in nature have scaling properties like those found in fractals. Euclidean geometry is often used as a simplified abstraction to describe highly complex systems. However, fractal geometry manages to describe the cascade of detail observed in every living system implying the idea of hierarchy.

It should be noted that many of the descriptions of fractals go back to famous mathematicians such as Georg Cantor (1890), David Hilbert (1981), Waclaw Sierpinski (1916), Gaston Julia (1918), etc. These mathematicians played a key role, but they did not see their creations as concepts leading towards a new general common concept, but more as shapes demonstrating the deviation from the familiar, rather than typifying the normal. Mandelbrot (1977) developed a mathematical, systematic language into which fractals could be embedded.

By definition a fractal is rugged, self-similar and independent of scale. Rugged identifies the degree of zoom or scale at which a certain object is looked at and analysed. If we go back to Mandelbrot's (1977) original question of how long the coastline of Britain is, we certainly always have to answer this question with a footnote stating the degree of zoom we are using in our assessment. Therefore, a multiple answer is correct. However, a fractal consists of self-similar geometrical elements found at an infinite number of scales. Ruggedness and self-similarity lead to the concept of multi-scale, which is the direct result of a fractal's construction process.
A fractal is nowhere smooth; different particles appear throughout their whole body structure and their transformation is iterative, depending on their starting conditions. Any part of the fractals can be repeatedly magnified, with each magnification resembling all or parts of the fractal (Czerkauer 2007, 90). A theoretical fractal can be continued to infinity in contrast to some fractal structures in nature.

Mandelbrot 1977

In principal, we can distinguish two main types of fractals:
unifractals and *multifractals*.

NATURAL PHENOMENA
and
THEIR APPLICATION

Czerkauer 2007

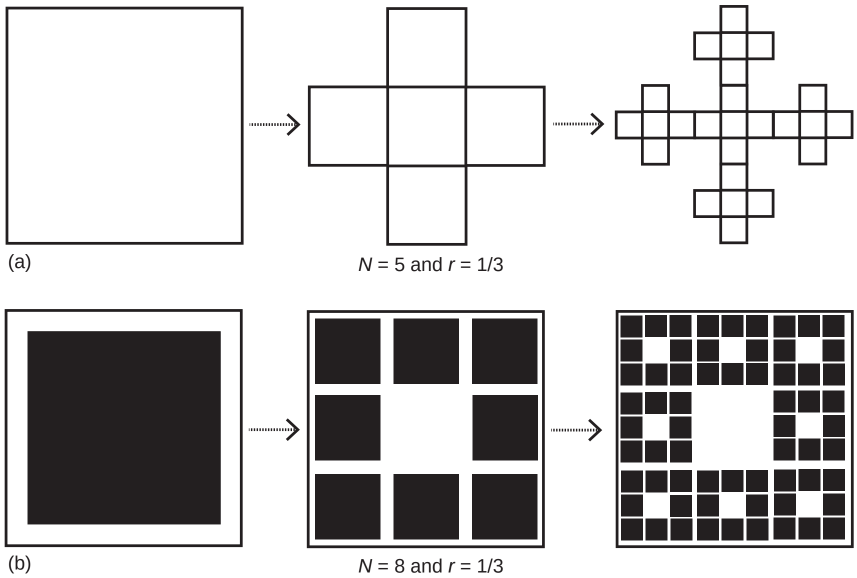


Figure 8: First steps in generating two different unifractal Sierpinksi carpets (a) and (b).
Two generators with different *Ns*, but identical reduction factors *r*
(from Czerkauer-Yamu 2012).

Frankhauser explains the interesting fact that from the geometrical point of view, Sierpinski carpets have some very curious properties: when computing their edge length and the black surface for each iteration step, it turns out that the surface eventually vanishes, whereas the edge length tends towards infinity (Frankhauser 2004, 85).

Frankhauser 1994, 2004

Organic growth is a good example of a fractal structure forming different urban forms, but with a similar underlying pattern formation (of free and occupied spaces) reflecting basic principles of interaction involving land prices, accessibility, etc. (Tannier, Pumain 2005). Accessibility generates star-shaped forms of growth (Batty 1994). Organic growth is a combination of radial and star-shaped growth. As seen in Berlin’s growth over time urban fractals can be compared with theoretical fractals.
If we look at the growth of Greater Berlin from 1875 to 1945 we can see that its growth along the railway axes reflects the logic of a Sierpinski carpet. Humpert stresses that the emergence of railways allowed an interweaving of the city with the countryside. It led to a growth along railway lines which remains significant for Berlin until the present day (Humpert 1997, 73).

Tannier, Pumain 2005

Batty 1994

Humpert 1997

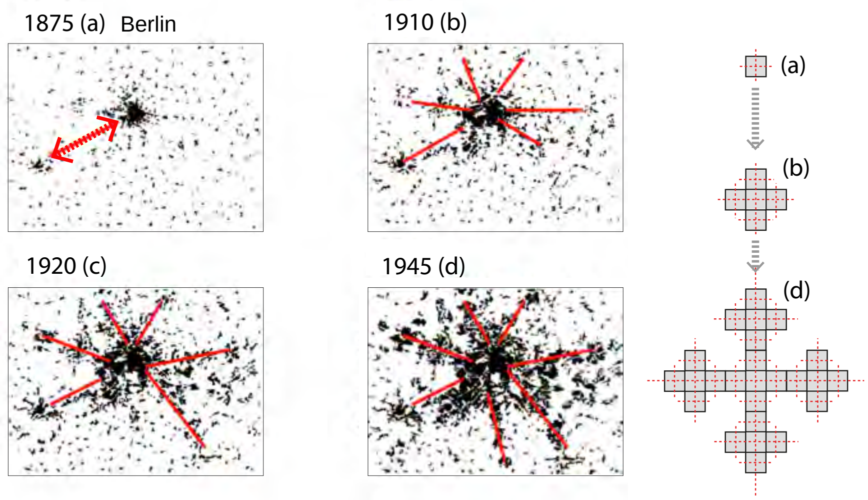


Figure 9: Berlin's growth (modified; original from Frankhauser 2012, working paper)

Thus, in thinking of a city as a fractal entity (Mandelbrot 1982; Batty et al. 1986, 1996, 1999; Frankhauser 1991; Batty and Longley 1994; Shen 2002; Benguigui et al. 2000; Salingaros 2003; Frankhauser and Pumain 2007; Thomas 2006) highly efficient and sustainable planning strategies can be derived from the concept of a highly efficient hierarchical structure.

Mandelbrot 1982
Batty et al. 1986, 1996, 1999
Frankhauser 1991
Batty, Longley 1994,
Shen 2002
Benguigui et al. 2000
Salingaros 2003
Frankhauser, Pumain 2007
Thomas 2006

The spatial layout and the configuration of the initiator, as well as the configuration of the generator are essential for constructing a fractal. (N.b. Random position of elements within the generator does not change the fractal properties). Based on these two premises a fractal can vary its composition in multiple ways. From its repetitive operation a minimal change at the beginning can lead to a totally different fractal than intended. One the one hand this makes fractals very sensitive, but at the same time it gives us the opportunity to customise and adjust fractals to urban planning needs (e.g. masterplanning) for consolidation, development and shrinkage.

The idea of a Sierpinksi carpet can be transposed to a more compact structure which incorporates *inner lacunae*. From an urban viewpoint we can now distinguish built-up areas and open space. The lacunarity of fractal objects is an essential element for the development of sustainable urban planning concepts. Lacunarity describes how patterns fill space by having larger or smaller gaps.

In general, where elements are contiguous and the fractal in all iterations consists of one cluster are called Sierpinksi.

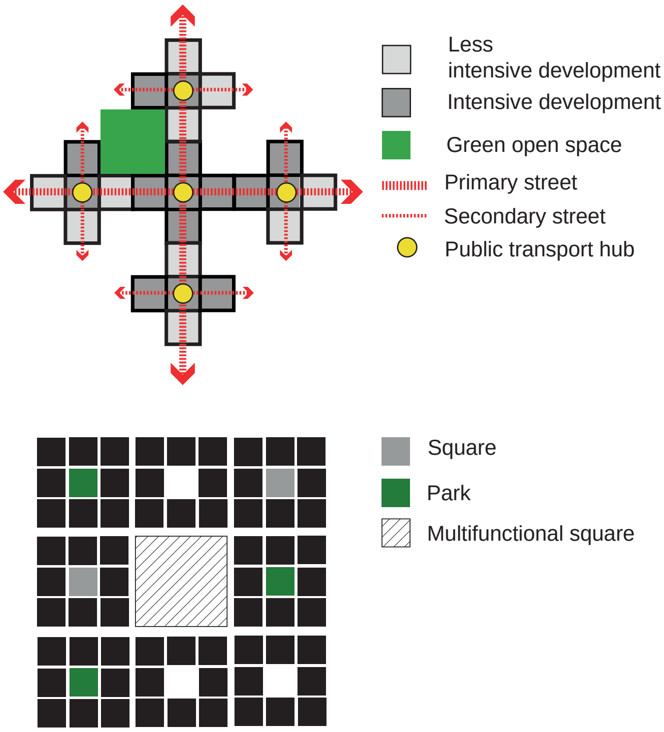


Figure 10: Masterplanning using a Sierpinski (inspired by Frankhauser, Houot et al. 2007:19)

The Sierpinski carpet in figure 8(a) was generated by the factor $r = 1/3$ and $N = 5$. We have seen that the operation of iteration generates an increase in perimeter length and a decrease in surface area. It represents a unifractal.

More complex hierarchies can be generated by combining different reduction factors. This in turn generates a multifractal structure.

Moreover, multifractals allow the generation of structures where the individual elements show hierarchical attributes. The elements defined *a priori* by the reduction factor. In nature multifractals describe e.g the behaviour of river networks (De Bartolo, Gabriele et al. 2000), land occupation index, economic markets and cities (Frankhauser 1998). We can explain a multi-scale behaviour for cities as different sized clusters in different locations appearing within an urban system.

De Bartolo, Gabriele et al. 2000

Frankhauser 1998

On account of the different element sizes a multifractal already links to the idea of clusters. This can be easily visually identified. A theoretical multifractal structure can be easily interpreted as a city with main centres and sub-centres. The "urban" clusters can be located both centrally and peripherally. As a multifractal object is heterogeneous, the fractal dimension also varies from global to local (not all points of the object have the same fractal dimension as as they do in a unifractal).

NATURAL PHENOMENA
and
THEIR APPLICATION

Frankhauser 1998, 2008

A multifractal can be broken down into subsets, each of which has its own dimension, such that a whole spectrum of dimensions is obtained (Frankhauser 1998, 214). This produces a hierarchy of clusters and bays as found in metropolitan areas. The figure shows the example of Stuttgart's metropolitan area, providing evidence that urban systems (built-up areas) follow the same logic as multifractals.

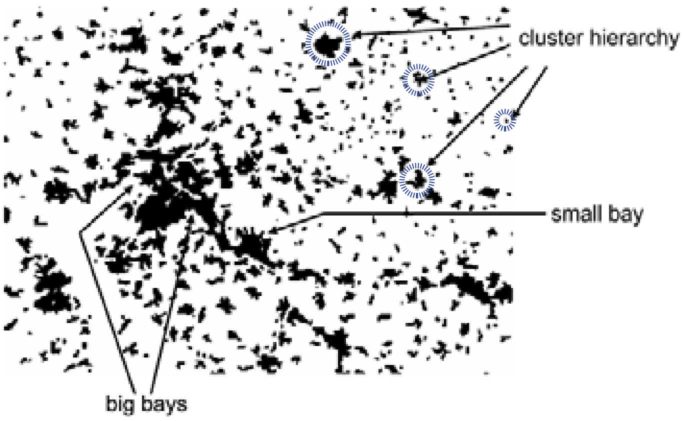


Figure 11: Stuttgart metropolitan area visualising multifractal attributes (from Frankhauser 2008:3).

Let us go back to the Sierpinski carpet and take it as a model for a town or village growing along radial axes (see figure 9 for Berlin's growth). This is close to the pattern produced by self-organisation, as in historic city structures we observe so-called deformed wheels representing the major axes along which urban growth primarily occurred. Each iteration step represents a higher resolution of the town. Figure 12 supports further incorporating the idea of different weightings and ponderations of the multifractal, as used in the herein presented multi-scale decision support system "*Fractalopolis*".

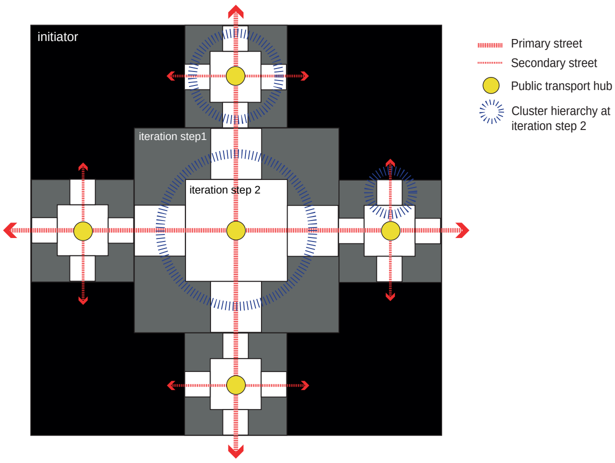


Figure 12: Scheme of a multifractal Sierpinksi represting growth along axes with reduction factor $r_1 = 0.5$ and $r_2 = 0.25$ for iteration steps 0-2.

2.2. Road Networks as Fractal Entity

A couple of authors have discussed fractal road networks (Batty and Longley 1994; Frankhauser 1992; Salingaros 2005) and fractal public networks (Benguigui 1995; Benguigui, Daoud 1991; Frankhauser 1994; Kim, Benguigui, Marinov 2003). Also, the German-born architect Hilbersheimer worked with fractal ideas as an ordering principle in his urban road network plans.

Batty, Longley 1994
Frankhauser 1992
Salingaros 2005
Benguigui 1995
Benguigui, Daoud 1991
Frankhauser 1994
Kim, Benguigui, Marinov 2003

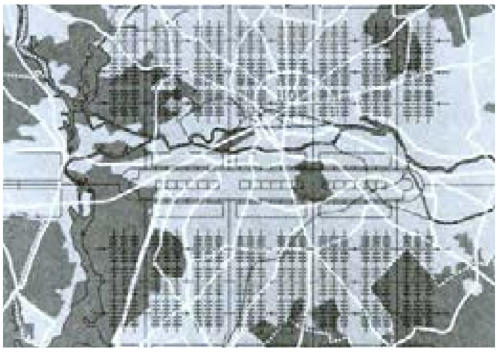
Hilbersheimer's development plan for Seattle (1957) as process-oriented planning follows in its amorphous forms and shapes a clear fractal geometry. Reminiscent to Hilbersheimer's traffic layouts, Batty and Longley use the analogy of a classical *space-filling curve for traffic systems* in residential areas and towns. The H-tree can produce more or less realistic structures according to the angle of its branches. Batty and Longley explain that it is possible to visit every branch of the tree without crossing any other branch. Further, they stress the fact that this kind of model was widely implemented in the design of residential areas in the British New Towns (Batty and Longley 1994, 80).

Hilbersheimer 1957

Frankhauser 1994, 2004

Hilbersheimer uses a descriptive morphological logic, whereas Batty develops a morphogenetic logic following the idea of dynamically generated patterns linked to emergence and patterns that have emerged through evolution. Salingaros (2005) adopts the idea of *capillarity* to explain a fractal road network and its benefits based on (traffic) flow. His explanation is highly reminiscent of a human vascular system (with the only difference that a human vascular system is a 3D fractal whereas a traffic system is a 2D fractal). From a systematic point of view both work with the same principle: higher-ranked movement channels have more capacity based on the size of the channel and the speed of the elements. The capacity changes in line with the level of hierarchy.

existing step 1 step 2



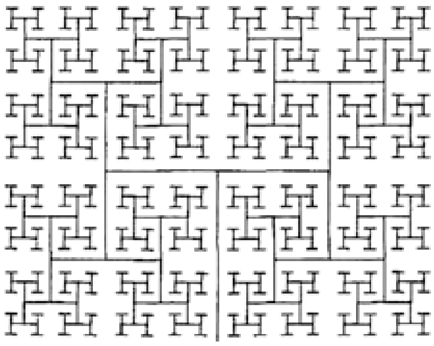


Figure 13: (above) Hilbersheimer's plan for Seattle (1957); (below left) Haller's "Totale Stadt" (total city) (1968). Haller overlays Berlin with his model of an ideal city for 6m inhabitants (from ArchPlus 2011:44). This recalls Hilbersheimer's "Geschäftsstadt" of 1928 as well as the schemata for a decentralised city ("Dezentralisierte Stadt") which aim to decompose the high-density urban structure that has evolved over time into an ordered, geometric pattern reminiscent of the "linear city" (from ArchPlus 2011:44). (Below right) A self-avoiding binary tree (from Batty and Longley 1994:79).

Hilbersheimer 1957
Haller 1968
Batty, Longley 1994

From an American point of view, Salingaros identifies an obsession with the largest scales in the "car networks". He is right when explaining that a preference of for large scales only lead to a disconnection in the urban geometry (Salingaros 2005, 155). We have widely recognised that European towns and cities stay vital when the right balance (equilibrium) exists between all the scales. This then supports all kinds of traffic modes: pedestrians, cyclists, vehicular transport (individual and public), trains. Sometimes a modal split is required, sometimes a healthy mix of different traffic modes on one hierarchical road layer is needed. This leads to the overlay of a road hierarchy layer with a transportat hierarchy layer (modal split).

Salingaros 2005

The benefit of a strong hierarchy as an efficient, functional system is naturally linked to the idea of a fractal road network. Every city incorporates a hierarchical road network (stronger or weaker hierarchies) as a combination of planning intervention and self-organisation processes with later consolidation. We can see planning and self-organisation as a mutual feedback loop as one is conditional upon the other (the process is simultaneously parallel and hierarchical).

The conclusion is that open systems, by means of the exchange of matter and energy, including a non-linear interaction between the micro-elements, can influence the state of macro-elements, and hence the global organisation of a system. The behaviour can undergo a *bifurcation,* which describes a system where for identical external conditions a variety of possible structures exist. Each of the emerging structures is compatible with the interactions on a micro-scale. Like fractals, the “bifurcation tree” tree is part of Chaos Theory (Czerkauer 2007, 51).

Czerkauer 2007

2.3. Fractal Parameters for Measuring Forms and Cities

Chen et al. (2003) illustrates that fractal methods can serve to analyze both cities as systems and systems of cities. He states that the fractal models of urban hierarchies support to relate elements of city systems and systems of cities as successive scales (cf. Batty and Longley 1994). As already mentioned by Batty and Longley (1994) he supports the idea of building a theory of fractal urban systems associated with fractal cities should be done by developing models of urban hierarchies; stating that in this context, the rank-size rule will play an important role (cf. Central places).

In the context of fractal cities, Thomas et al. (2007; 2008) demonstrate the usefuleness of fractal measures characterizing the spatial organization of urban patterns on different scales regardless of how planned they were. The authors were able to show a positive correlation between residential satisfaction and fractal dimension of the built environment (morphological diversity defined as the existence of empty areas of different sizes). De Keersmaecker et al. (2003) shows that by using fractal-based parameters it is feasible to linke observed spatial variations to land use planning.

Chen et al 2003

Batty, Longley 1994

Thomas et al. 2007; 2008

De Keersmaecker et al. 2003

The fractal dimension *D* of urban entities is considered as a global measure of spatial organization and surface coverage (Arlinghaus 1985; Batty and Longley 1994; White and Engelen 1993; Thomas et al. 2006, 2007) and characterises the scaling behaviour of fractals. Frankhauser describes the fractal dimension *D* as the *degree of concentration* of the occupied sites across scale (Frankhauser 2004, 87). It is important to clearly differentiate degree of concentration from *density*. These two terms sound similar, but do not have the same meaning. We will see later that from the fractal idea of concentration we can derive land use and from this the idea of density.The parameter D is not only useful to understand urban patterns but also could be an interesting technique to model urban sprawl (Cavailhès 2002, 2004; Thomas et al. 2006). As the fractal dimension is a *natural generalisation* of the *Euclidean dimension* (Frankhauser 2004) a black surface or homogeneous pattern has the fractal dimension $D = 2$; a line one $D = 1$ and a point zero $D = 0$. Thus, the fractal dimension varies within the range
$0 < D < 2$.

Arlinghaus 1985

Batty and Longley 1994

White and Engelen 1993

Thomas et al. 2006, 2007

Frankhauser 2004

Cavailhès 2002, 2004

Thomas et al. 2006

The fractal dimension *D* is directly linked to the number of elements *N* and the reduction factor *r*. Thomas et al. (2007) emphasises that *D* does not depend on the shape of the initial figure, or on the position of elements in the generator.

Thomas et al. 2007

$$N_k = (r_k{}^{-1})^D = r_k{}^{-D} \quad [1]$$

$$D_k = -\frac{\log N_k}{\log r_k} = \frac{\log N_k}{\log (\frac{1}{r_k})} \quad [2]$$

D_k = fractal dimension at any level k
N_k = number of elements
r_k = reduction factor (similarity factor)

How to measure the fractal dimension of urban patterns

Empirical structures follow an irregular and inordinate morphology than theoretical ones. For measuring empirical structures we assume that the same type of law holds for the empirical structures as for the theoretical ones. Thus, we can interpret spatial structures as random fractals (Mandelbrot 1982; Frankhauser 1994; Thomas et al. 2007, p. 102).
Thus, different methods of measurment have been elaborated to apply the fractal idea to urban systems, e.g. box counting method, correlation analysis. The correlation analysis can be used for analysing both the surface and boundary dimensions.
For the fractal surface distribution we can apply the same logic as for monofractals, as they will have the same fractal dimension value at every point. The logic of iteration is also applied by the increasing radius ε.
The number of elements within the radius (counting window) $N(\varepsilon)$ can be estimated by means of a power law (estimated curve).

Mandelbrot 1982

Frankhauser 1998

Thomas et al. 2007

$$N(\varepsilon) \propto \varepsilon^D \quad [3]$$

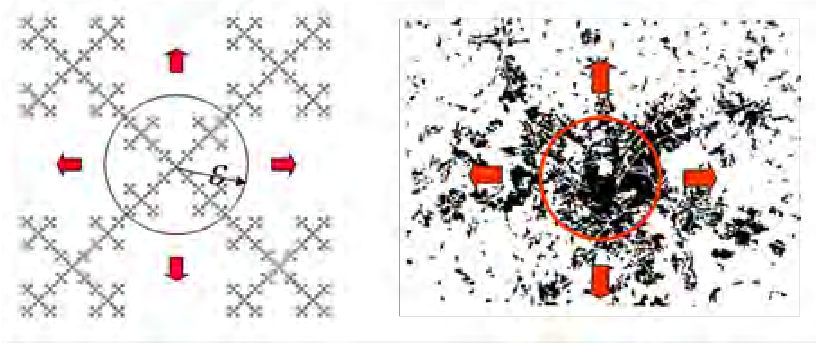


Figure 14: Fractal surface distribution/ soil occupation index for a theoretical fractal (left) and an urban system (right) (from Frankhauser, private information)

In contrast, an empirical curve would count the elements *N* within every enlargement of a counting window *ε* (distance). The series of elements thus obtained can be represented on a Cartesian graph. Thomas et al. (2006) proved mathematically and empirically that for a given size of basic spatial unit (window), density and fractal dimension are linked by an expotnetial relationship. Yet, the information captured for urban systems from the fractal dimension measured on surfaces has nothing to do with density.

Thomas et al. 2006

Frankhauser 1998

In this context, Fractalyse software can be used to study the fractal dimension of built-up patterns and street networks (freely downloadble from *www.fractalyse.org*; developed by Vuidel, Frankhauser and Tannier). For application the area of interest has to be transormed into a scaled raster image. The analysis follows the logic of iteration. An obtained series of points can be now represented on a Cartesian graph (x-axis corresponds to the increasing size of *ε* where as the y-axis reflects *N(ε)*. This empirical curve is compared and adjusted to an estimated curve. So, if the empirical curve follows a fractal law, the estimated curve has the form of a power law. In order to investigate real world patterns, a generalisation of the fractal law is useful containing two additional parameters.

$$N = a\varepsilon^{D} + c \qquad [4]$$

The prefactor of shape *a* summarises deviations, e.g. lacunas, from the fractal law. The constant *c* allows the deviation of the curve.

NATURAL PHENOMENA
and
THEIR APPLICATION

Vienna's street network has been extensively studied with fractalyse software (Czerkauer 2007). The fractal dimension was identified for correlation, accessibility and radius mass analyses for five starting points selected according to historic, economic, cultural and social aspects The below given areas are according to the best fit between empirical curve and estimated curve).

Czerkauer 2007

Correlation analyses (whole street network) D = 1.63
Correlation analyses (main street network) D = 1.40
Accessibility analysis (starting point: historic centre)
curve total: ε = 0–9km, D = 1.50
(a) ε = 0–0.9km, D = 1.60
(b) ε = 1–1.70km, D = 1.63 *(max)*
Radius mass analysis (starting point: historic centre)
curve total: ε = 0–12.1km, D = 1.50
(c) ε = 0–3.70km, D = 1.63
(d) ε = 0–7.66km, D = 1.69 *(max)*

ad a) historic city and former city wall (nowadays Ringstrasse with administrative buildings); ad b) inner districts

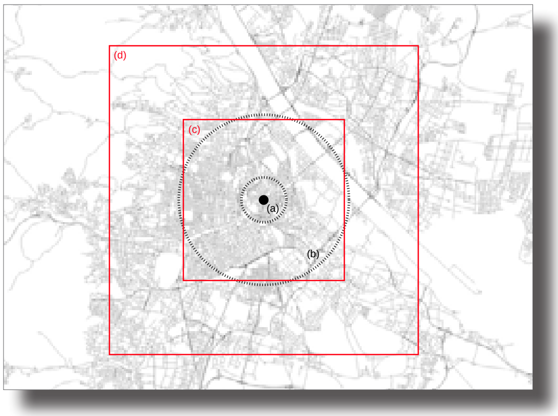


Figure 15: Vienna in 2006; Radii for (a) and (b) are schematic. Population approx.1.7 million people.

The analyis of Vienna showed that starting form different points of interest throughout the city, the fractal dimension varied according to the historic context and planning interventions. In this context, Thomas et al. (2007) and Badariotti (2005) showed that diffent types of urbanisation generate patterns that correpsond to typical ranges of fractal dimension. In the study of Thomas et al. (2007) for Brussel's peri-urban built-up area D differs depending on the gliding window size, e.g. window types containing only a few scattered buildings lead to D close to 0, which means that the mass is concentrated in a few places as in Fournier dusts; for larger windows with a defined centroid D varied beween 0.956 and 1.833 (Thomas et al. 2007).

Badariotti 2005
Thomas et al. 2007
De Keersmaecker et al. 2003

In general, the fractal dimension D computed for cities varies between 1.34 and 1.96 (De Keersmaecker et al. 2003). The range is based on the circumstance, that cities are treated as a whole.

The fractal dimension D is only a global measure, since in a multifractal the fractal behaviour varies according to one's position. Information about this local behaviour can be obtained by introducing the mass exponent or *Lipschitz-Hölder exponent* [21]. It is then possible to identify all the places for which there is the same value.

[21] $\alpha^{(L,H)} = \log\mu(\varepsilon)/\log\varepsilon$

ε = intervall
μ = mass

The equation shows that each point is surrounded by an intervalinterval, which can also be defined as a counting window ε. This interval is linked with the mass μ(ε) to it. Thus, the Lipschitz-Hölder exponent can give information about the local behaviour of multifractals and also detect clusters of the same and different sizes (Feder 1988, Frankhauser 1998 in: Czerkauer 2007, 102).

CHAPTER THREE:
FRACTAL VISUAL PERCEPTION AND AESTHETIC

3.1. Decoding the Built Environment

Morphology, dynamics and natural phenomena lead us directly to another important feature within the built environment: How do we perceive the world? Does visual perception also follow an inherent pattern like a power law distribution or Gaussian distribution?
We have to be aware that human visual perception is a highly complex topic which will be approached herein from the perspective of its *visual structure*. (The nature of visual structure is linked to the construction of spatial atmosphere.)

Generally speaking, visual perception is the ability of creatures to obtain information from their surrounding environment. Perception creates a bridge between the objective and the subjective world. Guski defines perception as an active process with a dynamic background. Perception is among other things based on locomotion, which ensures survival. Perception guarantees goal-based orientation, which is constituted by spatial information (Guski 2000). In addition, subjective perception is shaped by an individual’s cultural background (cultural value system, regulations, etc.) and his/her individual processing of information. Spatial information and visual information are not identical (Knauff 1997) as spatial information is not *a priori* linked to visual information (can be experienced via other sense channels as spatial space is tactile). Still, visual perception is the primary perception when experiencing the built environment.

Guski 2000

Knauff 1997

Perception is a relationship fabric constituting spatial atmosphere, which is a synaesthetic interaction of all senses.
Architects and planners construct atmospheres by the combination of rational and intuitive phases. The three main phases are visioning, planning and implementation. Every space is atmospheric and influences the users in their behaviour. Van Tonder et al. state that design principles (taking the example of garden design) affect two fundamental principles of visual perception – segmentation of the visual scene into meaningful parts, and perceptual grouping of parts into meaningful structural wholes (Van Tonder, Lyons, 2005, 354).

Van Tonder, Lyons 2005

To answer the question of the underlying pattern of visual perception we chose the example of a Japanese Zen garden. Reasons for this choice is based upon its highly sophisticated design principles, which in addition work with the overall concept of self-similarity and multi-scale grouping. At the same time, Japanese Zen gardens are very reductive while expressing maximum spatial atmosphere.

Van Tonder et al. outlined an approach using medial axis transformation to reveal the inherent global visual structure in the empty spaces between the rock clusters (Van Tonder 2007, Van Tonder & Lyons 2005, Van Tonder, Lyons & Ejima 2002). The concept of medial axis works with the idea of shape, as the latter is a particularly stable organisation of our visual stimulus (Blum 1967). It identifies the relationship between objects by the intersection of the objects' iso-concentric rings of different distances (wave fronts or fire excitation, see Figure 16). Relations between objects are defined via their distance and proportional relationship to each other. The intersections constitute the relationships between objects and combine to form a visual perception pattern (Mach 2010). Relative spacing between elements influences visual grouping – a basic principle of visual perception. Medial axis transformation identifies the underlying structure of the global whole.

Van Tonder 2007
Van Tonder, Lyons 2005
Van Tonder, Lyons, Ejima 2002

Blum 1967

Mach 2010

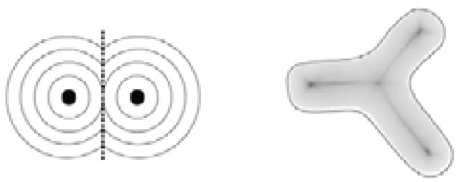


Figure 16: Medial axis (from Van Tonder 2005:356; Blum 1967:365)

Medial axis transformation reveals a pattern (skeleton structure) corresponding to the human subliminal perceptual structure which our brain produces in order to organise and structure sets of data. This faciliates human visual perception.

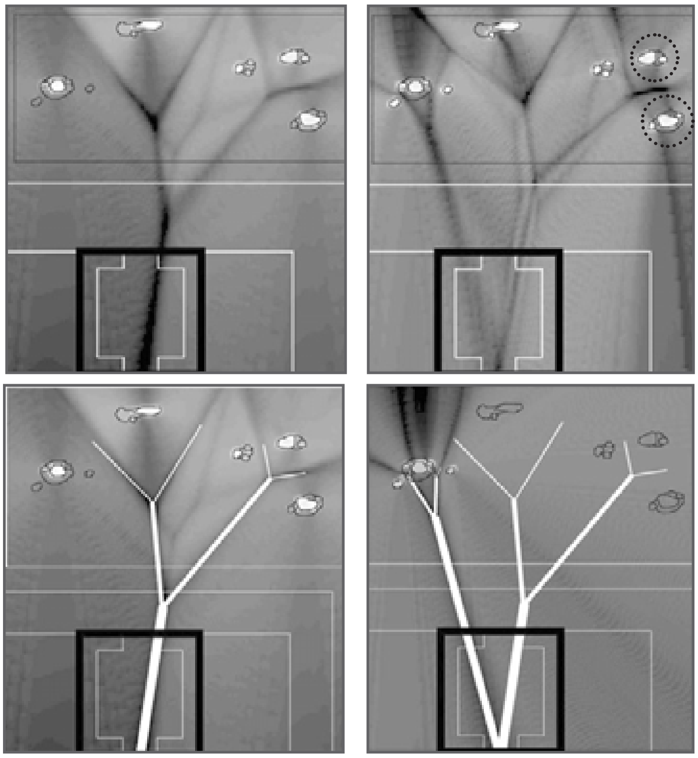


Figure 17: Medial axis transformation of Ryoanii; Verandah and main hall of the temple are outlined in white (AD 1681); the central room is outlined with a bold black line; the middle of the centre room was the traditional viewing point for the garden. The Simulations of medial axes (highlighted in white) is reminiscent of fractals. What is quite amazing about the medial axis transformation of the Zen garden is, that even the traditional viewing point (centre room) corresponds with the immanent fractal structure, as its leading line (initiator for iteration) penetrates this point (from Van Tonder, Lyons 2005:356)

Van Tonder, Lyons 2005

The Zen garden experiment proves that *fractals are a natural visual pattern* for decoding our built environment. As fractals are an underlying pattern of all living systems (from nature, to cities, language, and music) this is not very surprising in the context of evolution. It is well known, that fractal structures are interesting and that we find them harmonic (like musical rhythms, for example).

Interestingly, moreover, we not only decode natural phenomena with a fractal approach, but artificially designed objects, too. Thus, multi-scale patterns are one of our basic codes (visual cues) for decoding and structuring our environment.

3.2. Aesthetically Pleasing Street Vistas

Aesthetically pleasing environments not only respond to the human needs of comfort (and safety) but in addition are important in creating economically viable and sustainable urban environments (c.f. environmental psychology). The underlying idea is the human perception.

In this context Cooper and Oskrochi (2008) undertook an experiment analysing the relationship between fractal dimension and urban design, focusing on the vista of streets as a whole.

Cooper, Oskrochi 2008

The main aim of the experiment was to show how the calculation of fractal dimension might be carried out for a series of everyday street vistas and how the resultant numerical measurement might be related to the perception of the urban design quality of visual variety in those vistas – and by implication to the overall impression or character of the represented streets (Copper and Oskrochi 2008, 350). For Cooper and Oskrochi, visual variety is defined as the level of visual experience offered to the user. It is indicated by a subject's variety in terms of visible sizes, styles, materials, textures, and surface change.

The used herein technique to characterise the fractal dimension of the street view is the *box-counting method* [22] (fractal dimension D_b). Copper and Oskrochi use as grid size 0.25 image height to 0.03 image height with a reduction coefficient of 1.3, thus defining the reference length for each scale of analysis. A series of nine grids were superimposed and the number of boxes on each grid that contained white pixels was recorded. A double-logarithmic graph (log-log plots; Richardson plots (1961)) was produced and the fractal dimension calculated.

[22] *Box-counting method*: This method computes the number of cells required to entirely cover an object, with grids of varying in size. In practice, this is performed by superimposing regular grids over an object and by counting the number of occupied cells. The logarithm of N(r), the number of occupied cells, versus the logarithm of 1/r, where r is the size of one cell, gives a line whose gradient corresponds to the box dimension (Morency, Chapleau, 2003,30)

Here the fractal dimension links the length of the lines measured on different scales with the reference length of the scale.

(a) Warberg Crescent – the binary edge-detected image (on the right) has a fractal dimension with D_b = 1.434 (from Cooper, Oskrochi 2008:356).

(b) Argyle St. – the binary edge-detected image (on the right) has a fractal dimension with D_b = 1.783 (from Cooper, Oskrochi 2008:355).

(c) Park Town – the binary edge-detected image (on the right) has the highest fractal dimension of the whole set (240 images) with D_b = 1.825

Figure 18: Fractal vista (from Cooper, Oskrochi 2008:356).

Cooper and Oskrochi's results were not surprising but still very interesting as they were able to identify a strong relationship between the visual variety level and the fractal dimension. The visual variety level was assessed by a subjective survey[23] (31 participants examined case material – 26 sets of images (a total set of 240 images after removing 20 poor-quality images from the original 260 images)).

[23] The participants had to answer the following questions in relation to the images:
A.) Do you feel it is possible to rank them according to their relative degree of visual variety? (all agreed)
B.) Indicate the relative degree of visual variety for each set of street images in comparison to all the other sets of images (scoring on six-point scale) (Cooper, Oskrochi, 2008,358).

The result was that the fractal dimension D_b can be used to judge a street's characteristics. According to Cooper and Oskrochi [...] this is possible because the textures measured using the box-counting method of fractal calculation are produced by the extraction of detail representing the physical makeup of each street – building, vegetation, etc. – and it is these same physical details that are used by people in making judgments of visual variety (Cooper and Oskrochi, 2008, 361).

Cooper, Oskrochi 2008

The higher the visual variety, the higher the fractal dimension. We can hypothize that the higher the fractal dimension the more aesthetically pleasing an environment is and the more omfort and safety it imparts.

PART TWO:

SUSTAINABILITY

About this Part

In part one we investigated the question "How does the world work? How do we decode the built environment?". In part two we identify *sustainable and sustaining strategies* for the built environment in order to link the two approaches (*nature's strategy and sustainable strategies*).

First, we try to understand the key aspects of sustainability and how the United Nations (1987) defines sustainable development. Here we introduce the concept of the three levels of interdependency.

In the next step we link the idea of networks (as presented in part one) with the idea of robustness to explain the idea of a fault-tolerant system and how nature achieves robustness (cf. Baran 1964; Barabási 2003). We discuss nature's strategy of efficiency and how we can implement it in planning strategies. Introducing the concept of weighted interconnectivity (graph theory) allowing a hierarchically established mode of connection between different sized nodes, we then integrate the idea of a hierarchy's subsidiary, balancing more and less robust systems on different scales (thus linking back to part one and our discussion of small world and Granovetter's approach 1973). Finally, we identify rules for a planning strategy on a metropolitan scale.

United Nations 1987

Baran 1964

Barabási 2003

Proceeding from this we tackle the problem of urban sprawl resulting from today's constellation of agglomerations, which often do not follow a hierarchical distribution. We discuss the contemporary phenomena of Garreau's Edge City (1991), Lang's Edgeless City (2003) and Sieverts' Zwischenstadt (1997). From this we move on to look at forces that centralise and decentralise, discussing the concept of a compact city as favoured by some authorsfor its benefits in terms of access for all (which is inherently linked to the idea of sustainability). In this context we present arguments to explain why this concept is not the overall and only solution for a sustainable planning strategy.

Granovetter 1973

Garreau 1991

Lang 2003

Sieverts 1997

We further present the concept of a decentralised concentrated model as a well- balanced solution for a sustainable and sustaining planning strategy. In this context we discuss Calthorpe's (1993) TOD model and Frankhauser's (2007) reflections on a fractal city concept. In a next step we look at linear, clustered and fractal developments and their constraints and opportunities, identifying the fractal development approach as a concept that marries both axial and clustered development. We explore further important properties that are interwoven with the previous discussion, such

Calthorpe 1993

Frankhauser 2007

SUSTAINABLE and SUSTAINING BUILT ENVIRONMENT

as density, green open space and accessibility, placing a special focus on sustainable accessibility and how it can be achieved. This leads us to the idea of access for all on all interwoven scales, connectivity, green wedges and ecological networks, again linking back to Frankhauser's multi-scale model (2007). Finally, we go on to identify key factors for a sustainable and sustaining built environment.

Frankhauser 2007

N.b. For well-known concepts and planning implementations supporting both the theory of fractal logic and a sustainable strategy pls. see:

- Christaller's Central Place theory (1933)
- Howard's New Towns (1902)
- Bruno Taut's vision (1920)
- Villes Nouvelles (1961, 1965)
- Eberstadt, Möhring and Petersen's plan for Berlin (1910)
- Copenhagen Finger Plan (1947)
- Haussmann's interventions in Paris (in the second half of the 19th century)

Christaller 1933

Howard 1902

Taut 1920

Eberstadt, Möhring, Petersen 1910

Haussmann 19th century

CHAPTE FOUR:
SUSTAINABLE AND SUSTAINING BUILT ENVIRONMENT

4.1. Towards a Sustainable Future

Generally speaking, there is no universal valid definition for the term *sustainability*. Sustainability consists of three major aspects: *ecological* sustainability, *economic* sustainability and *socio-cultural* sustainability. These interwoven aspects with their associated multi- and interdisciplinary fields form a highly complex approach (Figure 19). Meadows (2009) points out that sustainability can be defined in various ways. Further, he adds that a sustainable society can exist over generations if it is flexible enough and wise enough not to undermine its own material and social existence.

Meadows 2009

Merl 2005, 2006

If we look back in history we see that sustainable activities were always of importance for humankind. In Europe, the first written documents dealing with resources date from the 12th century and pertain to a shortage of the energy source wood; therefore it was recognised that one should not cut more wood than the amount that could be regenerated to sustain a permanent availability (Merl 2005, 2006).

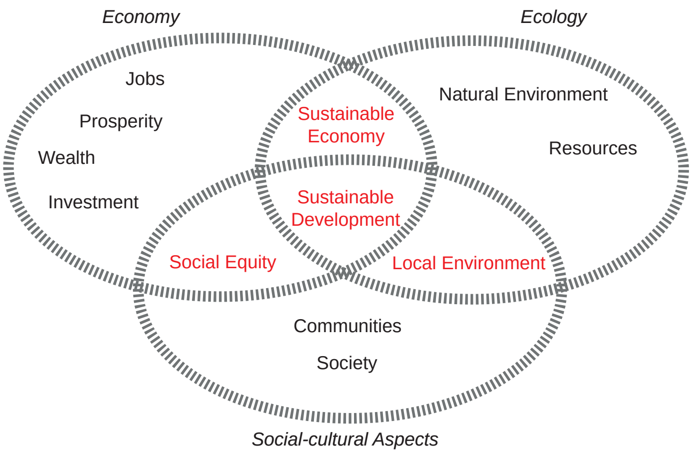


Figure 19: The structure of sustainability (modified; original: Merl 2006)

Resources are limited, and only available to a certain degree. The more sensibly we deal with resources by developing strategies[24] to minimize their use to an a necessary minimum, the more self-sufficient and self-sustaining a city or a region is. The oil crisis of the 1970s was a wake-up call that showed the potential consequences of not taking action. Later, in the 1980s, the hazard of ozone was fully recognised, and more important, the environmental movement was taken seriously. Rachel Carlsen's 1962 book

[24] The average use in Europe is approx. 6000 Watt per Person and year. Thus, at the ETH Zürich (Federal Institute of Technology Zurich, Switzerland) the concept of the *2000-Watt society* was developed. It aims to limit the emission of greenhouse gas to one tonne $C0_2$ per person and year, the amount needed to reduce global warming to max. two degrees Celsius by the end of the 21st century. A further aim is to reduce the demand for energy to 2000 Watt continuous rating per person and year – with 500 Watt from fossil fuels and 1500 Watt from renewable energy. (see: www.novatlantis.ch; www.2000watt.ch)

Carlsen 1962

"Silent Spring" is widely credited as having been one of the major factors in the launch of the environmental movement. Before the publication there was a strong opposition to it. In 1972, the Club of Rome launched a report entitled "Limits to Growth", using computer-processed scenarios for forecasting for the first time. An important document from the 1980s is the Brundtland Report by the United Nations, which defines sustainable development as "[…] development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Report, Our Common Future, Chapter II, 1987). The report also says of non-renewable resources like fossil fuels and minerals that their "use reduces the stock available 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. Thus land should not be degraded beyond reasonable recovery." This paragraph of chapter II of the Brundlandt Report repeats the content of the first-known document in Europe from the 12th century, with the one exception that new technologies are now available to minimize the impact (cf. Merl 2005, 2006).

To understand the impact of spatial planning in this context I would like to introduce the concept of *three levels of interdependency*. Minimizing the use of resources in the form of fossils and minerals is a first-level sustainable strategy as it minimizes the depletion of resources. Consumption and usage is a second-level strategy (linked to an individual's awareness of the environmental challenges) and spatial planning is a third-level strategy. Spatial planning strategies influence consumption and usage as well as production and recycling.

Merl 2005, 2006

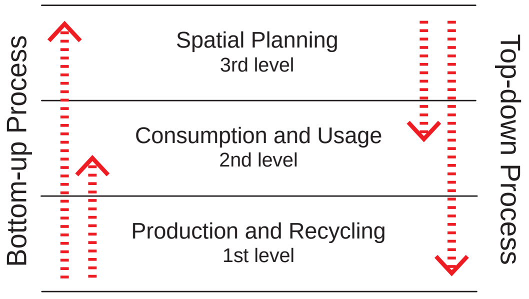


Figure 20: Levels of interdependency. Spatial planning has a direct impact on consumption & usage and on production & recycling.

Generally speaking, spatial planning is mainly a top-down process (though participation can also entail bottom-up processes). Nevertheless, the planner, by means of the planning strategy, influences individual behaviour (e.g. public transport: the easier it is for people to reach public transport stops and stations the higher their likelihood of using public transport). In additon, planners have the possibility to carry an out awareness-raising processes in order to enhance people's likelihood of acting sustainably on their own initiative (consumption and usage – 2nd level). Further, a direct action strategy of spatial planning on the 1st level is the zoning applied in the land use plan or zoning plan.

Is Robustness a Conception for a Sustainable Planning Strategy?

Robustness represents the idea of a *fault-tolerant system*, which is the property enabling a system to continue to operate properly in the event of failure (one or more faults) of one or more of its components (Wikipedia, accessed January 2011). It concerns biological systems, economic systems as well as the stability of human organisations. Nature achieves robustness through *interconnectivity* (Barabási 2003). Baran's 1964 idea for an optimal structure of the internet proposes a distributed, mesh-like architecture because the latter would continue functioning even if one or more nodes were down. We have to be aware that nature is highly flexible in order be able to readjust itself to changed environmental parameters. Thus, nature accepts a certain *sensitivity* in order to be highly efficient. Efficiency challenges the idea of sustainability.

Barabàsi 2001

Baran 1964

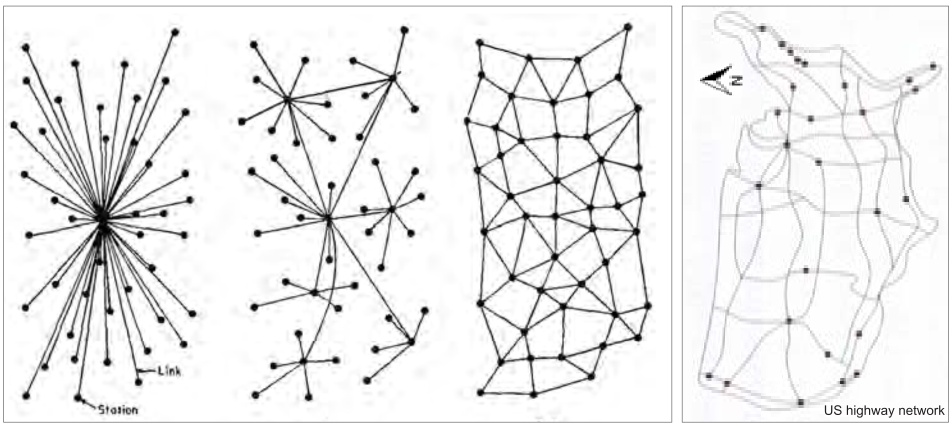


Figure 21: Baran's conceptualisation of networks (from Baran 1964) – from left to right: centralised (star), decentralised and distributed. The mesh on the far right is the most robust one. The decentralised mesh is sustainable but fragile. The US highway network shows a mesh-like distribution (from Barabási 2003:71).

Baran's conception of a network can be transposed to road networks and agglomerations, where the nodes represent settlements – a hamlet, a village, a town or city – and the links roads. In the context of spatial planning we also deal with weighted and hierarchically ordered graphs.

Barabási's diagram of the normal distribution of the US highway network where most nodes have approximately the same number of links – ideally, every node isconnected to every neighbouring node – is indeed very reminiscent of a robust network. Further, we showed before that dynamic systems in nature incorporating hubs (like metropolitan areas) follow a power law logic.

Hubs and networks (such as growing and shrinking regions) need to acquire the best fit for the respective economic and social exchange. Thus, a hierarchical street network connecting all nodes of different ranks will optimise their functional exchange and keep a robust region intact. Adapting Baran's idea for spatial purposes, we can introduce the concept of a *weighted interconnectivity.* It represents weighted graph allowing a hierarchical mode of connection between different-sized nodes (or clusters representing cities and towns; see also multifractal Sierpinski) and an equal-weighted connection for agglomerations of the same size or rank. In general, a hierarchy can be subsidiary, which means that sub-systems are more robust as they can "survive" even when links to superior levels are weakened or minimized (see small world and Granovetter's approach). This leads us to the question of the complementarity of spaces, and further to the need for more and less dense spaces and agglomerations. This will implies the following rules for a regional planning strategy:

A. Agglomerations of all sizes are connected by a hierarchical ordering principle in order to form a highly efficient region (exchange rate). Every node has to be connected with every neighbouring node of the next higher rank.

B. Main connections (roads) are weighted based on their size and rank of their nodes (cities, towns, villages), (power law distribution). The hierarchical level of the connection between agglomerations of two levels is always based on the lower rank of agglomeration.

C. Agglomerations of same size or rank have connections of the same rank for a robust network (mesh-like configuration).

D. Gravity theory can be introduced as the weighted parameter for distance d (e.g. strict rule: 0-100km $\mu(d)$ = 1; fuzzy rule: 100-500km $\mu(d)$ = 1-0).

We have to be aware that this rule set is normative and descriptive. The rules combine a hierarchical ordering principle with a mesh-like structure.

4.2. The Challenger: Centralisation versus Decentralisation

Nowadays, constellation of agglomerations within metropolitan areas often does not follow a hierarchical distribution logic (e.g. the metropolitan areas of Paris). The uniform distribution of agglomeration are driven *inter alia* by the preponderance of individual transport (carbon-intensive society). Urban patterns are increasingly being destroyed by the same forces.

This phenomenon is widely known as *urban sprawl,* which in turn can be dsubdivided into *mono-sprawl* (e.g. measuring only office development indicating office sprawl[25]) and *multiple-sprawl.* Generally speaking, European and Anglo-American towns differ based on their car user behaviour, a trend which began with the rise of cars.

[25] Office development is an important dimension of sprawl as it is a good way of understanding job growth; further it affects housing and has an impact on urban sprawl (Lang 2003, 6f).

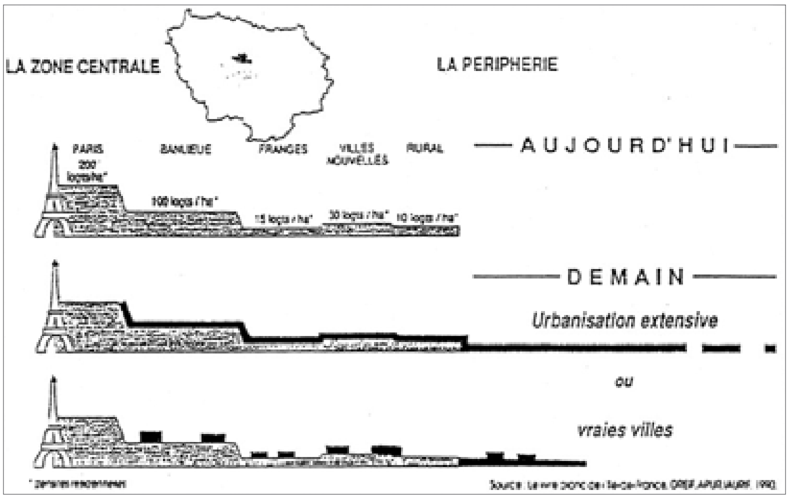


Figure 22: Hierarchical scheme for Paris metropolitan area according to Fouchier. He depicts the idea of urban sprawl through extensive urbanisation (middle) and a further scenario through creation of hubs within the metropolitan hierachy. This follows a multifractal logic. In general, the image highlights the difference between a monocentral system and a polycentral one (from Fouchier 1990).

When the car was invented (in late nineteenth-century Germany), Europeans regarded it as a luxury item for the rich, while Americans mass produced it and used it to radically *decentralise* their metropolitan areas. Same technology, but different outcomes based on different cultural predilections, as well as differences in existing transport networks, distances to be covered, and amount of land available to build roads (Lang 2003, 19). To this day, the United States remains the biggest energy consumer worldwide, where individual transport accounts for a major part of energy consumption. However, urban sprawl has no spatial order, no nucleus and no precise

Fouchier 1990

Lang 2003

edge. Lang defines a new urban concept for America's suburban regional sprawl when he talks about the *Edgeless City* as counterpart to Garreau's *Edge City* [26]. He states that Edgeless Cities are not new, but have been overlooked for a long time (Lang 2003). A few years earlier the German architect and urban planner Sieverts coined a term for the outcome of urban sprawl in Europe – the *Zwischenstadt* (in-between town) (Sieverts 1995, 1997; c.f. ville émergente in Dubois-Taine, Chalas 1998).

[26] The Edge City is any place that:
- Has five million square feet or more of leasable office space - the worksplace of the Information Age.
- Has 600 000 square feet or more of leasable retail space.
- Has more jobs than bedrooms.
- Was nothing like a "city" as recently as thirty years ago.
(Garreau 1991:7)

Sieverts 1995, 1997

Dubois-Taine, Chalas 1998

Lang sees the *Edgeless City* as a form of sprawling office development that does not have the density or cohesiveness of edge cities. Edgeless cities are not mixed-use, pedestrian-friendly areas, nor are they easily accessed by public transport. They are not easy to locate, because they are scattered in a way that is almost impossible to chart. Edgeless cities spread almost imperceptibly throughout metropolitan areas filling out central cities, occupying much of the space between more concentrated suburban business districts and ringing the metropolitan area's, built-up periphery. In contrast to some larger edge cities that combine large-scale office with major retail development, most edgeless cities contain isolated office buildings or small clusters of buildings of varying densities over vast swathes of metropolitan space. They are low-grade commercial fillers. Edgeless cities are not cohesive enough to pretend to be cities (Lang 2003, p. 1ff, p.10).

To summarise, Lang sees in the drive for office development the force behind the development of Edgeless Cities. Due to an accumulation process, office development reflects job growth and further attracts housing development, which itself attracts services and facilities (without location affinity between office buildings and shopping malls as in the edge city theory). An edgeless city has no incommon spatial logic and pattern (structure) with a traditional monocentric or polycentric city. The individual household becomes the geographic centre and the daily movement patterns (by car) are the spatial outcome. Morphological patterns, centrality and proximity are superseded.

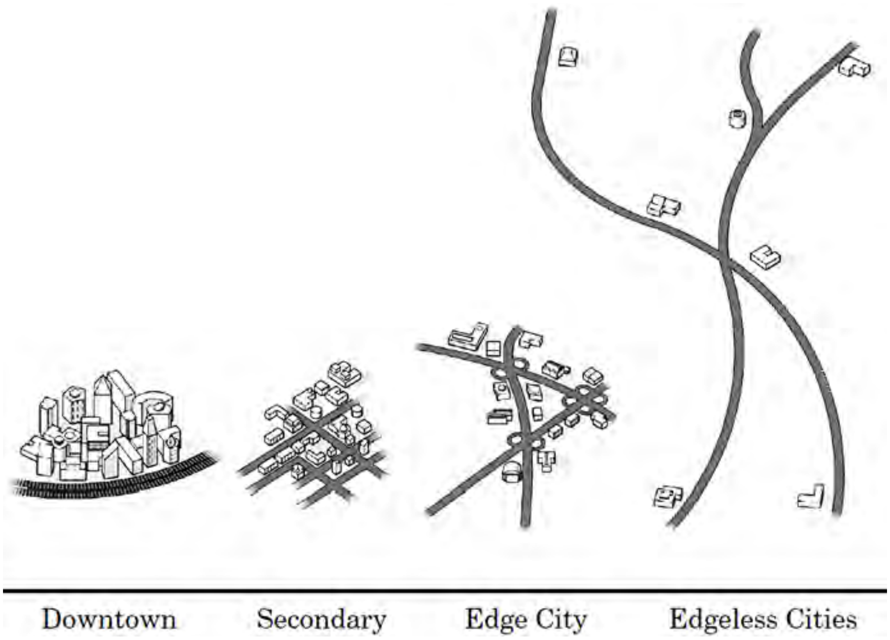


Figure 23: Office location type (from Lang, Le Furgy 2003:429)

The compound and generalised approach to Lang's Edgeless City is Sieverts' *Zwischenstadt*, a decentralist oscillating between an arbitrary diversity of morphological patterns and non-patterns. The Zwischenstadt is readable in terms of its roads (which provides accessibility to the different site, author's note) and, above all, is embedded like an archipelago in the sea of a tangibly cohesive landscape. The landscape has to be the real binding element of the Zwischenstadt [27, 28] (Sieverts 1997, p.20).

The *Zwischenstadt* has no hierarchical ordering principle, no centralisation forces. Another main indicator is its uniform distribution. The concept of the Zwischenstadt takes the inverse approach to Lang and Garreau as it sees the "true" cohesion in green open space and not in buildings. For Sieverts the *Zwischenstadt* model is an international phenomenon in contrast to Lang's Edgeless City model, a theory exclusively built upon Anglo-American urban growth indicators that mirror American urban sprawl. The Zwischenstadt is neither city nor countryside, it is unmarked. The attribute "unmark" can also be found in Lang's concept.

The *Zwischenstadt*'s emergence and expansion is triggered by the globalisation of capitalist industrial production and its inherent lifestyle and settlement patterns. Despite the differences between the various types of *Zwischenstädte* (based on cultural, economic and topographic indicators) they have a diffuse, disordered structure of different quarters with isolated islands of geometric patterns; a structure without a clear centre, but

[27] Original citation: "Die Zwischenstadt kann eine beliebige Vielfalt von Siedlungs- und Bebauungsformen entwickeln, solange sie insgesamt in ihrem Erschließungsnetz lesbar und vor allem wie ein "Archipel" in das "Meer" einer zusammenhängend erlebbaren Landschaft eingebettet bleibt: Die Landschaft muß zu dem eigentlichen Bindeelement der Zwischenstadt werden." (Sieverts 2008 [1997], 20)

[28] The *Zwischenstadt's* character differs from continent to continent. According to Sieverts, Asian metropolitan areas tend towards Hilberseimer's city concept, whereas American ones polarise between Hilberseimer and Frank Lloyd Wright's Broadacre City; and German metropolitan areas are a mix of Le Corbusier's Ville Radieuse and Broadacre City (Sieverts 2008 [1997]).

one with more or less strong functional specialised areas, networks and nodes. Sieverts' *Zwischenstadt* has no identity of its own, whether for its inhabitants or in political terms (Sieverts 2008 [1997]) .

Sieverts 1997

The *Zwischenstadt* its at the most identifiable where historic, traditional urban forces have no impact. One example Sieverts states leads directly back to Lang's edgeless city concept, when he quotes Fishman to explain the trend for living in proximity to workplaces, thus negating central places (as a historic compact conception).

Fishman explains decentrist development through the American trend for developing shopping malls and office buildings next to highway access points, thus catalysing settlement development (Sieverts 2008 [1997], p.16f). Both Lang and Sieverts are in line with Fishman's decentrist argumentation that the new suburban forms are a kind of chaos with no coherence between different functions, e.g. housing, industry, commerce and agricultural uses (Fishman 1987, Sieverts 2008 [1997], Lang 2003).

Fishman 1987

Sieverts 1997

Lang 2003

The idea of cohesion is the key attributes distinguishing *centrists* from *decentrist*. Garreau's Edge City claims a location affinity between office space and shopping mall, representing the traditional urban concept of a *loose compact city model*. The edge city can be seen in relation to a centralised decentralisation model or in other words a polycentric model.

Generally speaking, metropolitan areas form partly represents a compromise between forces that centralise and those that decentralise. The respective power of the two forces shifts with changes in technology, culture, economic production, regional scale, intergroup relations, social and political organisation, physical and regulatory constraints, demographic composition, and popular tastes. The existing built environment is also influenced by centralising and decentralising forces. Many of these variables differ dramatically from region to region, producing a nation of different contexts, different compromises, and corresponding different metropolitan forms. Those multiple forms are one reason why both centrist and decentrist perspectives can coexist (Lang and LeFurgy 2003, p.434).

Lang, Le Furgy 2003

However, we have to be aware that different metropolitan forms are subject to a basic, archaic formation pattern (a basic rule) – even when the force is influenced by complex dynamics (which is already a main school of thought in urban theory). On a meta-level, we can hypothesise that coexistence of multiple forms also follows a certain basic logic.

Element	Centrist Perspective	Decentrist Perspective
New metropolitan centers	Edge Cities, urban villages	Households
New metropolitan form	Polycentric	Postpolycentric
Key structuring force	Agglomeration economies	Personal mobility
Connection to traditional urban structure	Strong	Weak
Clustering of key urban elements (malls, offices)	More common, predictable, with clear borders	Less common, random, with fuzzy borders

Table 2: Comparing centrist and decentrist (from Lang and Le Furgy 2003:433)

In summary, the phenomenon of urban sprawl or polycentric cities arises due to a combination of land prices, commuting and the wish for individual family houses with a garden[29], and due to historic circumstances.

In reality, surveys have shown that a high percentage of people prefer households close to green areas, low-density developments and quiet residential areas, which are important factors in location choice (Gault and Bedeau 2007; Guo and Bhat 2002; Schwanen et al. 2004; Czerkauer-Yamu, Frankhauser 2010, 1;) (this will be discussed in more detail later).

Thus, the solution for an economic, ecological and social balance is to find ways of 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) was the first to reflect on the extent to which planning concepts having reference to fractal geometry could be of interest for reducing negative impacts of urban sprawl.

[29] LES FRANÇAIS ET LEUR HABITAT Perception de la densité et des formes d’habitat, TNS Sofres, Département Stratégies d´Opinion/Société 2007.

Gault, Bedeau 2007
Guo, Bhat 2002
Schwanen et al. 2004
Frankhauser 2004
Czerkauer-Yamu, Frankhauser 2010

4.3. Sustainable Metropolitan Area

Let us recall that sustainable planning (understood from its definition in the Brundtland Report, 1987) deals with 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 road networks; land use, movement economy; access for all to jobs, retail, services, healthcare, culture, and leisure), (Feldman 1990, Bolitzen and Netusil 2000, Bonaiuto, Fornara et al. 2003, De Clerq, De Wulf et al. 2006, Barbisa, Tratalos et al. 2007, Braubach 1997, Conway 2008).

Feldman 1990
Bolitzen and Netusil 2000
Bonaiuto, Fornara et al. 2003
De Clerq, De Wulf et al. 2006
Barbisa, Tratalos et al. 2007
Braubach 2997
Conway 2008

In order to reduce urban sprawl and fulfil the Brundtland Report Agenda, numerous authors recommend going back to the concept of compact cities. Thus, the compact city concept is an attempt to respond to changes in the urban morphology in the second half of the twentieth century. It is the reverse trend of the “dispersed cities” and the decomposition process better known as urban sprawl. A more vague definition is based on the comparison of American cities with European cities (Frick 2008). Thomas et al. compare initial impressions of the compact city concept as a concentrated medieval city, whose limits are clearly visible, and where the hub of daily activity is confined within the city walls (Thomas et al., 1996, 54). Christaller (1933) points out that one of nature’s basic forms of ogranisation is the centralistic ordering principle. Thus, the medieval city complies with the human nature as it underlies this centralistic logic. In addition, the external form of a medieval city is in line with its inherent functional logic. This may be one of the reasons for the pleasing aesthetics of a medieval town.

Czerkauer-Yamu,
Frankhauser 2010

Frick 2008
Thomas et al. 1996

Christaller 1933

Conversely, Frick (2008) not only thinks of the compact city concept on an urban scale, but also on a regional scale as the spatial relationship between diverse and differentiated agglomeration units known as *decentralised concentration*. It should also be recalled that this idea is already found in Howard’s Garden City concept as so-called *multiple extension*.

Frick 2008

Its foundations can be found in various centralised and decentralised concepts connected with efficient and intelligent infrastructure; more important , however, are its inherent characteristics. Hence, intensification of land use and density of population as well as mixed land use and mixed activities seem to be the response to the compact city vision. Authors such as Mayer Hillman (1996) who favour the compact city concept interpret

Mayer Hillman 1996

the idea in the context of its social effects (based on the two-class society of car-owners and non-car-owners; the discussion around transport efficiency was given impetus by the work of Kenworthy and Newman (1989)).

Kenworthy, Newman 1989

For Mayer Hillman (1996), the phrase "access for all" encapsulates the benefit of a compact city concept which is further linked to economic and ecological impacts.

Mayer Hillman 1996

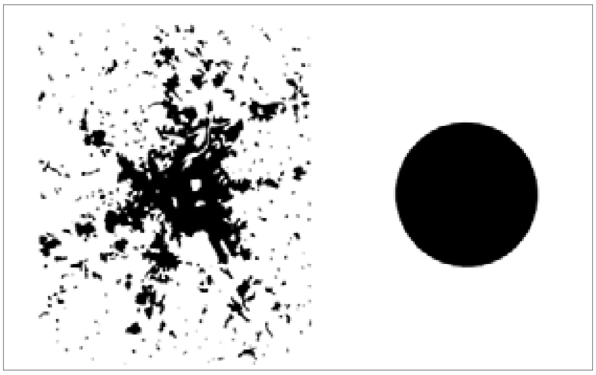


Figure 24: Figure ground plan of Berlin (left) in contrast to a circle with equal area (Humpert et al. 1991 in: Czerkauer-Yamu, Frankhauser 2011:28).

However, policies favouring the *Centralisation Concept* have turned out to be less efficient than expected. Authors such as Breheny (1996) and Schwanen et al. (2001, 2004) do not see the *Compact City Concept* as the overall and only solution for a sustainable planning strategy, claiming that a centrist will not deliver the environmental benefits on the basis that e.g. traffic congestion results in longer travel times. Schwanen et al. (2004) found out that a strict compact city policy seems to have some positive outcomes (lower travel distance, higher shares for public transport, cycling and walking), but it may encourage suburbanisation of households to lower density in the long term because of travel time considerations. Therefore, Breheny (1996) questions whether the compact city model in general can hinder decentralisation and the implementation of green land reserves in an urban system, as the latter is of prime importance for a high quality of life in cities. Green wedges act as recreation and leisure areas as well as being important for the urban microclimate.

Breheny 1996
Schwanen et al. 2001, 2004

	Reduction of driving	Stimulation of public transport	Stimulation of cycling and walking	Shorter travel distance (private car)	Shorter travel time (private car)
Policy of concentrated decentralisation (1970s and 1980s)	=	+	−	−	−
Strict compact-city policy (1980s and 1990s)	+	+	+	+	−
A-B-C location Policy	=	+	=	=	=
Retail planning	+/+ +	=	+ +	+	−

'+' policy made positive contribution; '=' policy had little (neutral) effect; '-' policy made negative contribution.

Table 2: Performance of national planning policies in the Netherlands (from Schwanen et al. 2004:597)

Jenks et al. concludes that the urban form that provides the most efficiency for transport and reduced car journeys is that of *decentralised concentration*. He further acknowledges that the savings in terms of greenhouse gases are not great, but that the concentration of areas (decentralised or within a city) provides proximity and accessibility to services and facilities, giving the chance of success for a modal shift from the car to cycling or walking. It is largely accepted that, however convenient, this will not encourage the majority to give up their cars. What may be gained in reduced car use for short journeys will make little overall difference when longer, often leisure -oriented journeys are taken into account. It is in this respect that the decentralised concentration model, if linked by good public transport (and eco-transport) may make some gains (Jenks et al., 1996, 342). Thinking in the same direction, Gordon et al. (1997) and Levinson et al. (1994) support the view that *decentralised structures* for a well-balanced solution tend to reduce commuting distance and commuting time. Schwanen et al. (2004) states that *concentrated decentralisation* (development of growth centres) stimulated the use of public transport (in his example of the Netherlands).

Jenks et al. 1996

Gordon et al. 1997

Levinson et al. 1994

Schwanen et al. 2004

The above-mentioned authors' line of thought leads us directly to Frankhauser's work on a fractal regional concept (Frankhauser 2007) combining a concentrated decentralisation of settlements with green wedges and public transport.

Frankhauser 2007

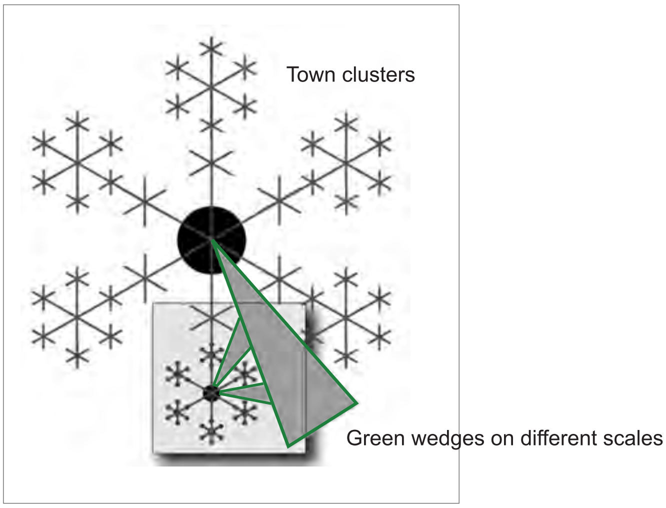


Figure 25: The structural approach of Frankhauser's regional fractal model (left), (from Frankhauser et al. 2007) providing town clusters similar to Howard's Garden City concept and Calthorpe's TOD.

In summary, the key to a sustainable and robust region is a *decentralised centralisation*, or as Calthorpe (1993, 2001) calls it, the *network metropolis*– with an inherent hierarchical ordering principle (cf. New Urbanism).

4.4. Sustainable City

Built Form and Transport

Transport and built form are causally linked to each other. In general, self-organised systems[30] or historically grown systems mainly have sustaining and sustainable patterns (deformed wheel with radials[31]).
Radial and orbital movement corridors are part of a linear development where density is graded and increases towards the centre (e.g. historic core). A consolidated linear development often arises historically from what was first a historical supra-regional road, ergo a *linear development*.
Thus, linear development can be part of a city or in a radical formulation can be implemented as a city itself as in Soria y Mata's *Linear City Model* (1894). Lynch points out that the concept of a linear city has repeatedly been rolled out as a new theoretical idea, but has rarely been applied (Lynch 1981:376). The linear city has no clear and dominant centre, as the underlying idea is equal access to services, facilities, culture, education, and green open space. Growth is simply accomodated by extending the line. This idea can be further found in Wright's *Broadacre City* (1932) or Le Corbusier (1887-1965) in France.
Lynch highlights the fact that the model has its flaws. The distancees between the elements are much greater thean in a compact city, and the choice of connection or of direction of movement is greatly reduced. While everyone lives on the main line, main line transportation cannot stop at every point along that line. It necessarily stops at stations, so that while a position elsewhere on the line is highly visible, it is nor more accessible than is some more remote interior point. This is true even for the car on an expressway, where flows are heavy and distance long. This may explain why the linear form does not work at smaller scales, since foot traffic, canal boats, bicycles, travelators, slow-moving trams, and even cars on low- capacity roads can all stop and start almost anywhere on the line (Lynch 1981:377). Hence, the model lacks of a clear hierarchy of centres further supporting an efficient modal split form a local to a city-wide scale. Lynch further highlights the fact, that centres are also psychologically important (Lynch 1981).
In contrast, a linear development addresses the idea of linearity and intensity of land use in proximity to the main arterial road, but also further implements a hierarchical ordering principle of interwoven main roads, secondary roads and tertiary roads (route hierarchy).

[30] N.b. Self-organisation is not a guarantee for "good" or "bad" developments, but depends on certain structures under certain conditions (cf. multi-criteria planning approach). Within the idea of self-organisation planers and institutions, lay persons and the public are incorporated which enhances a successful self-organisation process (cf. de Roo, Silva 2010).

[31] Space Syntax analyses of Vienna (2007), Dublin (2008), Berlin (2011), and other cities highlight the structure of a so-called deformed wheel. (for Vienna see Czerkauer 2007:151; for Berlin see Arch + 2011:23; for Dublin see Space Syntax Ltd. 2008)

Lynch 1981

Soria y Mata 1894

Wright 1932

Lynch 1981

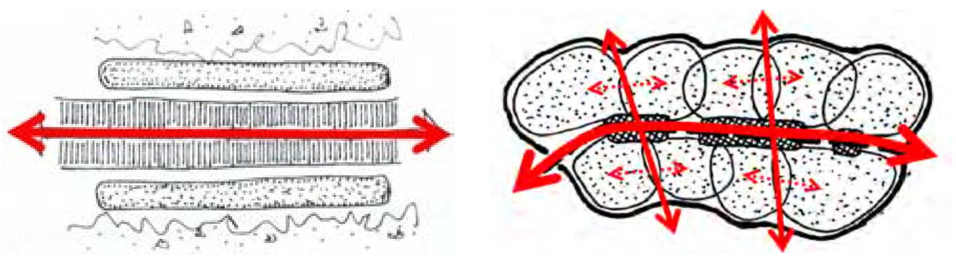


Figure 26: left: Soria y Mata's Linear City Model (1894), (from Lynch 1981:376); right: A linear development including route hierarchy (modified, original: SSx Ltd.); the model is partly based on Soria y Mata's model. According to Lynch, Mata was concerned with health, open space, cheap housing, and easy access for people of moderate means (from Lynch 1981:86).

Lynch 1981

This built form of a *linear development* maximises public transport viability along main arteries. Mixed use is found in areas with higher density and facilities are located on or offset from the central or main road corridor. As an urban continuum the form displays a series of fuzzy neighbourhoods and its boundaries are dynamic through time (Barton 2005). It has high levels of permeability between the neighbourhoods and a clear route hierarchy. Pedestrian movement can be the main mode on a local scale.

Barton 2005

Depending on the scale and detail of the urban form, connectivity, urban grain and permeability[32] can vary greatly. This will influence the level of accessibility and functionality of the neighbourhood within the bigger picture - the whole urban system. However, the urban hierarchy of the network can be spread by introducing a bypass route on an intermediate scale, preventing congested main roads. The diagram (Figure 26; right image) shows a single strand of development but it can also be developed as a double strand or even along two or more parallel routes.

[32] Permeability answers – where you can go – and is strongly linked to visibility – what you can see (Güney 2007).

Conversely, another scheme is the *clustered development* (Urban Task Force [Rogers] 1999, Barton 2005). The intensified cluster has a clear urban centre and sub-centres (distinct neighbourhoods).

Barton 2005
Rogers 1999

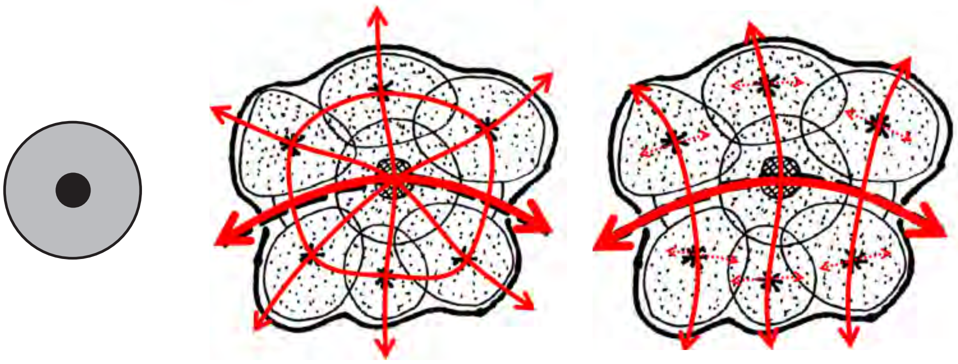


Figure 27: On the left the “mono-cluster”, a compact city model with an historic core; the compact city model has no distinct neighbourhoods.
Middle and right: Various clustered developments (modified; original: Space Syntax Ltd. 2008); the image in the middle, in particular, is reminiscent of a Christallerian logic. Herein, we also find the logic of a deformed wheel (radials and orbitals), (see middle image). This is reminiscent of Frankhauser’s fractal town clusters.

The design intention behind this urban form (Figure 27) is to develop a series of inter-related neighbourhoods around a district centre. In its built form it makes reference to Ebenezer Howards’s Garden City idea and even more to Christaller’s Central Place Theory model. However, it can also be linked to the idea of New Urbanism by maximising the number of people within walking distance of the district centre. It delivers a compact sense of place and order (Roger, Power 2000) which is the hallmark of popular inner neighbourhoods, districts, historic towns and villages.

Howard 1902

Christaller 1933

Roger, Power 2000

Barton 2005

Each neighbourhood is based on a high degree of mixed use with a well-defined core. The boundary of each neighbourhood can be fuzzy. Again, density is generated and increases first towards the district centre and further towards the hub (core) of the archetype. The archetype also has lowest density in the interstices between the cells, where, according to Barton (2005) education and small-scale green space can be sited. The distinct cells can also overlap in these areas as they are served by secondary routes and are therefore consistent in their accessibility. Further, the model contributes to formationing the identity of the diverse neighbourhoods.

In contrast, a fractal development model marries both an axial and clustered development.

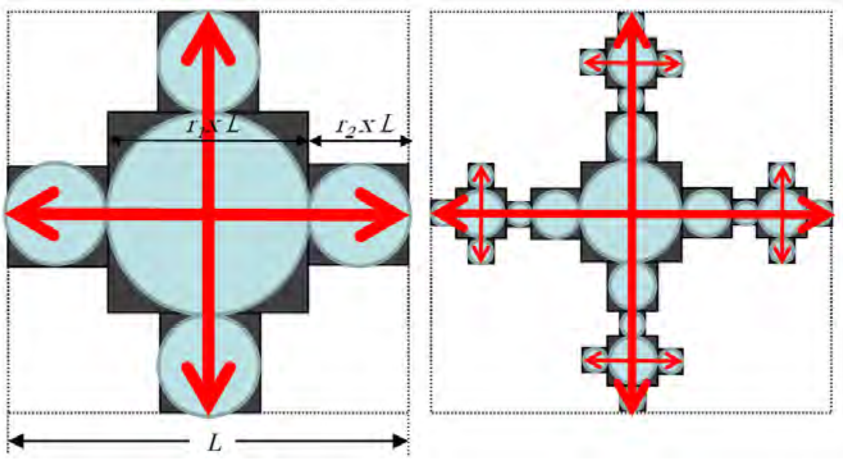


Figure 28: A fractal logic for regional and urban planning with arterial roads (from Czerkauer-Yamu, Frankhauser 2010).

Frankhauser, Czerkauer-Yamu 2010

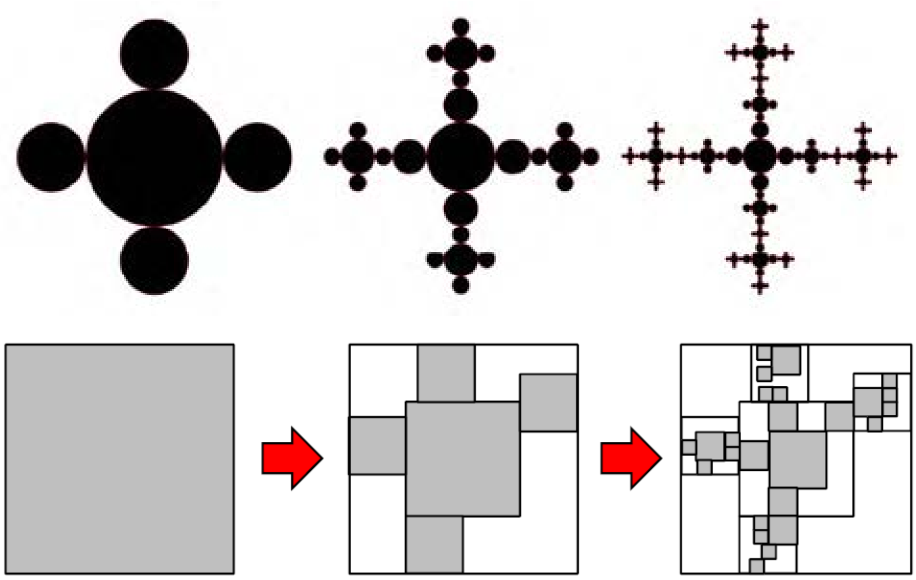


Figure 29: Masterplanning with fractals: the shape of the inital figure may be different. Further, the generator can be adapted to real-world situation by means of the following operations: The position of elements may be changed - even in the course of iteration - if previously generated lacunae are respected and overlapping of elements is avoided. In this way it is possible to combine more than two reduction factors (becoming rather complex) as well as a number of elements (Czerkauer-Yamu, Frankhauser 2011).

Czerkauer-Yamu, Frankhauser 2011

The fractal idea leads to Calthorpe's (1993) Transit Oriented Developments model (TOD). Based on the idea of compactness it shows an integration of fractal planning on a neighbourhood scale. Calthorpe addresses the idea of reshaping suburban sprawl into walkable settlements served by public transport. A development area comprises a surface covered by a maximum radius of 400-600m (5-10 walking minutes; as a 10-minute walk 800m (Space Syntax Ltd. London)) with different land uses and urban grains. Critical abut Calthorpe's model is the separation of activities and uses which will not refer to a sustaining and sustainable planning model; even the model refers to the accessibility of daily needs within minutes.

Calthorpe 1993

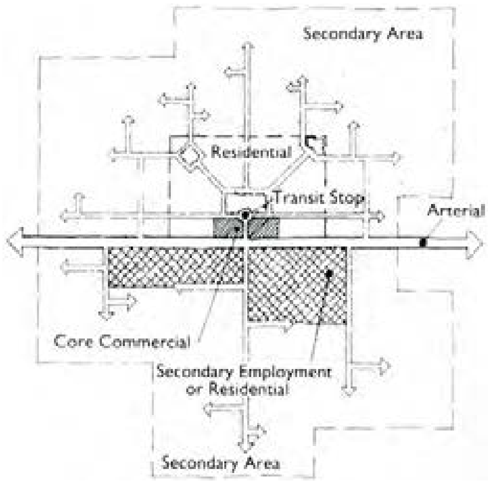


Figure 30: Calthorpe's TOD (right) on an intermediate urban scale
(from Calthorpe in: Jenks et al (eds) 1996:330).

Let us recall that urban patterns after the industrial revolution show a fractal organising principle, even when perceived as amorphous (Shen 2002). This hierarchical ordering principle is changing with increasing car traffic (urban sprawl) towards an uniform distribution of settlements, and even remote, rural settlements are showing disproportionate growth (Frankhauser 1998). The axial growth along transport axes as found in Berlin or the *Copenhagen Finger Plan* (1947) mostly corresponds to a fractal logic. The hierarchy of centres is highly reminiscent of a Christallerian logic (1933). In Christaller's theory the settlements are uniformly distributed. In the spatial planning logic with fractals the cores of the settlements are in proximity to transport axes which are the axes for public transport. The nodes are preferred locations for services and facilities and are hierarchically ordered based on their frequentation.

Shen 2002

Christaller 1933

This approximates to the idea of a *City of Short Distances.*
It optimises the energy efficiency of an urban and regional structure. In addition it adds value to the concept of an *Ecocity* [33]. With a fractal planning strategy the guidelines for an Ecocity can be achieved and surpassed.
Generally speaking, a fractal planning logic marries the advantages of an axial (linear) development with those of a clustered development.

[33] *Ecocity. A better place to live* - reserach project by the European Comission, DG Research, under Key Action 4: "City of Tomorrow and Cultural Heritage" of the Thematic Programme "Energy, Environment and Sustainable Devlopment", 5th Framework, 2002-2005.

Sustainable Accessibility

Based on the traffic collapse of megapolis (e.g. as in Asian cities) adequate public transport and sustainable planning strategies are crucial for today's mobile society. In general, the focus has shifted from the idea of a transport infrastructure to the provision of accessibility. We must be aware that the term accessibility itself is a slippery notion and that it is hard to define and measure. Accessibility defines the ease of reaching a destination or interaction (Hansen 1959, Allen et al. 1993) from a specific location. It also takes into account the degree to which the transport system enables people to reach a specific activity or destination by combinations of various transport modes. For Morris accessibility measures the spatial separation of human activity (Morris 1979). Efficient provision of accessibility not only depends on the attributes of a transport system, but in particular on the spatial distribution of attractions and facilities. Cerwenka, Hauger et al. (2007) define two criteria for improving accessibility: Either the reduction of travel time for reaching a certain location; or the inclusion of one or several important and attractive locations by expanding the catchment area for an equal travel time.

Hansen 1959

Allen et al. 1993

Morris 1979

Cerwenka, Hauger et al. 2007

Accessibility is also linked to costs that affect each person individually. The challenge is to plan a consistent and coherent whole balancing transport infrastructure and land use.

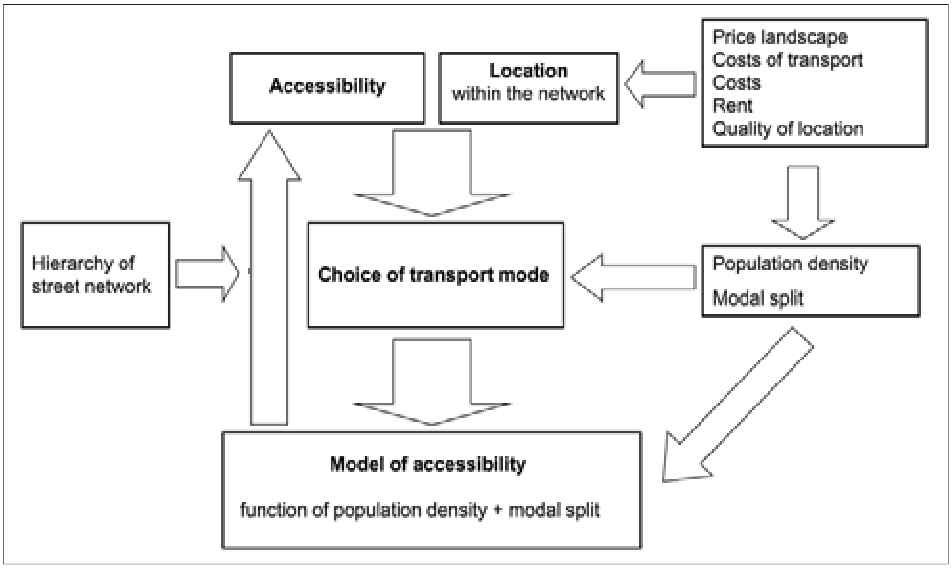


Figure 31: Interdependency of accessibility and socio-economic factors
(modified; original: Rau 2008:21).

Accessibility always refers to people or businesses depending on certain activities (housing, work, education, consumption, production). Therefore, these activities are indicators for evaluating accessibility. It is hard to quantify accessibility as the complexity lies in the wide range of aspects and attributes such as centrality, transport costs, connectivity, and integration for different models. The quality of a location (node in the network) and its relative relation to the whole network is therefore a key concept of accessibility. When considering transport and traffic in models, spatial distribution of uses (services, facilities and housing), i.e. land uses, as well as density (see also distance decay models[34]) is also crucial. This dimension will represent a realistic measure of accessibility as it answers both the questions of "what is reached" and "how it is reached". An integrative concept indicates a potential measure of interaction and can be approached by taking into account the costs of ease of reaching a destination (Bleisch 2005). The advantages of accessibility for individuals are time and cost savings in terms of consumption and production. It leads to an increased quality of life, more choice, and more chances for higher profit and income.

The spatial pattern of a city or a metropolitan are reflects transport costs and ground rent. Haig (Theory of Urban Land Values [ökonomische Theorie der Stadtstruktur] 1928) sees the economic rent and transport costs as complementary parts of the total costs. In his view the spatial structure of a metropolis is driven by the minimizing of these costs.

[40] *Distance decay* describes one of the basic concepts in analytical geography. It emphasises e.g. the idea of a centre-periphery gradient. Two major concepts exist: gradient of population density and gradient of land price. (Lichtenberger 1991).
In more general terms it describes the effects of spatial or cultural interaction based on distance

Bleisch 2005

Haig 1928

Alonso (1964) suggests an economic theory – the bid rent function theory – where single decision makers, companies or households are interested in minimizing transport costs and rent while at the same time maximising the used space (an extension of Von Thünen's theory of 1826). Alonso posits a "rent paying ability" indicating the biggest revenue from a location. This revenue depends on the accessibility of the city centre.

Alonso 1964

A criticism of Alonso's theory is that it assumes of only one city centre, the symmetric distribution of transport costs (not taking into consideration attractivity of a location, environmental quality, growth direction of a city). Alonso's model (1964) also fails to take into considertation planning restrictions (as e.g. zoning plans) and the 3rd dimension (building height classification), (cf. Lichtenberger 1991).

Von Thünen 1826

Lichtenberger 1991

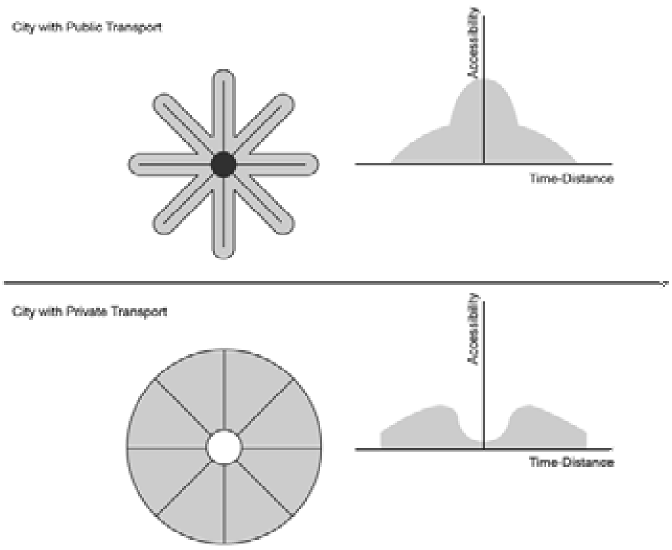


Figure 32: Based on Alonso's theory (1964) an explanation was found for the decrease in accessibility with increasing distance from city centres – for radiocentric city systems (from Allpass 1967 in: Lichtenberger 1991:106; modified).

Allpass 1967

Cities as Travel Markets according to Metcalfe's Law [35]

The size of the networks *S* grows non-linearly as nodes are added to the network. El-Geneidy and Levinson (2006) assume that the growing network increases in value since in their opinion people are more willing to pay more for goods of higher value. Thus, people would pay more to live in a larger network. This brings us back to Christaller's theory and the impact of hierarchy. Accessibility differs from network size S in that sense, that it is not can be differentiated in divers types (hence can be seen from many viewpoints what makes the definition of the term so vague), multiplies interaction by travel costs, time and distance.

[35] Metcalfe's Law states that the value of of a telecommunications network is proportional to the square of connected users of the system (n^2). (www.wikipedia.com, accessed 22.02.2012)

El-Geneidy, Levinson 2006

$$S = N\,(N\text{-}1) \qquad [4]$$

where:
S = the size of the network (number of markets)
N = number of nodes

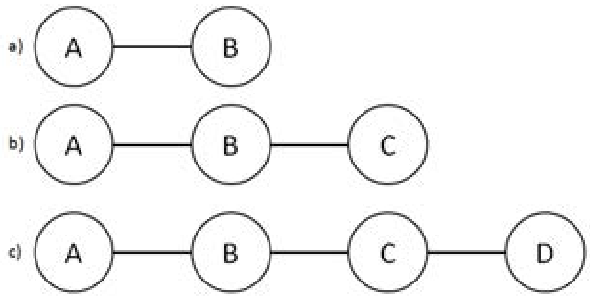


Figure 33: Law of Networks
a) shows two cities being represented as two nodes with two travel markets (2^1): AB, BA. b) adds one link and one city, but the travel markets (in total 2^3) increase in accordance with Metcalfe's law to: AB, BA, AC,CA, BC, and CB. c) another link and city are added, the travel market (in total 2^4) increases by the following travel markets: AD, DA, BD, DB, CD, and DC; still having AB, BA, AC,CA, BC, CB (from El-Geneidy, Levinson 2006)

The Sustainable Transport Egg and the Idea of an Ecological Network

Gaffron, Huismans et al. 2005

The pattern of people's activities is always linked to the transport mode. Hence, Gaffron, Huismans et al. (2005) states that the structure of activity locations forces people to use transport and further influences the transport mode they choose. Travel activities are always a combination of land use (services and facilties) and transport offers. Thus, Gaffron and Huismans et al. (2005) suggest using a hierarchical ordering principle by ranking of preferences. Preference should be given to those transport modes that diminish the need for transport. The *Sustainable Transport Egg* depicts this idea.

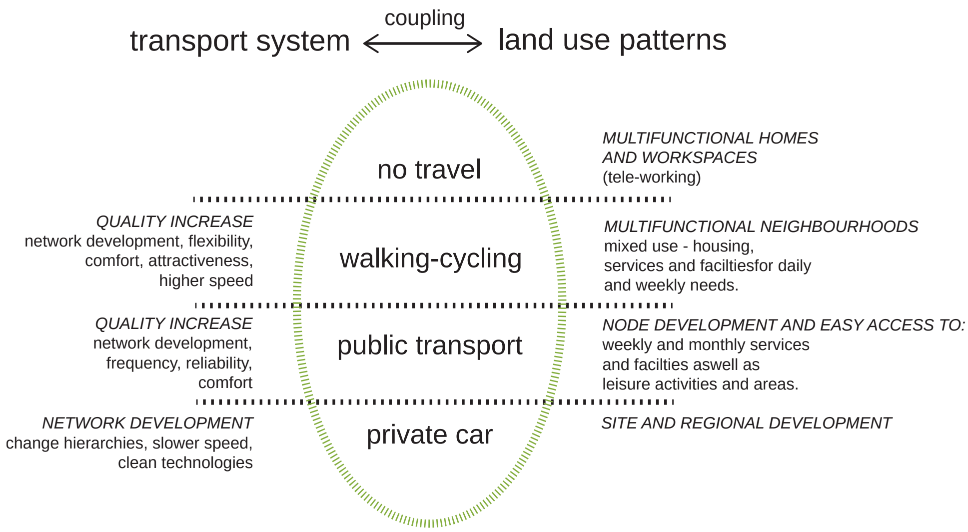


Figure 34: The sustainable transport egg
(modified; original from Gaffron, Huismans, Skala 2008:29)

Spatial planning strategies have to consider and integrate transport modes and nodes. Sustainable planning should rank the transport modes in accordance with the *Sustainable Transport Egg*: pedestrians and cyclists first, follwed by public transport and finally private car use (only when necessary). The costs of infrastructure for public transport determine their function for achieving the best results:

- Rail best serves corridors (linked to weekly and monthly needs and commuters travelling to work). Rail stations tend to concentrate attractive services and facilties.
- Buses are more flexible as their route can be changed. The costs of infrastructure are less expensive. Buses have the potential to connect more dispersed locations (but this should not support urban sprawl!)

Routes and route choices as well as the idea of corridors brings us back to the network idea. In order to provide high accessibility the overall network from a local to a region-wide scale has to be efficient and to serve people's need and demand for access to services and facilties as well as leisure areas.

Thus, cities and towns schould be designed as networks linking together residential areas to public space and natural green open areas and corridors with direct access to the countryside (Urban Task Force, Rogers 1999). If the network is realised in a highly efficient way the idea of *access for all* can become true. A diagram from Andrew Wright Associates (1999) illustrates this idea of a hierarchical organisation for sustainable access (and connectivity).

Rogers 1999

Andrew Wright Associates 1999

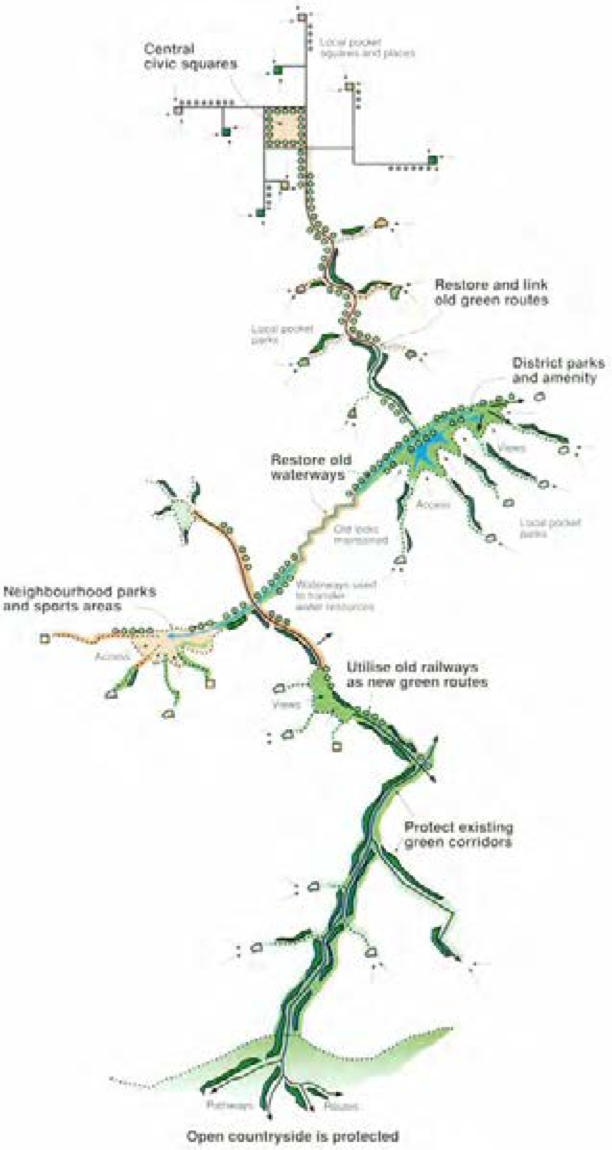


Figure 35: The regional network for sustainable access (from Andrew Wright Associates 1999:58).

In this context we also introduce the notion of an ecological network. The idea of access for all also needs to incorporate the needs of fauna. Both, the road network and the ecological network must be interwoven in such a way that they provide access to both people and animals (e.g. wandering possibilities for deer) (cf. fractal logic for planning).

However, accessibility brings us back to the idea of well-connected cities and regions. In this context the question of organisation of agglomerations to provide sustainable accessibility arises. We have already discussed the idea of density and how public transport can concentrate activities as suggested by TODs. In terms of access density plays a key role as it indicates capacity for transport. Sustainable access needs moderate density to function efficiently. For cities Rogers suggests 100 people per hectare (Rogers 1999, p.61) as the threshold to support good bus services and a socially mixed population. (His assumption is based on White 1975, Addenbrooke 1981 and University of the West of England [UWE] 1995.) Further, Rogers proposes in contrast to the compact city model an alternative model founded on the idea of a *decentralised centralisation* for cities which can easily be translated into a regional model. The advantages of his model are that compact centres are more vibrant whereas local facilties become more vibrant as well as they are within walking distance. Alternative public transport hubs are more affordable.

Rogers 1999

White 1975

Addenbrooke 1981

UWE 1995

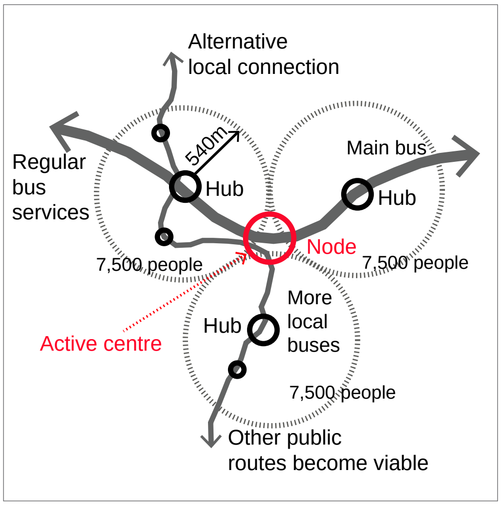


Figure 36: The idea of a decentralised centralisation for cities in the context of accessibility and connectivity (modified; original: from Andrew Right Associates in: Rogers 1999:61).

Density and Green Open Space

Built forms always possess a certain *density*.
Density, all its various forms, is a complex but substantial issue, which has many connections with the value of a settlement (author's note: in the context of planning). Plagued by numerous myths, it nevertheless has a very real impact on the performance dimensions, which must be traced out in any given situation (Lynch 1981, 265). Thus density is an ideological term which is both a measure and a concept at the same time.

Lynch 1981

Sensitive and careful design combined with an appropriate mix of building heights, plot coverage, and open green spaces can produce attractive high-density areas within a city. Increased density around transport hubs and centres is a sustainable planning and design strategy. Thus, the urban capacity increases. However, density has to follow the population pattern. Density also means neighbourhoods. Making them work as communities in line with the traditional patterns can make communities in a long run more viable and sustainable in the long run.
The continental European scheme consists of concentrated buildings, mixed uses, clear openings along the street, attractive facades, planned public spaces, and gardens with a cluster of activities and high density. Density does not mean being overcrowded. Density interacts with open space. On a superordinated level open space defines the sum of all unbuilt areas of an agglomeration. It is differentiated by its usage as: private space, communal space, public space.

To support a sustainable concept a mix of all three types is important to serve the maintenance and improvement of the urban microclimate, ecological variety and diversity; maintenance of leisure facilities for improving the quality of life; and conservation of land and groundwater.
Green areas are mostly important for cities and regions. The functions of green areas are (cf. Vogt and Marans 2003; De Clerq, De Wulf et al. 2006; Gill, Handley et al. 2008):

Vogt, Marans 2003
De Clerq, De Wulf et al. 2006
Gill, Handley et al. 2008

- leisure and adventure
- habitat for fauna and flora
- urban microclimate and urban hygiene function

The higher the density is, the lower the amount of open space *vice versa*, depending on the density typology carried out. Of course, huge variances exist, if we think of Mies van der Rohe's archetype. To be sustainable it is important to introduce a threshold for green space as a bottom limit. This can be compensated by higher buildings. The overall density stays the same.

Mies van der Rohe

In contrast, the fractal law as used for the multifractal decision support system contains a proportion factor which is a natural *intensive land use value* preventing the green area from being zero.

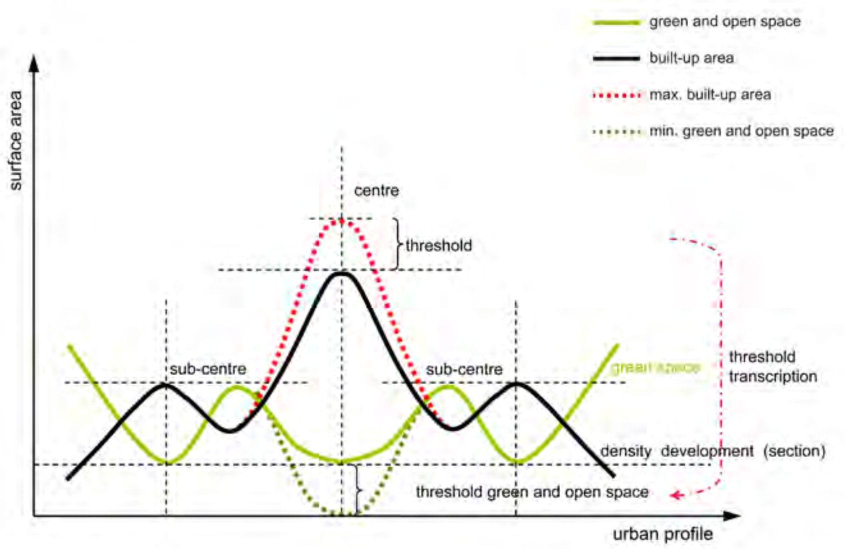


Figure 37: Relationship between density, height, green space and open space.

A high-rise development standing in open space (like Mies van der Rohe's or Le Corbusier's[36] architectural inventions) will not provide appropriate space for private gardens or amenities. Further, the large area of open space demands significant levels of investment to manage and maintain it at acceptable standards. Rogers stresses the fact that density per se is not an indicator of urban quality. Totally different architectural typologies can be designed with the same density. High-rise buildings with low area coverage, low-rise buildings with high coverage, or medium-rise buildings with medium coverage with the same number of dwelling units per hectare will give different results in terms of the amount of public and private space or services (Rogers 1999).

[36] France faces manifolds problems with its Le Corbusier urban neighbourhoods and quarters.

Rogers 1999

Figure 47: Relationship between built form and urban density - all building mass models cover a a density of 75 units per hectare (from Rogers 1999:62).

This discussion leads us to the classification of building heights that act as a framework for spatial and urban planning. Nowadays, classification of building heights is mainly influenced by the city of Paris. In 1974 Paris was the first city in Western Europe to revise its building height classification. While the height of the historic core remained the same, an increase in height was implemented at the edge. According to Lichtenberger a revision of the zoning principle generated a new model influencing South European and socialist cities like those in Russia (Lichtenberger 1991, p.189). While the historic core of European cities is preserved, skyscrapers are pushed to the edge. In contrast, based on the land prices in North America skyscrapers dominate the inner cities (skylines).

Lichtenberger 1991

Vista and Visibility

Building height, ergo the third dimension, is essential not only in a cognitive context for wayfinding and perception of the built environment, but also in a functional one. Lynch's famous urban terms *landmark* (1960) and *attractors* (1965) highlight the importance of the third dimension for wayfinding and perceiving the built environment. Lynch 1960, 1965

Lynch's theory (1960) deals with the "image" of cities and supports the idea of "legibility" of urban systems. Legibility is the clarity of the cityscape (Morello, Ratti 2009, p.838) – how easily individual parts or elements can be organised mentally to forma a coherent pattern. The easier the "mental map" can be derived from the built environment, the easier wayfinding and orientation is (see also Cullens's serial vision of 1961). Thus, the topological relationship between elements of the "real world" (Voigt, Walchhofer 2009) links "legibility" of urban space to wayfinding and orientation. "Good" visibility further influences the overall quality of cities.

Morello, Ratti 2009

Voigt, Walchhofer 2009

Hillier adds the notion of "intelligibility" for his space syntax theory. He defines intelligibility as [...] the essence of urban form that is spatially structured and functionally driven. Between structure and function is the notion of intelligibility, defined as the degree to which what can be seen and experienced locally in the system allows the large-scale system to be learnt without conscious effort. Structure, intelligibility and function permit us to see the town as social process [...] (Hillier 1996; revised 2007, p.171).

Hillier 1996, 2007

In summary, we have to be careful not to compensate and acquire open space only by increasing building height. Density and building height in combination with green space needs to be balanced with and oriented towards the surrounding historically evolved morphological patterns.

Within an urban system, the urban pattern and density is linked to location and functions and further to wayfinding and perceiption of the built environment. Transport hubs and historic centres justify a higher population density. In general, density should always be linked to appropriate transport, services, educational uses and other social facilities. A mixed-use planning strategy will help to manage urban space in a vital and sustainable way.

In addition, the urban morphology will further influence the functionality of a system as it determines wayfinding and cognitive mapping. The easier wayfinding and orientation is within an urban system (the more shallow a system is) the more movement will be enhanced, as this it further influences the local and city-wide accessibility of a system.

Optimised land use, density, accessibility, and permeability of the urban system (though not over-permeability as this will restrict a people's clear cognitive mapping and wayfinding), public transport, and an appropriate scale will create sustainable neighbourhoods, cities and regions.

(We will have an in-depth look on how to carry out visibility analyses: point isovist; serial vision; visibility graph analyses; voxels.)

SUSTAINABLE and SUSTAINING BUILT ENVIRONMENT

4.5. Key Factors for a Sustainable and Sustaining Built Environment

Gaffron, Huismans et al. 2008

Gaffron, Huismans and Skala (2008) state that the planning process of an Ecocity focuses on the interaction of urban structures and functions with the transport system. From the perspective of urban structure, these interactions depend on such factors as location, size, density and mix of use [...]. These factors determine the distances people have to cover to travel from their home to school, work, shops, leisure facilities and for other purposes, therby influencing accessibility [...]. Another important parameter for the Ecocity are smaller-scale, multifunctional areas: these are more stimulating and pleasent places and as they are generally easier to "read" they feel safer than large monofunctional developments with little direct connections to other parts of a city. While quality of life and easily accessible urban and social facilities are necessary for an Ecocity's inhabitants to fulfil their needs and have to be maximised, resource consumption through transport and other activities must be minimised (Gaffron, Huismans, Skala 2008, p.24).

The core strategies for an Ecocity are after Gaffron, Husimans, Skala (2008):

A. *Locating* developments in such a way that they are suitable for an attractive public transport system and provide short distances to other parts of the city (author's note: or the region)
B. Creating *qualified high densities* (author's note: *moderate density*) and limited *size of settlement units*,
C. Providing an attractice *mix of uses* and
D. Paying attention to *urban ecology* and *microclimate.*

The same principles can also be applied to a region.

In summary, key areas of sustainable and sustaining intervention on a macro, meso and micro scale for metropolitan areas are:

A. Integrated with a wider network (regional and urban context)
B. City of short distances, high accessibility and centrality, balanced sub-centre structure within the spatial system.
C. Mixed-use design: everyday facilities, services and education within a short walking distance of max. 20 minutes (1600m)

D. Adapt urban design to strengthen walking, cycling and public transport
E. Reinforce the appropriate urban grain to support the development of sub-centres
F. Good interface between park and ride, and public & private transport
G. Consistency of green spaces hierarchy
H. Consistency of network hierarchy
I. Consistency of public spaces hierarchy
J. High correlation between global and local accessibility
K. High correlation between centrality and route choice for retail (it is proven that the overlap of both values supported the emergence of medieval markets; cf. Czerkauer 2008)
L. Appropriate density
M. Introduction of regional production and consumption projects

Czerkauer 2008

To achieve sustainable cities we must shift from an individual perspective and self-interest to a more collective and public services-oriented ethos. Therefore, sustainable city is not only a matter of pollution and energy; it ialso has a social dimension which therfore has a major impact on planning and rebuilding. To put it simply, if people like their city, the endless rebuilding and renewal problem can be stopped. This leads us to the ideas of economic viability, activation of citizens, and a genuine democracy in the everyday life of the city. Persson says that a sustainable city should be further (Persson 2005, p.39):

Persson 2005

A. Adapted to history
B. Adapted to landscape
C. Energy-conserving
D. Ecocycle adapted
E. Built for reuse
F. Healthy and beautiful
G. Integrated with biology
H. Understood by its residents and democratically governed

CHAPTE FIVE:
MULTI-SCALE AND STRATEGIC PLANNING IN THE CONTEXT OF SUSTAINABLE SPATIAL STRATEGIES

5.1. Why a Multi-scale Approach to Planning?

Let us recall that sustainable planning deals with the development of strategies to reduce the use of resources, increase economic efficiency and improve intergration 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). It is not only dispersed development (such as e.g. urban sprawl) that generates traffic overload and congestion; interestingly, the *over*-compact city also has this effect as it engenders longer journeys to green and leisure areas (cf. Schwanen et al. 2004). Minimising trip length to work places cannot be the only parameter. Accessiblity to service and leisure facilties as well as green areas must be included in the overall assessment. On an urban scale, over-compactness causes ecological problems such as a lack of green wedges for supplying the city with fresh air (urban micro climate). Thus, we need to find a solution for managing dispersed development that marries the twin elements of green and built-up space in a highly efficient manner. This solution also needs to incorporate dynamic aspects of a city as well as minimizing traffic costs, emission and avoiding scouring of agricultural land.

Schwanen et al. 2004

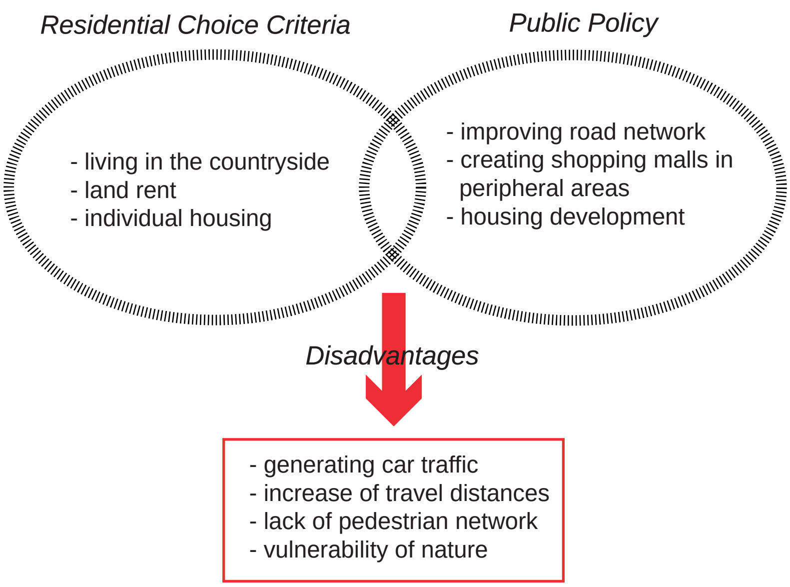


Figure 39: Recap of some realitites of urban sprawl
(from Frankhauser, Czerkauer-Yamu 2011).

As already pointed out, urban space is founded on the principle of *fractal geometry*. Morphological analyses of cities have shown that urban patterns after the industrial revolution, which are often perceived amorphous, mostly follow a fractal structural principle (Frankhauser 1994, 2008; Batty and Longley 1994; Batty 1996, 1999; Benguigui et al.2000; Shen 2002; Salingaros 2003; Tannier and Pumain 2005; Franck 2005; Thomas et al. 2010). Urban growth appears to be governed by complex dynamic processes generating morphologically well-defined macrostructures. This is reminiscent of other evolutionary systems such as clouds, trees, leaves or the human vascular system.

Frankhauser 1994, 2008
Batty, Longley 1994
Batty 1996, 1999
Benguigui et al. 2000
Shen 2002
Salingaros 2003
Tannier, Pumain 2005
Franck 2005
Thomas et al. 2010

Fractals are *multi-scale* and *self-similar;* their ordering principle is based on cascades with similar elements on different scales with idifferent inherent levels of detail. In an urban context this is e.g.: house, block, quarter, city or: path, residential street, side street, main street, through road, freeway, and highway. According to Read (2000), different scales of hierarchy are distinguished by scales of mobility, and are designed to convey different scales of movement.

Read 2000

However, this hierarchical ordering principle is changing with increasing car traffic, with the effect that agglomerations are becoming more and more uniformly distributed due to the increased growth of remote suburbs (Frankhauser 2008).

Frankhauser 2008

Thus, the spatial-functional pattern of cities describes a relationship between their inhabitants' usage of space and movement. This relationship has to be considered when developing sustainable and sustaining planning strategies and models (as the logic of the Haussmann's intervention – fractal scaling).

Due to its inherent characteristics, the use of a fractal (multi-scale) logic for spatial planning supports sustainable and sustaining planning strategies.

Using fractal geometry for urban planning implicitly assumes that fractality corresponds to underlying optimization criteria, as is supposed to be the case in natural structures (see part one). Indeed, fractal surfaces seem to be optimal for spatial systems requiring a high articulation between subsystems. Then, hierarchical structures seem very efficient. This holds true for many natural networks such as lungs or vascular systems.

In urban planning, an example could be the urban road network. As described before, it has been shown that the street system of Paris including Haussmann's street openings of the 19th century, indeed follows a fractal scaling logic (Frankhauser 1994).

Frankhauser 1994

Since every building must be accessible, transport networks generally play a crucial role in urban growth, consolidation and downsizing (shrinking). Therefore, during the trolley period, public transportation networks generated axial growth, as can still be seen in the case of Berlin, where the suburban railway network structured urban space. Railway networks are usually hierarchically organised and cover space less uniformly than road networks do nowadays. This explains why emerging patterns showed particularly fractal properties as long as public transport use preponderated. In Berlin this type of growth (see Figure 9, p.47) became the basis for urban planning strategies by privileging development around the suburban railway axes. This holds even more explicity for the Copenhagen's Finger plan. Privileging transportation axes as development axes is an important aspect of the fractal (multi-scale) planning concept.
Starting from the underlying logic of fractals – the *self-organising processes* of cities and metropolitan areas – we can develop scenarios whose underlying concept takes advantage of these natural growth processes. Frankhauser 2008

On an urban scale, the multi-scale planning concept (model) prevents interlaced peripheral roads from penetrating into green open space. Local recreation areas, which simultaneously function as ecological conversation areas and climate corridors, are brought into close proximity to residential areas. With their 1910 plan for Greater Berlin, Eberstadt, Möhring and Petersen developed 1910 the first archetype for such an organic link between the city and the open landscape. Eberstadt, Möhring, Petersen 1910

Another well-known property of urban systems is the emergence of a central place hierarchy known as rank size distribution, which corresponds to a fractal hierarchy. The concept presented for the planning model refers to such a hierarchical organization of metropolitan areas. The hierarchical structure of an agglomeration, developed on the basis of 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 the foundation for his Central Place theory, which is based on a reflection about the catchment areas of different levels of services depending on how often the services are used. Christaller 1933 That is why the services for everyday life (e.g. supermarkets) are close to housing, whereas weekly or monthly services require bigger catchment areas. The limitation of Christaller's theory is that it is only concerned with the functional hierarchy, and does not reflect the spatial structure (topography). 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. In our research, Christaller's theory, which was already installed as a regional model in post-war Germany, undergoes a reconception that is clearly differentiated from Hillerbrecht's ideal city structure of the Regionalstadt. Christaller's conception leads further to the sustainable concept of a city of short distances supporting a functional, administratively sustainable urban planning concept.

Christaller 1933

The concept used modifies the Christaller scheme by introducing an uneven spatial distribution of settlements where urbanized areas are concentrated close to public transport axes (Frankhauser 2008). Nodes of a hierarchically structured transport network are the preferred locations for services and shopping areas. This calls to mind the concept of decentralised centralisation or, as Calthorpe (2001) formulates it, the regional town, which also enables an intraregional supply for in-between spaces of global axes. The first approach aiming at decentralised centralisation can be identified in Howard's regional scheme (1902) and further in the New Towns (Les Villes Nouvelles).

Frankhauser 2008

Calthorpe 2001

These examples and the emergence of centre hierarchies in urban systems show that fractal geometry has attributes which can be used by planners to create sustainable, sustaining structures on all substantial scales – from a regional scale to an architectural scale. A further specific fractal attribute is the consistency through scale.

In particular, on an urban scale the interface between existing urban morphology and new potential development (option testing and scenario development) 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 either for the urban structure or the residents of the area. Standards have to be developed that correspond to a city's population, ranking different levels of central places.

SUSTAINABLE and SUSTAINING BUILT ENVIRONMENT

Salingaros 2010
Batty, Longley 1994
Batty 1996, 1999, 2000
Shen 2002
Frankhauser 2008

In general, fractal urban planning follows a naturalistic approach (*biophilic planning and design;* see further Salingaros 2010) being inspired by the emergence of urban patterns. Thus, we can describe the growth of cities and metropolitan areas as fractal entities (Batty and Longley 1994, Batty 1996, 1999, Benguigui 2000, Shen 2002, Thomas and Frankhauser 2008) – in line with fractal system descriptions of other evolutionary, biological systems like clouds, trees, leaves or the human vascular system.

Herein we explicitly present a multi-scale planning concept where fractal measures become norms for planning, starting from a metropolitan scale down to a local scale (urban context for growth, consolidation and downsizing scenarios). The metropolitan area is thus an organic entity in which different parts of the agglomerations are linked to each other.

Following features can be identified as being important for a sustainable and sustaining planning strategy:

- Hierarchical ordering principle of agglomerations (e.g. Christallerian logic);
- Interweaving of built-up and green open space;
- Interconnectedness of green areas for accessibility on all levels;
- Access for all to services and facilities as well as leisure;
- Hierarchy of the street and road network;
- Public transport;
- Strategic visibility for orientation and wayfinding;
- Density and city image.

5.2. Strategic Planning for Solving Complex Spatial Problems

Strategic spatial planning has been widely discussed in the literature (Bryson & Roering 1988; Bryson 1995, Healy 1997a, 2004; Mintzberg 1994, 2002 Mastop & Faludi 1997; Poister and Streib 1999; Kunzmann 2000, Kreukels 2000; Albrechts, Healey & Kunzmann 2003; Friedmann 2004), giving us the awareness that there are no single universally accepted definitions (Albrecht 2006) as the topic can be approached from many viewpoints. According to Kaufman and Jacobs (1987) it originated in the 1950s in the private sector out of the need for rapidly changing and growing cooperation in order to plan effectively for and manage the future (in: Albrecht 2004, 746).
We can summarise *strategic spatial planning* as a “[…] disciplined effort to produce fundamental decisions and actions shaping the nature and direction of an organisation’s (or other entity’s) activities within legal bounds” (Olsen et al. 1982 in: Bryson 1988,74). Briefly, strategic planning includes directly witnessing, experiencing and observing aspects of behaviours in the real world as a proven way of inspiring and informing new ideas. Careful observation of people’s behaviour and market forces (socio-economic interactions) combined with the urban and regional layout can open up an insight that uncovers a broad spectrum of opportunities that were not evident before (Fulton Suri 2005). This is based on the consideration that for any planning and design strategy we need to start with an original insight about the usage of space (movement, activities, etc.) and its physical layout. The meta-idea is to address diverse levels of the built environment such as transport, demography, businesses, production, services, tourism, health sector, living, leisure, etc. We have to acknowledge that the built environment on all scales (from global to local and vice versa) is driven by various forces that are interwoven in quite a complex manner. Thus, strategic planning is a *systemic approach* incorporating the elements of a multi-disciplinary and inter-disciplinary holistic approach.

Bryson , Roering 1988
Bryson 1995
Healy 1997
Healy 2004
Mintzberg 1994
Mintzberg 2002
Mastop and Faludi 1997
Poister, Streib 1999
Kreukels 2000
Albrechts, Helay, Kunzmann 2003
Friedmann 2004

Albrecht 2006

Kaufman, Jacobs 1987 (1996)

Bryson 1988

Fulton Suri 2005

In general, each planning and design strategy can only be vital with respect to the use of the space under scrutiny. In order to achieve sensitive and appropriate handling of the above-mentioned forces for sustainable and sustaining planning interventions, planners must not only analyse the factors of transport, market forces, land use and people’s behaviours, etc. but also understand them in their singularity as well as in their mutual interaction, embedded in the built environment on both a local and global scale (system-environment paradigm within the field of system theory) (Luhmann 2004; Bäcker 2005).

Luhmann 2004
Bäcker 2005

A strategic planning approach serves to realise a sustainable and sustaining planning strategy. Let us recall that sustainable planning is concerned with developing strategies to reduce the use of resources, increase economic efficiency and improve integration of social aspects (i.e. pedestrian-friendly environments, well-balanced public and private transport modes, efficient street networks; land use; movement economy: access for all to jobs, shopping, services, health care, culture and leisure) (Czerkauer-Yamu et al. 2010).

Czerkauer-Yamu et al. 2010

The structured process for strategic spatial planning can be adapted (after Bryson 1988) as follows (Czerkauer-Yamu 2011):

Bryson 1988

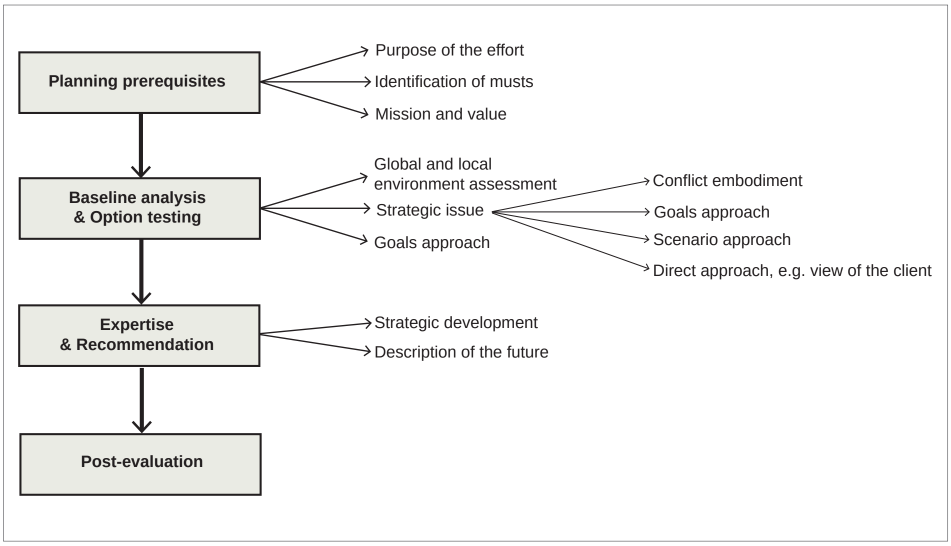


Figure 40: The structure of strategic planning (modified; original Czerkauer-Yamu 2011).

The *identification of musts* confronts the planner with constraints and opportunities of the area under scrutiny; e.g. regulation rules. Further, the *clarification of mission and value* is important as it defines the context of a strategy; e.g. sustainability with an in-depth focus on e.g. accessibility. Within the baseline study (strategic issue), the conflict embodiment identifies potential conflicts considering: what, how, why, where, when , and who. In the same context, the *direct approach* is directly derived from the view of the users or client.

In addition, the *post-evaluation* provides useful information approx. two years after the planning strategy or design has been implemented. Furthermore, participation processes are important throughout the whole planning process. These can be carried out as stakeholder consultations, developer consultations, public consultations, design workshops, etc.

In summary, the benefits of strategic planning are (selected and adapted from Bryson 1988, 78): Bryson 1988

- Clarify future directions
- Make today's decisions in the light of their future consequences
- Develop a coherent and defensible basis for decision-making (see further: informed decision-making)
- Exercise maximum discretion in the areas under scrutiny/development
- Solve major spatial problems
- Deal effectively with rapidly changing circumstances
- Build expertise

Based on this background and requirements, it can be seen that concepts, models and simulations (2D, 3D, 4D) are important, as all of them (bundled) contribute significantly to the formulation and exchange of spatial ideas. These visualised ideas address the users of space to obtain a further in-depth interpretation in order to reach the next level of a more specific and realisable interpretation (awareness-raising process) (Voigt 2005). Voigt 2005

Strategic planning is also linked to the idea of spatial planning support systems. In summarising the story of PSS, Batty explains the added value of planning support systems:

"I had always thought the term "Planning Support Systems", abbreviated to PSS, had been coined by the father of land use modelling, Britton Harris [...]. Until I asked him, that is. In response to a paper [...] in summer of 1987, he told me that someone in the audience who he cannot quite remember actually coined the term, referring to "planning support systems" as the constellation of digital techniques (such as GIS) which were emerging to support the planning process (Batty 2003, 2). Batty 2003

Hence, Batty explains that the unknown originator of the term planning support system defined it by analogy to its predecessor term "decision support system" (DSS), (Batty 2003). Yeh summarises PSS as a combination of computer-based methods and models that support planning functions. PSS not only serve as a decision support system for decision-makers, they also provide the tools, models and information used for planning (Yeh 2008:7). Klosterman adds an interesting thought when he says that the increased concern with issues such as global warming, urban sprawl, and Batty 2003 Yeh 2008 environmental degradation creates an increased demand for computer-based analysis and forecasting tools (Klosterman 2008:85). In general, a PSS has the ability to visualise complex problems and future solutions embedded in a certain approach.

Klosterman 2008

6.3. Structure of the Planning Support System (PSS) and added Value to the Decision Support System Fractalopolis

Fractalopolis, the multi-scale decision support system (DSS) is the basis for the strategic planning approach; combined with other GIS analyses it becomes part of a planning support system (PSS). The combination of developed and presented herein methods follows the idea of spatial models that are consistent across scales with defined levels of details (LoD) corresponding to the respective scales.

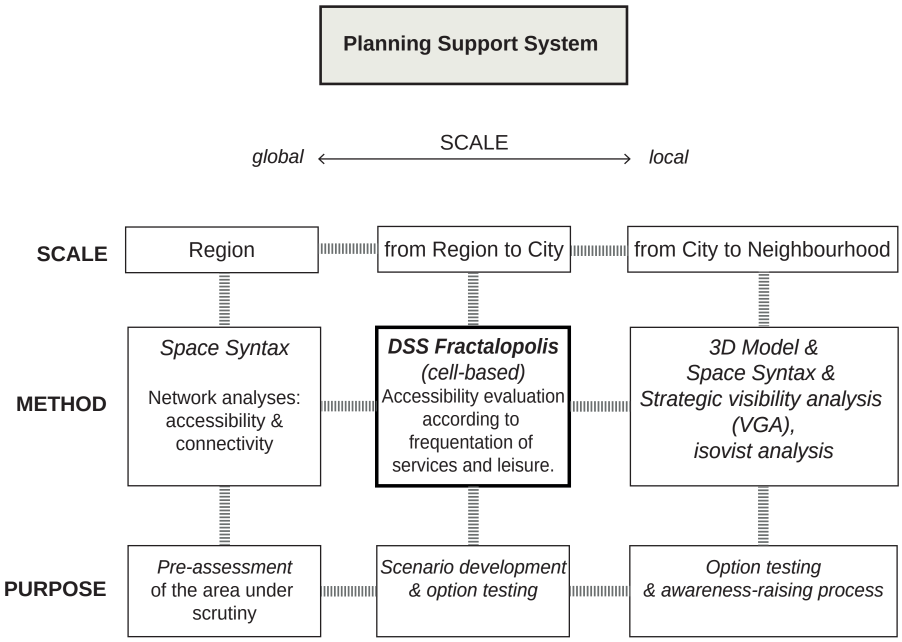


Figure 41: The structure of the multi-scale planning support system herein presented.

The method and analyses set of *Space Syntax*, *isovist*, *serial vision* and *3D visualization* is used to answer questions which are not covered by Fractalopolis.

- *Identifying the centre for the starting point of Fractalopolis.*
  Space Syntax centrality analyses offers to identify on a global scale a centre hierarchy which in turn supports to define the starting point for the decision support system Fractalopolis.

- *Further, the regional Space Syntax analysis (potential through movement) identifies local centres for potential development.*

- *Network adjustments from a planning point of view*
  On a neighbourhood scale the graph-theoretical approach evaluates the network itself, which Fractalopolis does not (cell-based approach). By doing this an optimisation process for the network and the potential additional services and facilities can be identified. Fractalopolis software is based on the idea of accessibility, but does not take into account the role of the network itself (network segment analysis).

- *Optimisation Evaluation*
  By adding network links and services based on the Space Syntax analyses, the Fractalopolis cell (chosen neighbourhood area for the network analyses with Space Syntax) can be re-evaluated and potential optimisation identified.

- *Strategic Visibility, isovists and serial vision*
  Fractalopolis does not include the idea of wayfinding and orientation based on visibility aspects of the built environment. Thus, these analyses support to position possible developments (buildings) in such a way that it supports the approach of simple and direct links (see master planning principles, p.XX). The visual graph analyses identifies potential places for stationary activities (e.g. facilities like a café with outdoor seating). Route and wayfinding based on visibility is further linked to the constuction of mental maps (perceptual information).

- *3D visualization*
  3D models and visualizations are commonly used to overcome lack of communication between different parties (e.g. laypeople, general public and planners) as they can translate convential analyses and drawings into a format that is more easily understood. Thus, a 3D visualization often works as as a communication tool and can be seen as a supporting tool for a decision-making proces (cf. Roupé, Johansson 2010).

As the core of this work; the *multi-scale decision support system* “Fractalopolis” will be described first, followed by *space syntax* and *strategic visibility* (visual graph analysis). Finally, the idea of *3D modelling* and its added value in the context of spatial simulation and modelling will be described.

PART THREE:

SPATIAL MODELLING and SIMULATION

About this Part

In part II we anserwed the question “Why a multi-scale (multi-fractal) approach to planning?”, underpinning our arguments with ideas, thoughts and conclusions from parts one and two. From this discussion we derive important features for a multi-scale decision support system.

Following on from this, we describe in this part the methodology and formalization of Fractalopolis, the multi-scale decision support system developed in this research, detailing its coding system, population model, accessibility and evaluation rules for services, leisure facilities and green open space, as well as the morphological rules (lacunarity rules) it uses to evaluate landscape view. The Fractalopolis software is also explained.

(The accessibility rules are adjusted to the case study of the Vienna-Bratislava metropolitan region, but in the Fractalopolis software are flexible enough to be used for any spatial system.)

In a next step we describe and discuss accessibility, connectivity and centrality opportunities and constraints in the context of the Space Syntax theory, taking this method in combination with Fractalopolis to illustrate how a Planning Support System can be carried out (see also the diagram in the introduction of this work).

Space Syntax’s integration, choice and visibility graph analyses link back to the introductory thoughts on “How does the world work?” and “Identification of sustainable and sustaining strategies” presented in parts one and two.

Finally, we discuss how modelling and simulation allow us to depict a complex reality in a simple manner, supporting the evaluation of a priori interventions and their spatial impacts. This leads us to the added value of 3D models and visualisations in supporting complex planning and decision-making processes.

CHAPTER SIX: METHODOLOGY AND FORMALISATION

6.1. Methodology and Formalisation of the Multi-Scale Decision Support System Fractalopolis

The herein presented multi-scale decision support system *Fractalopolis* refers for the regional model to a hierarchical organization of metropolitan areas (Christallerian logic) and on the local scale is based on an accessibility logic; in addition incorporating a population model.
Borsdorf stresses the fact that within Christaller's system, surrounding villages near a central city could never gain a higher centrality, as Christaller's theory took gravitation and transportation costs (= distance) as a basic principle (Borsdorf 2004, p.131). Borsdorf's view on Christaller is right if we try to implement Christaller as a rigid, non-flexible system, that is not adapted to the surrounding built environment in which it is embedded.
Christaller's conception leads further to the sustainable concept of a city of short distances supporting a functional, administratively sustainable urban planning concept. Christaller's theory also follows a similar line of thought to the concept of decentralised centralisation which also enables an intraregional supply for in-between spaces of global axes. But, if we vary Christaller by viewing his scheme as a modular system and rescale it by adding new hierarchies and interfaces for agglomerations (working, living, leisure), we will find surprising new insights and possibilities for use in a differentiated spatial context, e.g. *Hillebrecht's Regionalstadt* (regional town, 1962) incorporates central locations for commerce, services and workplaces.

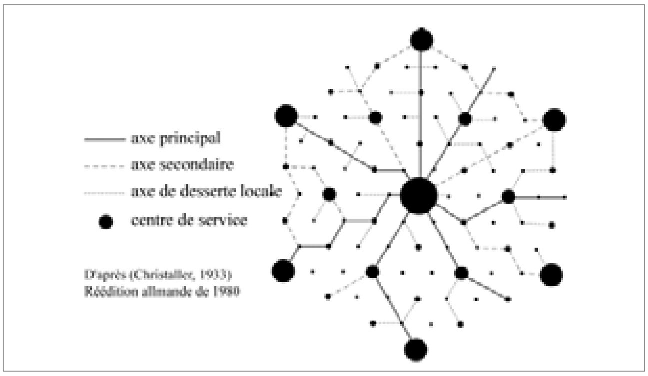
Christaller 1933

Borsdorf 2004

Generally speaking, the core of idea of Christaller's theory is the *application and mapping of a spatial hierarchy as a holistic system approach*. Further, we should not be trapped by the idea of mono-scale functional units when looking at Christaller. Borsdorf is right when he explains that Christaller's theory deals first and foremost with spatial structures and not a strategy for the allocation of central function (Borsdorf 2004, p.132). This distinction is important to make when addressing new planning strategies based on the underlying idea of the Central Place theory.

With this in mind,within the framework of the PREDIT research programme a first draft of a planning scheme featuring Christaller's centre hierarchy was developed at ThéMA, Université de Franche-Comté, France, in which spatial distributions are linked to the hierarchy of the traffic infrastructure, equating to a multifractal structure (Frankhauser et al. 2007, 2008).

Frankhauser et al. 2007, 2008



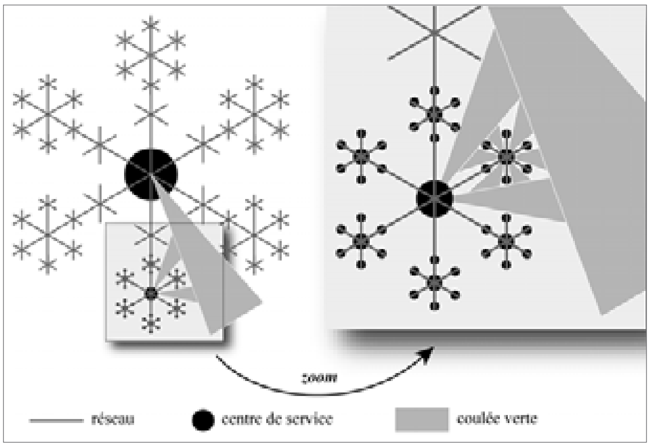


Figure 42: Christaller's network of central places including traffic infrastructrure and a multifractal hexagonal approach. The hexagonal shape of this system is reminiscent of the Christaller scheme. Towns are concentrated in proximity to axes, which can be interpreted as public transport axes. Between the axes there is connected green open space (green wedges) which can be interpreted as areas of natural landscape and agricultural land. By its shape the system avoids fragementation of these rural and natural zones (consistently across scales) (from Christaller 1933, reprint 1980; Frankhauser et al. 2006, 2008:31).

The agglomerations are thus 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 at 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 (Oberzentrum, Mittelzentrum, Unterzentrum, Kleinzentrum). 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 open spaces allows small green areas to be retained next to housing estates as well as nature reserves and vast woodlands. The green corridor principle is thus expanded as not only non-built-up surfaces and corridors are kept free, but the interweaving of urban space and open space on all scales becomes the predominant concept. The urban and agglomeration fringes are deliberately not chamfered, but linked to green spaces on all scales in order to reduce traffic flow and minimize travel distance to leisure areas.

Proceeding from Frankhauser's multi-fractal model a further step was taken and the multiscale decision support system (and software) *Fractalopolis* was developed.

Of course, hierarchy is the underlying idea for the regional scale (and further the urban and architectural scale) in order to establish a principle that follows in the footsteps of Calthorpe and Fulton's *regional city conception* (2001) as well as *Ebenezer Howard's principle of city growth* (1898, 1902) and further developments such as the *Ville Nouvelles* (1965). The idea of hierarchy as a foundation for developing a regional growth model allows an efficient usage of space based on the *law of all living systems*, ergo a fractal logic.

Let us recall some features of fractal geometry according to a multifractal logic (for a sustainable and sustaining planning strategy):

- A fractal is based on a scaling law; the same structure appears on different scales
- Non-uniform distribution of mass; uniformity and concentration are limit cases
- A fractal is neither dense nore diluted; it is more or less contrasted
- Mass is distributed according to a precise law (Pareto-Zipf distribution)
- Strong hierarchical order
- Fractal structures may look "irregular/amorphous", but may nevertheless be organised according to a fractal ordering principle. Such structures may be described by fractal scaling law.

The fractal law is further combined with social need with respect to accessibility, generating the distance and evaluation rules for services and leisure amenities for daily, weekly, monthly and occasional use.

However, let us emphasize that the proposed spatial system aims to take simultaneous account of different kinds of objectives:

- reducing travel distances required to access higher-order facilities;
- respecting the diversity of social demand i.e. taking into account the fact that certain types of households prefer living in a quiet, low-density environment with good access to green amenities;
- avoiding leapfrogging that lengthens the distances to acceded to centers and avoiding the fragmentation of natural or agricultural areas.

Howard 1902

To fulfil these aims we introduce in the following a spatial model which uses iterative mapping procedures similar to those used for generating multifractal Sierpinski carpets. We assume that there exists a hierarchical system of central places structured according to the different levels of services and commercial amenities they provide. However, as we will see later, towns belonging to the same hierarchical level no longer have the same population: towns of a given level but which are close to a higher-ranked centre are assumed to concentrate more population than those lying close to lower-ranked centres.

Zipf 1949

Formalisation of Fractalopolis

To provide a convenient introduction to the quantitative modelling approach we consider a model version that is simpler than the multi-fractal hexagonal approach, but which follows the same logic.

Let us start by drawing a large-sized square of a certain base length which we will normalise to one. We assume that the most important centre of the system is localised in the centroid of the square. The surface of the square in some sense represents the catchment area (or area of attraction; sphere of influence) of our central place. Now we introduce a generator which consists of a square of base length $r_1 < 1$ centred on the first-order centred (framed with a dotted line). This square is surrounded by $N = 4$ smaller squares (sub-centres) with the base length $r_0 < r_1$. Let us emphasize that the generator lies just within the inital square so that the outer corners of peripheral squares are identical to that of the initial square. Moreover, no overlapping of squares is allowed (see also morphological rules).
We assume that the first step corresponds to the implementation of $N = 4$ second-order centres (or sub-centres) localised in the centroid of the smaller squares. The surface of the squares now corresponds directly to the catchment areas of these centres. Hence, the central square has a bigger second-order catchment area than the peripheral centres. In the next step we reiterate the procedure (Figure 43). Each of the existing squares is replaced by a smaller replication of the generator. In accordance with our logic we keep the already generated first-order and second-order central places and add third-order central places lying within the catchment areas of the second-order centres. Again, these centres are localised in the centroid of the generated smaller squares.

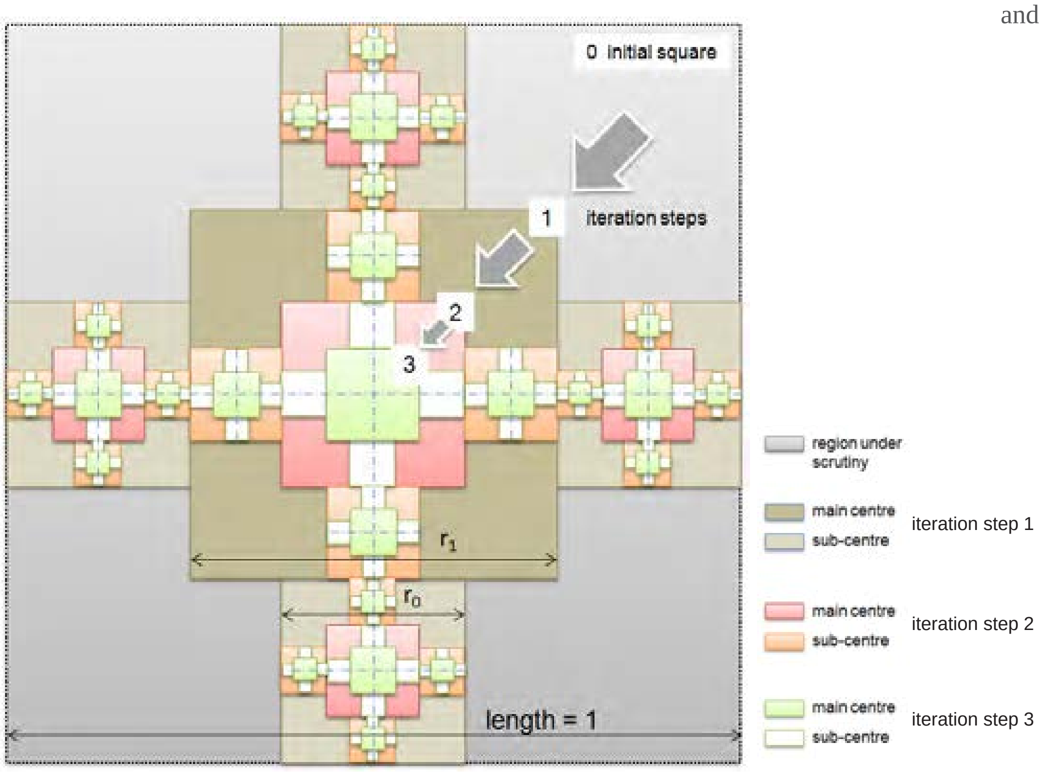


Figure 43: Hierarchy of Centres (centrality levels) according to the iteration steps 1-3.

By the iteration process the reduction factors r_1 and r_0 are combined according to all possible combinations, which yields, e.g. for the second step:

$$r_1 \cdot r_1 , r_1 \cdot r_0 \quad [5]$$

Because of the commutativity property we have:

$$r_1 \cdot r_0 = r_0 \cdot r_1 \quad [6]$$

This is the reason why the catchment areas of the second-order centres are as those of the third-order centres belonging to the highest-ranked centre. This corresponds to a peculiarity of multifractal structures and we will come back to this topic when considering the population distribution[58].

Another consequence of this feature of multi-fractals is that the direct catchment areas belonging to the third-order centres no longer have the same size. Within the multifractal figure we find small squares of base length $r_0 \cdot r_0$ and large ones with base length $r_0 \cdot r_1$.

The next step adds another hierarchical level and we again discover that the size of the catchment areas of centres issuing from different iteration steps and thus corresponding to different hierarchical levels is the same;

and on the other hand that the catchment areas of centres belonging to the same level are different. Two logics can be distinguished:

- the first one generated the central place hierarchy by adding a lower level at each iteration step. Hence, the iteration step where the centroid is generated, determines its service level in the central place hierarchy;
- the second one is linked to the mentioned “degernation” effect. Since permutations are allowed we have direct catchement areas which have the same size but belong to different service levels.

[58] This is the reason why the distribution function of the squares does not follow a Pareto distribution as a monofractal but a binominal distribution, c.f. Feder 1988

However, we should emphasise that the logic of spatial configuration of the centres corresponds to the logic of the Central Place theory. The fact that the areas influenced by the centres are of different size depending on their localisation seems an interesting feature, since we can assume that cities lying close to important high-level centres are usually bigger than those lying close to low-level centres. This logic wil be reconsidered when defining the theoretical population numbers.

By going on with iteration, it is of course possible to generate a more hierarchical spatial system. Let us recall that Christaller, for instance, distinguishes seven different service levels. However, in order to conserve a certain legibility, we shall restrict ourselves to the four service levels already introduced. These levels correspond to the following purchase rates or frequency levels:

- Level 1: *occasional* frequented services, shops or leisure amenities
- Level 2: *monthly* frequented services, shops or leisure amenities
- Level 3: *weekly* frequented services, shops or leisure amenities
- Level 4: *daily* frequented services, shops or leisure amenities

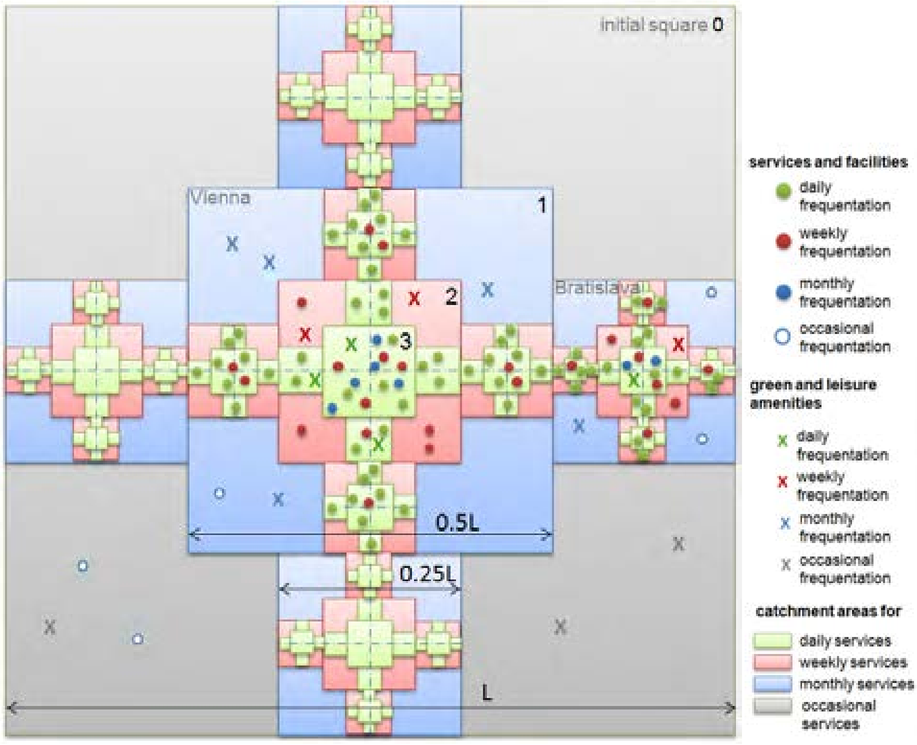


Figure 44: Services and leisure amenities according to their level of frequentation in the context of their catchment areas.

The hierarchical structure also determines the hierarchy of green open space.

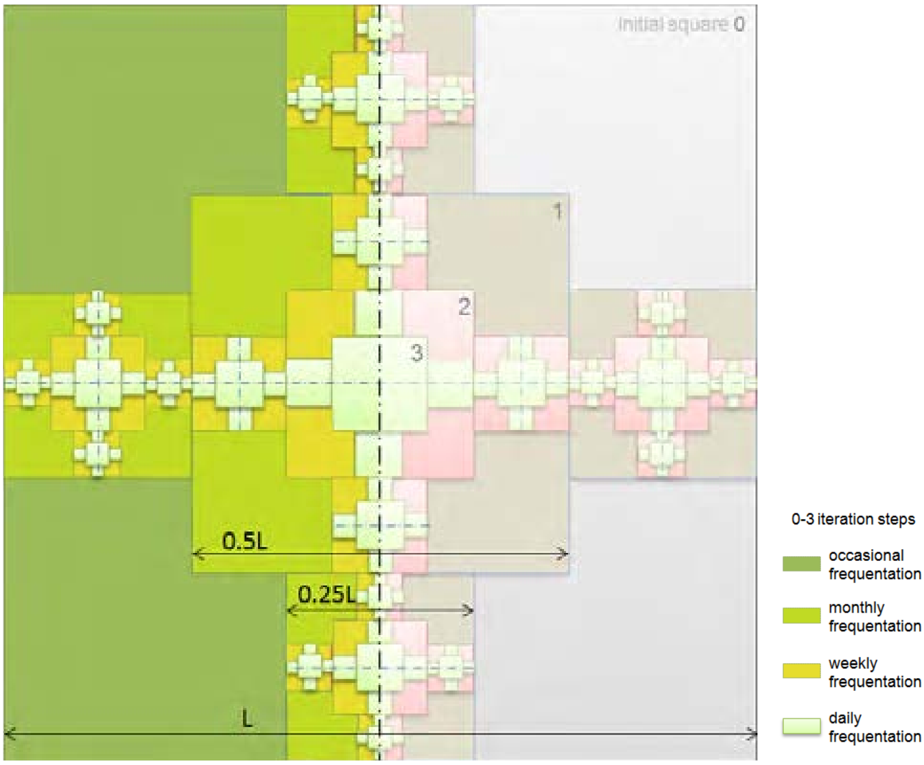


Figure 45: Hierarchy of green open space.

6.1.1. The Coding System [37]

A coding system is introduced in order to distinguish the different centres according to the two their service level. Hence for the first iteration step we distinguish the large central square which we denote by the digit 1 and the four smaller peripheral squares denoted by 0. In each following step we now add another digit to the right of the existing one, according to the same logic. This indicates that the hierarchy is created by combining just two factors. Hence in the next step the highest-order central square is now called 11, the four adjacent smaller ones 10. The four peripheral squares generated in the previous step are replaced, too, by the generator. The occurring central place are called 01 and the four peripheral ones 00. This procedure is reiterated in the third step (cf. figure 2c). We thus obtain a set of 8 different codes, each one consisting of three digits. The first-level center with the highest facility level $m = 1$ has the code 111. The four directly adjacent squares of level $m = 2$ have the codes 110. They correspond to suburban areas of the main center. The four centers 011 correspond to the four centers of level $m = 2$ generated at the first iteration step. The peripheral centress 101 and 001 are issued from the second iteration step and correspond to centers of the facility level $m = 3$. Of course the 101 centers belong to the catchment area of 111 for higher-level facilities, whereas the centres 001 belong to the catchment area of the second-level 011 centres. The small elements 100 and 000, adjacent to these third-level centres, are all low-level $m = 4$ centres.

[37] by Frankhauser 2012

The step-by-step generation of the elements can hence be represented as follows:

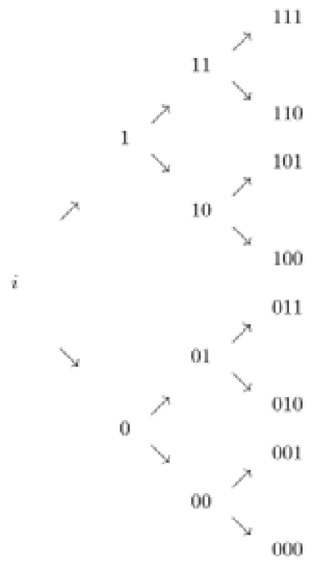


Figure 46: The coding system

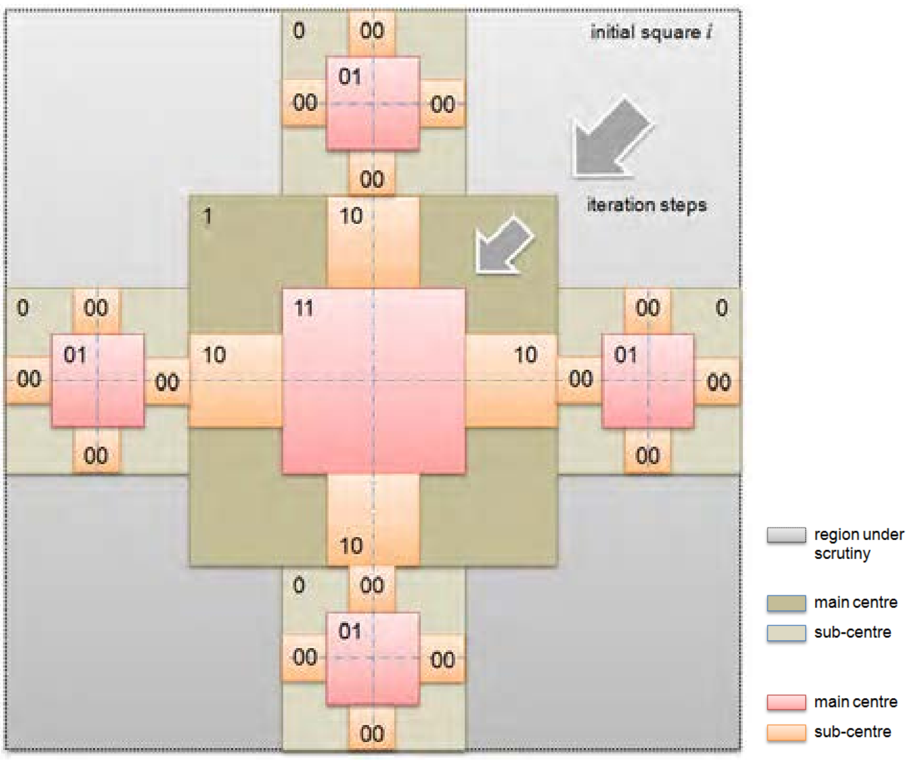


Figure 47: The coding system; iteration step 0-2.

Figure 48: The coding system; iteration step 1-3 for the central square

We can identify the following properties for the different kinds of elements:

code	level	next superior center	number	surface
111	1		1	$(S_1)^3$
110	4	1	4	$(S_1)^2 \cdot (S_0)$
101	3	1	4	$(S_1)^2 \cdot (S_0)$
100	4	3	16	$(S_1) \cdot (S_0)^2$
011	2	1	4	$(S_1)^2 \cdot (S_0)$
010	4	2	16	$(S_1) \cdot (S_0)^2$
001	3	2	16	$(S_1) \cdot (S_0)^2$
000	4	3	64	$(S_0)^3$

Table 3: Basic surfaces corresponding to the code and levels

Where we have set the basic surfaces as $(r_1)^2 = S_1$ and $(r_0)^2 = S_0$.
The codes inform us directly about the facility levels. Using a generalised code *ijk*, we obtain:

$$k = 0 \longrightarrow m = 4$$
$$jk = 10 \longrightarrow m = 3$$
$$ijk = 110 \longrightarrow m = 2$$
$$ijk = 111 \longrightarrow m = 1$$

By introducing these codes we have given up the previously discussed commutativity. Indeed, in the introduced system the codes 101 and 110 or 011 are not equivalent, even though the surface of their direct catchment area is the same. Hence, the code introduces a non-commutative operation. The consequence is that even multi-fractal, the system shows properties of unifractals.
Thus, making an abstraction of their size, we verify that the total number of centres belonging to the different levels follows a geometrical series, except the transition from the highest to the next subordinate level.

level	number	multiplicator
1	1	
2	4	4
3	20	5
4	100	5

Table 4: Hierarhical logic of total numbers of centres

This corresponds to the usual hierarchical logic observed in fractals.

6.1.2. The Population Model [38]

We shall now focus on the population numbers, which requires some preliminary reflections. We assume that the population model assigns a certain amount of population to the generated catchment areas. First, however, we should remind ourselves of some fundamental features of multifractal geometry. Two fundamentally different iteration concepts can be distinguished:

- The first one resembles to the usual iteration procedure e.g. for generating Sierpinski carpets and corresponds to the procedure we used before for generating our central place hierarchy. The procedure reduces an initially given figure using several – in the present case two – reduction factors. As pointed out before, this corresponds to the progressive generation of a set of points corresponding to the centroids of the smaller copies of the initial figure. Hence, the total areas – in our example the direct catchment areas of the centres of different order – is reduced at each iteration step.

- Another way of proceeding is to give a certain mass, e.g. a population, and distribute this mass progressively to different parts of the space according to an iterative mapping procedure. For example, we may cover a given area with a grid consisting of large meshes and distribute the mass among these different meshes according to some weighting factors p_0, p_1,... . Then the iteration procedure generates smaller meshes within each mesh and distributes the mass within these meshes according to the previously introduced distribution procedure. By this procedure the weighting factors are again combined in the same way as the previously introduced reduction factors, i.e. we obtain combined factors such as p_0^2, $p_0 \cdot p_1$, p_1^2. This procedure is reiterated. However, since we are reasoning in parts, the sum of mass over all grid elements remains constant over iteration, whereas the mass is more and more concentrated in the meshes which combine the high values of weighting factors.

[38] by Frankhauser 2012

In our case the situation is peculiar since we combine a surface model with a weighting logic rather reminding the second approach. Let us remind ourselves that the former one serves to generate a subset of areas which we consider as suitable for further urbanization. The latter corresponds to the distribution of population in these areas. However, this does not really hold since, at each iteration step, we reduce the total amount of surface for which we assume future development to be possible. This means that we subsequently cut settlements, and thus population, out of the system. Thus must be taken into account, which leads us to propose the following model. We assume that when introducing the generator in the first step we split the population p living in the square corresponding to the initially selected area into two parts:

$$\begin{aligned} p &= \alpha \cdot p + (1-\alpha) \cdot p \\ &= \alpha \cdot p + p_{rur(1)} \end{aligned} \qquad [7]$$

Hence the population $p_{rur(1)}$ is the amount the population living in the zones cut away by the generator and $(1 - \alpha)$ is the corresponding part of the population. This shows that α is directly derived from empirical data by the equation (relation):

$$\alpha = \frac{p - p_{rur(1)}}{p} \qquad [8]$$

The amount $\alpha \cdot p$ of the population lives in the “urban system” as defined at this first iteration step. Hence we are reasoning in parts (proportions) of population:

$$1 = \alpha + (1 - \alpha) \qquad [9]$$

The urban system consists of the generator, i.e. of the centre with code 1 and the four sub-centers coded by “0”. We now assume that this urban population is distributed among these 5 elements so that the main center concentrates the part a_1 of the urban population and each of the sub-centers a_0. Hence we obtain:

$$\begin{aligned} p &= \alpha(a_1 + 4a_0)p + p_{rur(1)} \\ &= \alpha(a_1 + 4\frac{1-a_1}{4})p + p_{rur(1)} \end{aligned} \qquad [10]$$

The second equation holds since we are reasoning in parts, i.e. $(a_1+4a_0) = 1$.

Hence the model assigns (affects) the following population numbers to the different elements:

code	level	population	surface	density
1	1	$\alpha p a_1$	(S_1)	$\frac{\alpha p a_1}{(S_1)}$
0	2	$\alpha p a_0$	(S_0)	$\frac{\alpha p a_0}{(S_0)}$

Since α is already determined we have to compute a_1 and a_0 respecting the normalization requirement. Again we compute both the parameters by direct reference to empirical data, distinguishing the center "1" from the four subcenters "0". If we call $\hat{p}_1$ the population living in the area "1" and $\hat{p}_0^{(i)}$ where $i = 1 \ldots 4$ the empirical populations living in the surrounding sub-centres, we obtain:

$$\begin{aligned} a_1 &= \frac{\hat{p}_1}{\alpha p} \\ a_0 &= \frac{1}{4\alpha p} \sum_i \hat{p}_0^{(i)} \end{aligned} \qquad [11]$$

Of course the normalization requirement is strictly fulfilled.

We now go on with iteration. In the next step we again assume that amount of population $p_{rur(2)}$ lives in the parts of space now cut away by iteration. We obtain the following ratio (relation):

$$\begin{aligned} p &= \alpha\beta \cdot p + \alpha(1-\beta) \cdot p + p_{rur(1)} \\ &= \alpha\beta \cdot p + p_{rur(2)} + p_{rur(1)} \end{aligned} \qquad [12]$$

Again β is easy to compute according to the ratio (relationship):

$$\alpha = \frac{p - p_{rur(2)} - p_{rur(1)}}{\alpha \cdot p} \qquad [13]$$

This means that we estimate the parameters – here α, β, etc. – step by step. This means that each iteration is consistent with itself – the sums of the ratios of population assigned to the different areas are by definition identical to the initally given total population. This seems strictly coherent with the iteration logic, which can be stoppped at an arbitray iteration step without affecting parameter values determined for previous steps. We apply the same logic for all subsequently introduced parameters.

We now must reflect on how to distribute the population remaining in the new "urban system" among the elements belonging to our multifractal. If, according to the iterative logic of fractal geometry, we were to use the logic we applied for constructing the multifractal Sierpinski carpet, we would obtain the following ratio corresponding to:

$$\begin{aligned} &= \alpha\beta(a_1(a_1 + 4 \cdot a_0) + 4a_0(a_1 + 4 \cdot a_0))p + p_{rur(2)} + p_{rur(1)} \\ &= \alpha\beta(a_1^2 + 4a_1 \cdot a_0 + 4a_0 \cdot a_1 + 4^2 a_0^2)p + p_{rur(2)} + p_{rur(1)} \end{aligned} \quad [14]$$

Again we would have distributed the population according to the parts a_1 and a_0 among the different elements of the multifractal Sierpinski carpet. Since $a_1 \cdot a_0 = a_0 \cdot a_1$, the population would be the same for the cities with code 10, correponding to peripheral zones of the most important centre, and 01, which is the second-order main centre. By going on with iteration at the next step a centre 110 with facility level 4 would have the same population as the level 3 center 101 or the level 2 center 011. Such a logic seems unrealistic since we should expect e.g. the density in the level 2 center 011 is to be superior to that of the level 3 centre 101.
It is evident that this is a consequence of the commutative logic of multifractal iteration. Due to this property multifractals follow a binomial logic rather than a hyperbolic distribution logic as unifratcals do.
Hence we modify the strict iteration logic by allowing another ratios for the distribution of population in the subsequent iteration steps. Thus by introducing parts b_1 and b_0 for the second iteration step we may rewrite the ratio (14):

$$b_0 = \frac{1 - b_1}{4} \quad [15]$$

Of course this assumption destroys the commutative logic and we clearly may distiguish centers of type 10 from those of type 01 with respect to their population numbers. This also holds for the next step if we introduce additional factors c_1 and c_0.

It is evident that b_1 and b_0 are again linked by the requirement of normalisation,
so that:

$$p = \alpha\beta \left(a_1 \left(b_1 + 4 \cdot \frac{1-b_1}{4} \right) + 4 \cdot \frac{1-a_1}{4} \left(b_1 + 4 \cdot \frac{1-b_1}{4} \right) \right) p + p_{rur(2)} + p_{rur(1)} \quad [16]$$

Hence we again obtain the model values of the population assigned to the different elements genereted at this iteration step:

code	level	population	surface	density
11	1	$\alpha\beta p a_1 b_1$	$(S_1)^2$	$\frac{\alpha\beta p a_1 b_1}{(S_1)^2}$
10	3	$\alpha\beta p a_1 b_0$	$(S_1)\cdot(S_0)$	$\frac{\alpha\beta p a_1 b_0}{(S_1)\cdot(S_0)}$
01	2	$\alpha\beta p a_0 b_1$	$(S_1)\cdot(S_0)$	$\frac{\alpha\beta p a_0 b_1}{(S_1)\cdot(S_0)}$
00	3	$\alpha\beta p a_0 b_0$	$(S_0)^2$	$\frac{\alpha\beta p a_0 b_0}{(S_0)^2}$

For determining the parameters b_1 and b_0 we proceed according to the previously defined logic which respects the different iteration steps. Hence, α, β, a_1, a_0 are known. If we introduce the empirical data according to the same logic as previously, we obtain the empirical equation which is the equivalent to:

$$p - p_{rur(2)} - p_{rur(1)} = \hat{p}_{11} + \sum_{i=1}^{4} \hat{p}_{10}^{(i)} + \sum_{i=1}^{4} \hat{p}_{01}^{(i)} + \sum_{i=1}^{16} \hat{p}_{00}^{(i)} \quad [17]$$

in which restricted ourselves to considering only the “urban population”. We rewrite this equation (17) in order to group the data referring to b_0 and those referring to b_1:

$$\begin{aligned} p - p_{rur(2)} - p_{rur(1)} &= \hat{p}_{11} + \sum_{i=1}^{4} \hat{p}_{01}^{(i)} + \sum_{i=1}^{4} \hat{p}_{10}^{(i)} + \sum_{i=1}^{16} \hat{p}_{00}^{(i)} \\ p - p_{rur(2)} - p_{rur(1)} &= \alpha\beta(a_1 \cdot b_1 + 4a_0 \cdot b_1 + 4a_1 \cdot b_0 + 4^2 a_0 \cdot b_0)p \end{aligned} \quad [18]$$

We now require the part of the urban system which contains the parameter b_1 to correspond to the total real population of this part, which yields

$$\hat{p}_{11} + \sum_{i=1}^{4} \hat{p}_{01}^{(i)} = \alpha\beta(a_1 \cdot b_1 + 4a_0 \cdot b_1)p \qquad [19]$$
$$= \alpha\beta p \cdot b_1$$

taking into account the normalisation $a_1 + 4a_0$. The same is required for b_0 , which yields:

$$\hat{p}_{11} + \sum_{i=1}^{4} \hat{p}_{01}^{(i)} = \alpha\beta(a_1 \cdot b_1 + 4a_0 \cdot b_1)p \qquad [20]$$
$$= \alpha\beta p \cdot b_1$$

Both the equatios are of course coherent, their sum is by definition the empirical population and the normalization $b_1 + 4b_0$ is verified. Ratios (19) and (20), respectively the normalization, allow us to determine the parameters b_1 and b_0:

$$b_1 = \frac{\hat{p}_{11} + \sum_{i=1}^{4} \hat{p}_{01}^{(i)}}{\alpha\beta p} \qquad [21]$$

$$b_0 = \frac{1 - b_1}{4} \qquad [21a]$$

We can now go on with iteration using the same logic. We then introduce a ratio γ of the population now assigned to the elements now belonging to the urban system. Again, normalized ratios c_1 and c_0 are introduced according to $c_1 + 4 \cdot c_0$. The time we shall restrict ourselves to giving the populaton numbers as they are generated by the model:

code	level	population	surface	density
111	1	$\alpha\beta\gamma p a_1 b_1 c_1$	$(S_1)^3$	$\frac{\alpha\beta\gamma p a_1 b_1 c_1}{(S_1)^3}$
110	4	$\alpha\beta\gamma p a_1 b_1 c_0$	$(S_1)^2 \cdot (S_0)$	$\frac{\alpha\beta\gamma p a_1 b_1 c_0}{(S_1)^2 \cdot (S_0)}$
101	3	$\alpha\beta\gamma p a_1 b_0 c_1$	$(S_1)^2 \cdot (S_0)$	$\frac{\alpha\beta\gamma p a_1 b_0 c_1}{(S_1)^2 \cdot (S_0)}$
100	4	$\alpha\beta\gamma p a_1 b_0 c_0$	$(S_1) \cdot (S_0)^2$	$\frac{\alpha\beta\gamma p a_1 b_0 c_0}{(S_1) \cdot (S_0)^2}$
011	2	$\alpha\beta\gamma p a_0 b_1 c_1$	$(S_1)^2 \cdot (S_0)$	$\frac{\alpha\beta\gamma p a_0 b_1 c_1}{(S_1)^2 \cdot (S_0)}$
010	4	$\alpha\beta\gamma p a_0 b_1 c_0$	$(S_1) \cdot (S_0)^2$	$\frac{\alpha\beta\gamma p a_0 b_1 c_0}{(S_1) \cdot (S_0)^2}$
001	3	$\alpha\beta\gamma p a_0 b_0 c_1$	$(S_1) \cdot (S_0)^2$	$\frac{\alpha\beta\gamma p a_0 b_0 c_1}{(S_1) \cdot (S_0)^2}$
000	4	$\alpha\beta\gamma p a_0 b_0 c_0$	$(S_0)^3$	$\frac{\alpha\beta\gamma p a_0 b_0 c_0}{(S_0)^3}$

The parameters are estimated according to the previously introduced logic by determining first γ and then c_1 and c_0.

6.1.3. Accessibility and Evaluation Rules

In the following we discuss two different types of accessibility analyses and evaluations:

- Fractalopolis' accessibility and evaluation rules
- Space Syntax

The accessibility and evaluation rules for *Fractalopolis,* from a regional to a neighbourhood scale, allowing the three aspects of sustainability – economic, ecological and social – to be combined. On a local scale the rule set supports the creation of a pedestrian-friendly environment (daily and weekly facilities) at the same time balancing private and public space (morphological rules and multifractal IFS – iterated function systems). Further, the accessibility evaluation takes into account access to monthly and occasionally used facilities and open green space following the logic of TOD (Transport Oriented Development), prioritising public transport. (On a global scale the model employs a descriptive-normative approach.)
The rules support interlacing of public and individual transport modes on all interwovens scales (metropolitan area to neighbourhood quarter) in order to support optimal land use and appropriation as well as economy of movement; access for all; and a crosslinking of work, trade, health care, culture, leisure, and green open space. Interwoven multi-fractal scenarios shown later on further enable the classic contraction of city and countryside to be overcome.
In summary, the Fractalopolis software delivers a *"suitability map"* coloured from red to green (traffic light principle) evaluating the distance to service clusters (daily and weekly used facitilities), monthly and occasionally used facilities including green open space. It also shows the distance to the existing street and road network plus access to the public transport network. Depending on requirements, topographical conditions can be integrated as restriction zones restricted.

In contrast, the *Space Syntax* methodology (Hillier and Hanson 1984, Hillier 1996) addresses the relationship between physical elements and social activity and the pattern of utilisation. The main variable of the space syntax theory is accessibility between spaces, which varies according to changes in the configuration of the spatial form.

Hillier, Hanson 1984
Hillier 1996

Space syntax works with the concept of *graph theory* to describe relative centrality (and in-between centrality) of single components (e.g. street segment, axial line). Therefore, in Hillier's theory configuration deals with interdependent relationships of the simultaneous co-presence of elements (Hillier 1996).

Hillier 1996

In summary, Space Syntax describes network configuration in the context of accessibility (cf. structure of the Planning Support System (PSS) and added value to the Decision Support System Fractalopolis).

Fractalopolis' Accessibility Rules

In Fractalopolis two main scales are considered:

- *Macro* level: refers to amenities of type occasional and monthly
- *Micro* level: refers to amenities of type daily and weekly.

The fractal decomposition (as described above) starts with the macro level. As for the case study, the Vienna-Bratislava metropolitan region, it turns out that for Vienna the 3rd and 4th decomposition steps correspond to the scale of the municipal territories. Thus, it is possible to define centres according to the Christaller norms applied at this level, i.e. we distinguish:

- the *Oberzentrum;* includes all facilities up to level 1 (occasional)
- The *Mittelzentrum;* includes all facilities up to level 2 (monthly)
- the *Unterzentrum;* includes all facilities up to level 3 (weekly)
- the *Kleinzentrum;* includes all facilities up to level 4 (daily)

Vienna combines levels 1 and 2. Thus, the whole metropolitan area is dealt with up to these steps.

Based on this, the classification of services and leisure amenities detailed below serves to generate the data base (GIS) for the accessibility evaluation of the *Fractalopolis* software. The classification applies to points and areas for the data base. The below-defined areas [ha] for open green space are based upon the *Accessible Natural Greenspace Standard* [39] (ANGSt).

[39] Nature Nearby - Accessible Natural Greenspace Guidance (NE265) *http://publications.naturalengland.org.uk* (accessed 31.07. 2012)

N.b. The following rule set is adjusted to the existing structure of the Vienna-Bratislava metropolitan region. It is flexible enough to be modified in the software for every spatial system.

Classification of Services and Leisure Amenities

Level 2 (monthly) = Level 1 (occasional)

Services

university
central public administration (e.g. ministry, court, embassy, etc.)
cultural centre (opera, theatre, museum, etc.)
specialised shops (cobbler, jewellers, tools shop, arms shop, etc.)
shopping mall
hospital and health centre
DIY and garden centre
casino

Distance Service, level 1 + 2:

0-20,000m $\mu(d)$ = 1
20,000-40,000m $\mu(d)$ = 1-0

Leisure Amenities

skiing
water sports (e.g. windsurfing, kitesurfing, sailing, etc.)
golf
recreation areas
moors and heathlands
forests
mountains
big natural areas (e.g. alluvial forests)
UNESCO world heritage

Area Size, Leisure, level 1 + 2:

>150 ha

Distance Leisure, level 1 + 2:

0-60,000m; $\mu(d)$ = 1
60,000-100,000m; $\mu(d)$ = 1-0

Public Transport

rail (station)

Level 3 (weekly):

Services

post office	cinema
secondary school	household shop
bank	local cultural centre
hairdresser	drugstore
florist	place of worship
café, restaurant, bar	library
pharmacy	DIY and garden
car repair, bicycle shop	farmer's market
supermarket	clothes shop
dentist	beauty salon
sports centre (competitive leisure services; e.g. indoor climbing, gym, etc.)	spa centre (competitive leisure services; including beauty salon)
local public administration (including social facilties; e.g. municipal office, etc.)	

Distance Service, level 3:

0-3,000m; $\mu(d)$ = 1
3,000-10,000m; $\mu(d)$ = 1-0

Leisure Amenities

small weekly recreation areas
sports areas (tennis, soccer, basketball, public swimming pool, etc.)

Area Size, level 3:

2-150 ha

(reason for range: combines sports grounds with recreation areas)

Distance Leisure, level 3:

0-2,000m; $\mu(d)$ = 1
2,000-15,000m; $\mu(d)$ = 1-0

Public Transport

bus (stop)
rail (station)

Level 4 (daily):

Services

corner shop, organic store
primary school
kindergarten and crèche
newsagents and tobacconist
bakery
butcher
general doctor
cash machine

Distance services, level 4:

0-600m; $\mu(d) = 1$
600-1,200m; $\mu(d) = 1\text{-}0$

Leisure Amenities

playground
dog exercise area
small park (Beserlpark)

Area Size, level 4:

0-2 ha

Distance Leisure, level 4:

0-400m; $\mu(d) = 1$
400-800m; $\mu(d) = 1\text{-}0$

Public Transportation

bus (stop)

Accessibility Rules - MACRO Level

Level 1 (Occasional Level)

Services

- Distances are not taken into account (identification of potential).
- The logic follows a quality evaluation and checks whether amenities are present or not; multiple presence of same amenities is not important (competition between services is not taken into account on the regional scale – iteration step 1-3).
- Combination of amenities: no preference is assigned to specific types of amenities (all types have the same weight).

The *presence of several amenities within a cell* (square) is taken into account by means of a linear increase:

$$\mu(S_1) = \frac{1}{4}\delta \qquad [22]$$
$$\mu(S_1) = 1 \quad for \quad \delta > 3$$

where:
S_1 = service amenities level 1
δ = diversity of services

N.b. the services correspond to the same attribute (variable) and the different services are just different characteristics (values).

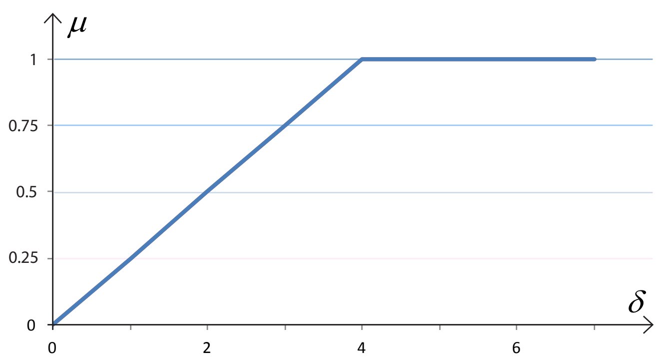


Figure 48a: Linear increase function for services on level 1: 1 service amenity 0.25; 2 service amenities 0.5; 3 service amenities 0.75; and > 3 services 1.

Green and Leisure Amenities

- Distances are not taken into account (identification of potential).
- The logic follows a quality evaluation and checks whether amenities are present or not; multiple presence of same amenities is not important (competition between services is not taken into account on the regional scale – iteration step 1-3).
- Combination of amenities: no preference is assigned to specific types of amenities (all types have the same weight).

The *presence of green amenities within a cell* (square) is taken into account by means of a linear increase:

$$\mu(L_1) = \frac{1}{4}\delta \qquad [23]$$

$$\mu(L_1) = 1 \quad for \quad \delta > 3$$

where:

L_1 = green and leisure amenities level 1

δ = diversity of green and leisure amentities

N.b. the green and leisure amenities correspond to the same attribute (variable) and the different services are just different characteristics (values).

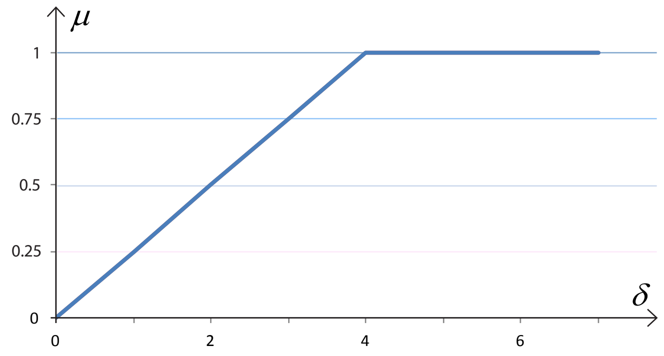


Figure 49: Evaluation of green and leisure amenities on level 1.

<u>No</u> *morphological rule.*

Level 2 (Monthly Level)

Services

- Distances are not taken into account (identification of potential).
- The logic follows a quality evaluation and checks whether amenities are present or not; multiple presence of same amenities is not important (competition between services is not taken into account on the regional scale – iteration step 1-3).
- Combination of amenities: no preference is assigned to specific types of amenities (all types have the same weight).

The *presence of several amenities within a cell* (square) is taken into account by means of a linear increase:

$$\mu(S_2) = \frac{1}{4}\delta \qquad [24]$$
$$\mu(S_2) = 1 \quad for \quad \delta > 3$$

where:
S_2 = service amenities level 2
δ = diversity of services

N.b. the services correspond to the same attribute (variable) and the different services are just different characteristics (values).

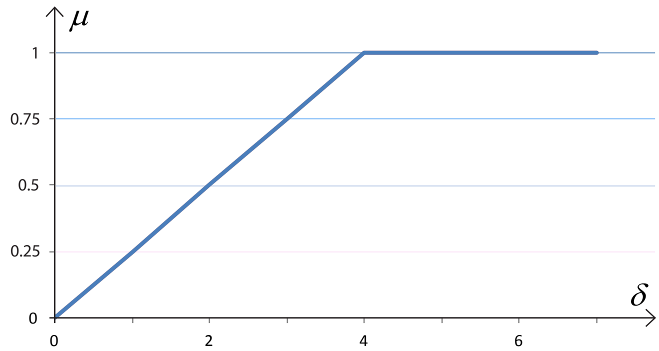


Figure 50: Evaluation of services on level 2.

Green and Leisure Amenities

- Distances are not taken into account (identification of potential).
- The logic follows a quality evaluation and checks whether amenities are present or not; multiple presence of same amenities is not important (competition between services is not taken into account on the regional scale – iteration step 1-3).
- Combination of amenities: no preference is assigned to specific types of amenities (all types have the same weight).

The *presence of green amenities within a cell* (square) is taken into account by means of a linear increase:

$$\mu(L_2) = \frac{1}{4}\delta$$
$$\mu(L_2) = 1 \quad for \quad \delta > 3 \qquad [25]$$

where:
L_2 = green and leisure amenities level 2
δ = diversity of green and leisure amentities

N.b. the green and leisure amenities correspond to the same attribute (variable) and the different services are just different characteristics (values).

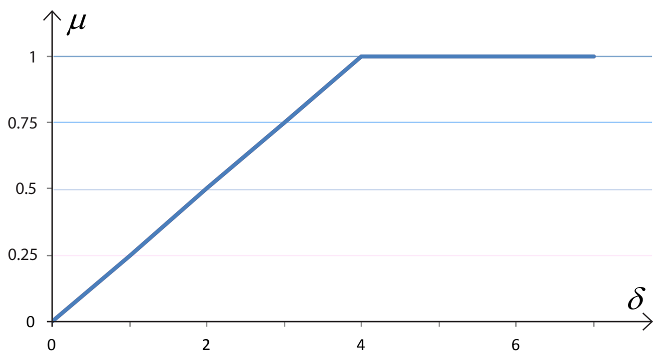


Figure 51: Evaluation of green and leisure amenities on level 2.

<u>No</u> *morphological rule.*

Level 3 (Weekly Level)

Services

- The presence of several amenities is taken into account (diversity) with evaluation of number of the same category.
- Diversity is measured by means of the number of different types of facilities (e.g. for services: supermarket, lower-level administration, post office, etc.) present in the cell (or possibly in a cluster in accordance with the rules outlined below).
- Distances are not taken into account (identification of potential).
- Clusters are not taken into account (aggregation level is too coarse for a 800m cluster)

Combining the number and diversity yields:

$$\mu(S_3) = \mu(n)\mu(\delta) \quad [26]$$

where:
S_3 = service amenities level 3
n = number of amenities
δ = diversity of amenities

Both criteria, i.e. diversity and number evaluation, are presumed to be "equivalent". The product corresponds to a rather "pessimistic" evaluation: this seems realistic since the individual seem to be interested in both the criteria in equal terms an number of services (e.g. the square root or a potential weighting of one characteristic with respect to the other one to be too „optimistic").

$$\mu(n) = 0.25 \cdot n \quad \mu = 0-1 \quad for \quad n \leq 4 \quad ; \quad \mu = 1 \quad for \quad n > 4 \quad [27]$$
$$\mu(\delta) = 0.20 \cdot \delta \quad \mu = 0-1 \quad for \quad n \leq 5 \quad ; \quad \mu = 1 \quad for \quad n > 5 \quad [27a]$$

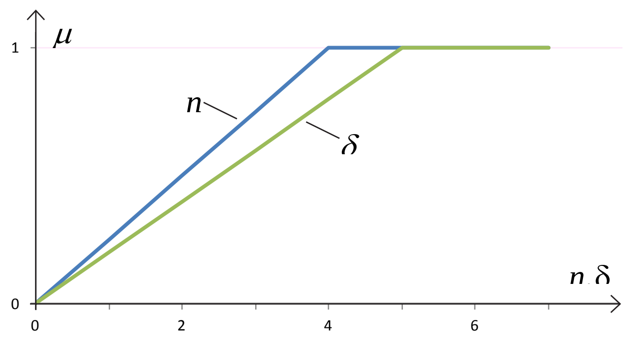


Figure 52: Evaluation of number and diversity on level 3.

Green and Leisure Amenities

- The presence of several amenities is taken into account (diversity) without evaluation of number of the same category (no competition, since usually publicly managed facilities).
- Distances are not taken into account (identification of potential).

The presence of several green amenities within a cell is taken into account in the following way:

$$\mu(L_3) = \frac{1}{4}\delta \qquad [28]$$
$$\mu(L_3) = 1 \quad \mathit{for} \quad \delta \geq 4$$

where:
L_3 = green and leisure amenities on level 3
δ = diversity of amenities

N.b. the green and leisure amenities correspond to the same attribute (variable) and the different services are just different characteristics (values).

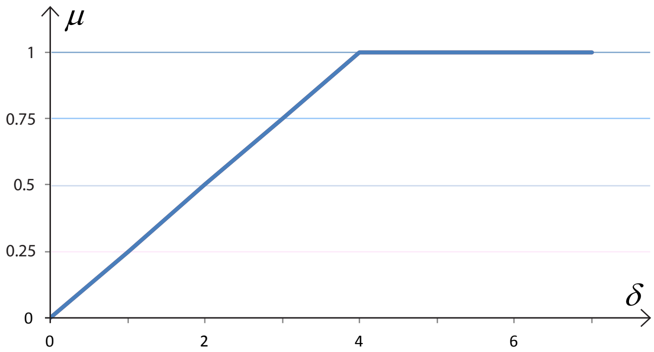


Figure 53: Evaluation of green and leisure amenities on level 3.

Morphological Rule

Distance between neighbouring cells decreases in a linear fashion (according to von Neumann logic); for morphological rule see p.154f.

Level 4 (Daily Level)

Services

- The presence of several amenities is taken into account (diversity) with evaluation of number of the same category (no competition, since usually publicly managed facilities).
- Distances are not taken into account (identification or potential)
- Clusters are not taken into account (aggregation level is too coarse for a 800m cluster).

Combining the number and diversity yields (same logic as above): [29]

$$\mu(S_4) = \mu(n)\mu(\delta)$$

where:
S_4 = service amenities on level 4
n = number of amenities
δ = diversity of amenities

$$\mu(n) = 0.25 \cdot n \quad \mu = 0 - 1 \quad \mathit{for} \quad n \le 4 \quad ; \quad \mu = 1 \quad \mathit{for} \quad n > 4 \qquad [30]$$
$$\mu(\delta) = 0.20 \cdot \delta \quad \mu = 0 - 1 \quad \mathit{for} \quad n \le 5 \quad ; \quad \mu = 1 \quad \mathit{for} \quad n > 5 \qquad [30a]$$

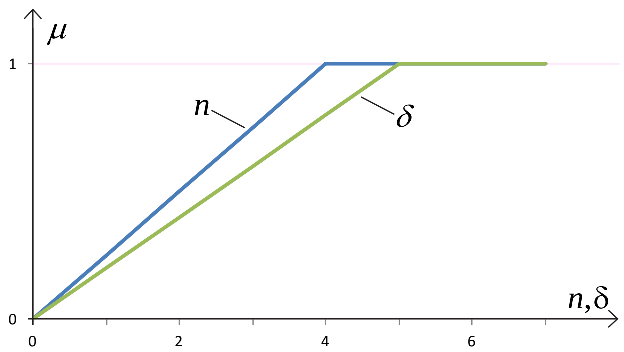


Figure 54: Evaluation of number and diversity on level 4.

Green and Leisure Amenities

- The presence of several amenities is taken into account (diversity) without evaluation of number of the same category (no competition, since usually publicly managed facilities).
- Distances are not taken into account (identification of potential).

The presence of several green amenities within a cell is taken into account in the following way:

$$\mu(L_4) = \frac{1}{3}\delta \qquad [31]$$
$$\mu(L_4) = 1 \quad \textit{for} \quad \delta \geq 3$$

where:
L_4 = green and leisure amenities on level 4
δ = diversity of amenities

N.b. the green and leisure amenities correspond to the same attribute (variable) and the different services are just different characteristics (values).

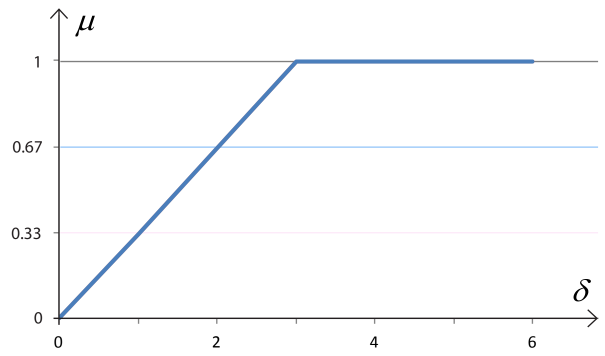


Figure 55: Evaluation of green and leisure amenities on level 4.

Morphological Rule

Distance between neighbouring cells decreases in a linear fashion (according to von Neumann logic); for morphological rule see p. 154f.

Combining the Criteria for Each MACRO Level

Amenities (services and facilities):

- F_4: Daily frequentation, services S_4 and leisure amenities L_4, morphological rules M_4
- F_3: Weekly frequentation, services S_3 and leisure amenities L_3, morphological rules M_3
- F_2: Monthly frequentation, services S_2 and leisure amenities L_2
- F_1: Occasionally frequentation, services S_1 and leisure amenities L_1

Centrality levels:

- P_1: Important central place (e.g. Vienna; prime city) “Oberzentrum”
- P_2: Intermediate central place (town) “Mittelzentrum”
- P_3: Small central place “Unterzentrum”
- P_4: Petit central place (village, hamlet) “Kleinzentrum”

At each level the three or respectively two types of criteria (service, leisure and morphology evaluation) for M_4 and M_3 are weighted and the *arithmetic mean* is computed, i.e.

Level P_1

$$\begin{aligned}
A(P_1)[F_4] &= \mu(S_4) \cap \mu(L_4) \cap \mu(M_4) = 0.33\mu(S_4) + 0.33\mu(L_4) + 0.33\mu(M_4) \\
A(P_1)[F_3] &= \mu(S_3) \cap \mu(L_3) \cap \mu(M_3) = 0.4\mu(S_3) + 0.4\mu(L_3) + 0.2\mu(M_3) \\
A(P_1)[F_2] &= \mu(S_2) \cap \mu(L_2) = 0.4\mu(S_2) + 0.6\mu(L_2) \\
A(P_1)[F_1] &= \mu(S_1) \cap \mu(L_1) = 0.4\mu(S_1) + 0.6\mu(L_1)
\end{aligned} \quad [32]$$

Level P_2

$$\begin{aligned}
A(P_2)[F_4] &= \mu(S_4) \cap \mu(L_4) \cap \mu(M_4) = 0.33\mu(S_4) + 0.33\mu(L_4) + 0.33\mu(M_4) \\
A(P_2)[F_3] &= \mu(S_3) \cap \mu(L_3) \cap \mu(M_3) = 0.4\mu(S_3) + 0.4\mu(L_3) + 0.2\mu(M_3) \\
A(P_2)[F_2] &= \mu(S_2) \cap \mu(L_2) = 0.4\mu(S_2) + 0.6\mu(L_2) \\
A(P_2)[F_1] &= \mu(S_1) \cap \mu(L_1) = 0.4\mu(S_1) + 0.6\mu(L_1)
\end{aligned} \quad [33]$$

Level P_3

$$\begin{aligned}
A(P_3)[F_4] &= \mu(S_4) \cap \mu(L_4) \cap \mu(M_4) = 0.33\mu(S_4) + 0.33\mu(L_4) + 0.33\mu(M_4) \\
A(P_3)[F_3] &= \mu(S_3) \cap \mu(L_3) \cap \mu(M_3) = 0.4\mu(S_3) + 0.4\mu(L_3) + 0.2\mu(M_3) \\
A(P_3)[F_2] &= \mu(S_2) \cap \mu(L_2) = 0.45\mu(S_2) + 0.55\mu(L_2) \\
A(P_3)[F_1] &= \mu(S_1) \cap \mu(L_1) = 0.45\mu(S_1) + 0.55\mu(L_1)
\end{aligned} \quad [34]$$

<u>*Level P_4*</u>

$$A(P_4)[F_4] = \mu(S_4) \cap \mu(L_4) \cap \mu(M_4) = 0.33\mu(S_4) + 0.33\mu(L_4) + 0.33\mu(M_4)$$
$$A(P_4)[F_3] = \mu(S_3) \cap \mu(L_3) \cap \mu(M_3) = 0.4\mu(S_3) + 0.3\mu(L_3) + 0.3\mu(M_3) \quad [35]$$
$$A(P_4)[F_2] = \mu(S_2) \cap \mu(L_2) = 0.4\mu(S_2) + 0.6\mu(L_2)$$
$$A(P_4)[F_1] = \mu(S_1) \cap \mu(L_1) = 0.4\mu(S_1) + 0.6\mu(L_1)$$

Combining the Levels for MACRO Level (Accessibility Rules)

The rules depend on the areas considered (area of level 1, 2, 3, 4 – occasionally, monthly, weekly and daily). The logic strictly follows the means defined by Tannier (2012; working paper) modified by Czerkauer-Yamu, Frankhauser:

The accessibility *A* is hierarchically structured. From a functional point of view the explicit hierarchical approach allows a relational link to be made betweenfrequentation of different amenities and the corresponding distances.

Oberzentrum P_1 to amenities F_4, F_3, F_2, F_1 :

$$A(P_1) = 0.25A(P_1)[F_4] + 0.25A(P_1)[F_3] + 0.25A(P_1)[F_2] + 0.25A(P_1)[F_1] \quad [36]$$

Mittelzentrum P_2 to amenities F_4, F_3, F_2, F_1 :

$$A(P_2) = 0.25A(P_2)[F_4] + 0.25A(P_2)[F_3] + 0.25A(P_2)[F_2] + 0.25A(P_2)[F_1] \quad [37]$$

Unterzentrum P_3 to amenities F_4, F_3, F_2, F_1 :

$$A(P_3) = 0.3A(P_3)[F_4] + 0.3A(P_3)[F_3] + 0.2A(P_3)[F_2] + 0.2A(P_3)[F_1] \quad [38]$$

Kleinzentrum P_4 to amenities F_4, F_3, F_2, F_1 :

$$A(P_4) = 0.5A(P_4)[F_4] + 0.25A(P_4)[F_3] + 0.1875A(P_4)[F_2] + 0.0625A(P_4)[F_1] \quad [39]$$

Accessibility Rules – MICRO Level

Within the “fine” scale accessibilities via networks are included.

Level 1 (Occasional Level)

Services

- Distances d_i are computed on the network for each cell *i* (centroid) to the gravity centre of the set of the level 1 facilities.

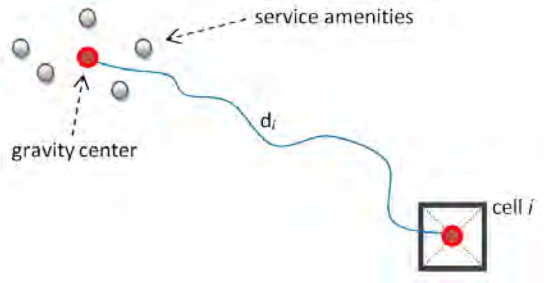


Figure 56: Processing distance d_i for service amenities on level 1.

- Neither diversity nor number are important since they are the same for all sites in the highest-level catchment area. Hence, only distance is taken into account. This is a linearly declining μ-function.

$$\mu_i(S_1) = 1 \quad for\ d_i \le 20km$$
$$\mu_i(S_1) = 2 - \frac{1}{20} d_i \quad for\ 20km < d_i \le 40km \qquad [40]$$
$$\mu_i(S_1) = 0 \quad for\ d_i > 40km$$

where:
S_1 = service amenities on level 1
d_i = distance [km]
i = cell

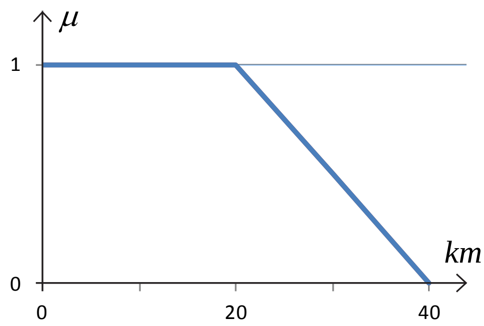


Figure 57: Evaluation of distance for services on level 1.

Green and Leisure Amenities

- The presence of several categories of amenities is taken into account (diversity) without evaluation of numbers of the same category (no competition since usually publicly managed facilties).
- No clusters
- Distances are taken into account: nearest distance to amenity for each category and mean distance for all categories.
- The green and leisure amenities are identified by their accessibility points. These points correspond to the centroid for sports areas etc..
- For area objects such as e.g. forests we take the intersection point between the shortest route between the gravity centre of the cell and the area object's boundary.

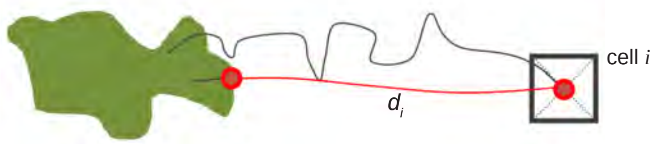


Figure 58: Processing distance d_i for green amenities on level 1.

- For each leisure category we take the nearest leisure amenity; further all categories are then combined. The evaluation of distance again follows a linearly declining function.

$$\mu_i(L_1) = 1 \quad for\ d_i \le 60km$$
$$\mu_i(L_1) = \frac{5}{2} - \frac{1}{40} d_i \quad for\ 60km < d_i \le 100km \qquad [41]$$
$$\mu_i(L_1) = 0 \quad for\ d_i > 100km$$

where:
L_1 = green amenities on level 1
d_i = distance [km]
i = cell

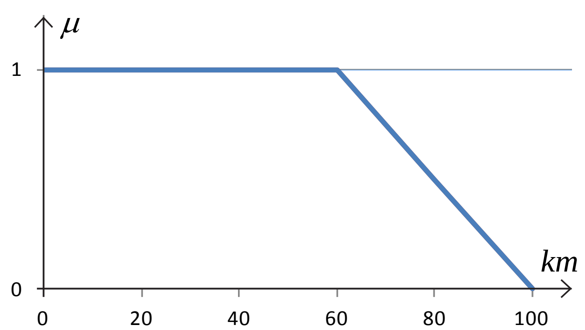


Figure 59: Linear distance decrease for services on level 1.

No Morphological Rule

Level 2 (Monthly Level)

Services

- Distances d_i are computed on the network for each cell i (centroid) to the gravity centre of the set of the level 2 facilities.

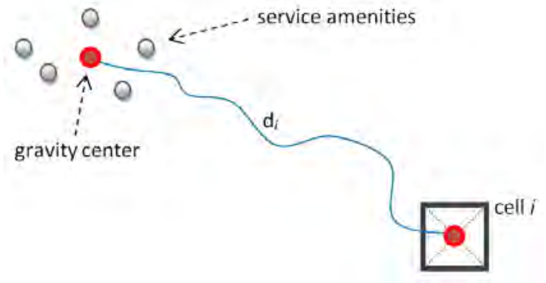


Figure 60: Processing distance d_i for service amenities on level 2.

- We assume that diversity δ and distance d_i *are important, not the amount* (number) of services. Diversity is considered as the different central places of level 2 may have different types of services. Hence, we combine diversity and distance.

$$\mu_i(S_2) = \mu(d_i)^{\mu(\delta)} \quad [42]$$

where:
S_2 = services on level 1
d_i = distance [km]
δ = diversity
i = cell

Diversity is of importance for distinguishing the attractiveness of the different central places of the same level. This formalisation has been chosen since diversity is more important than distance.

This is a linearly declining μ-function:

$$\begin{aligned} &\mu_i(d_i) = 1 \quad \text{for } d_i \leq 20km \\ &\mu_i(d_i) = 2 - \frac{1}{20} d_i \quad \text{for } 20km < d_i \leq 40km \\ &\mu_i(d_i) = 0 \quad \text{for } d_i > 40km \end{aligned} \quad [43]$$

where:
d_i = distance [km]
i = cell

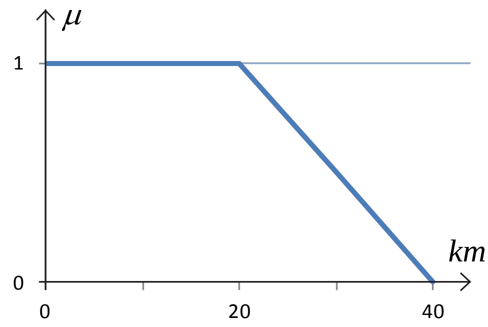


Figure 61: Evaluation of distance for services on level 2

Green and Leisure Amenities

- The presence of several categories of amenities is taken into account (diversity) *without* evaluation of numbers of the same category (no competition since usually publicly managed facilties).
- No clusters
- Distances are taken into account: nearest distance to amenity for each category and mean distance for all categories.
- The green and leisure amenities are identified by their accessibility points. These points correspond to the centroid for sports areas etc..
- For area objects such as e.g. forests we take the intersection point between the shortest route between the gravity centre of the cell and the area object's boundary.

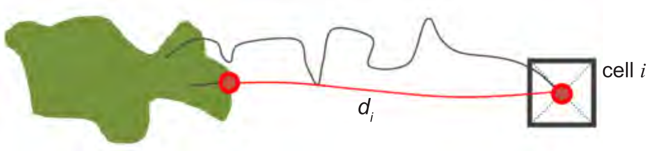


Figure 62: Processing distance d_i for green amenities on level 2.

- For each leisure category we take the nearest leisure amenity; further all categories are then combined. The evaluation of distance again follows a linearly declining function.

$$\mu_i(L_2) = 1 \quad for\ d_i \leq 60km$$
$$\mu_i(L_2) = \frac{5}{2} - \frac{1}{40} d_i \quad for\ 60km < d_i \leq 100km \qquad [44]$$
$$\mu_i(L_2) = 0 \quad for\ d_i > 100km$$

where:
d_i = distance [km]
i = cell

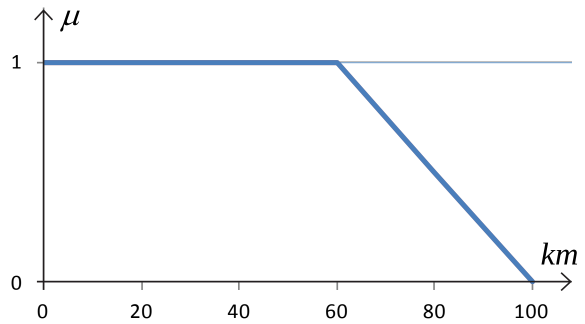


Figure 63: Linear distance decrease for services on level 2.

No Morphological Rule.

Level 3 (Weekly Level)

Services

- The presence of several amenities is taken into account (diversity δ_j) with evaluation of numbers n_j of the same category
- Different centres lying within a distance range are taken into account (3 km), usually by means of a linearly declining function ($\mu(d)$ = 1 up to 3km, linear decrease up to 10km, then $\mu(d)$ = 0
- Clusters are introduced (range: 800m)
- Distance d_{ij} from cell i (centroid) to cluster j is taken into account
- The formalization strictly follows that proposed by Tannier according to the MUP-city logic (Tannier, Vuidel, Houot, Frankhauser 2012). (*Zimmermann-Zysno operator combining the different effects as in MUP-city*[40] *with other distance standards*).

Tannier, Vuidel, Houot, Frankhauser 2012

[40] MUP-city is a software package developed at ThéMA, Université de Franche-Comté, France.

$$Y_{ij} = [\mu(n_j)^{\mu(\delta j)} \mu(d_{ij})]^{1-\mu(d_{ij})} \cdot [1-(1-\mu(n_j)^{\mu(\delta j)})(1-\mu(d_{ij})]^{\mu(d_{ij})} \quad [45]$$

where:
cell = i
services = j
number of services = n_j
diversity (number of differernt types)for aggregation j = δ_j
distance for every cell i and aggregation j = d_{ij}
accessibility for a cell i and aggregation j = Y_{ij}

The operator $\mu(S_3)$ evaluates the accessibility of the cell i to the set of service clusters with weekly frequentation:

$$\mu(S_3) = 1 - \prod_j (1 - Y_{ij}) \quad [46]$$

Green and Leisure Amenities

- The presence of several amenities is taken into account (diversity δ_j) <u>*without*</u> evaluation of numbers of the same category.
- No clusters.
- Distances d_i are taken into account: nearest distance to amenity for each category and further mean distance for all categories.
- Green and leisure amentities are identified by their accessibility points. These points correspond to the centroid for *sports areas* etc.
- For area objects such as e.g. forests we take the intersection point between the shortest route between the gravity centre of the cell and the area object’s boundary.

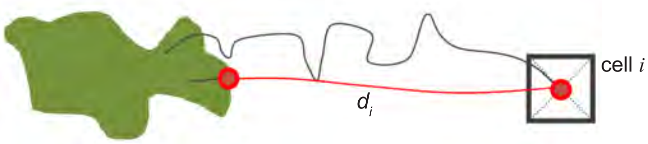


Figure 64: Processing distance d_i for green amenities on level 3.

- For leisure then we take the nearest leisure amenity; further all categories are then combined. The evaluation of distance again follows a linearly declining function.

$$\mu_i(L_3) = 1 \quad for\ d_i \leq 2km$$
$$\mu_i(L_3) = \frac{15}{13} - \frac{1}{13}d_i \quad for\ 2km < d_i \leq 15km \qquad [47]$$
$$\mu_i(L_3) = 0 \quad for\ d_i > 15km$$

where:
L_3 = green amenities on level 3
d_i = distance [km]
i = cell

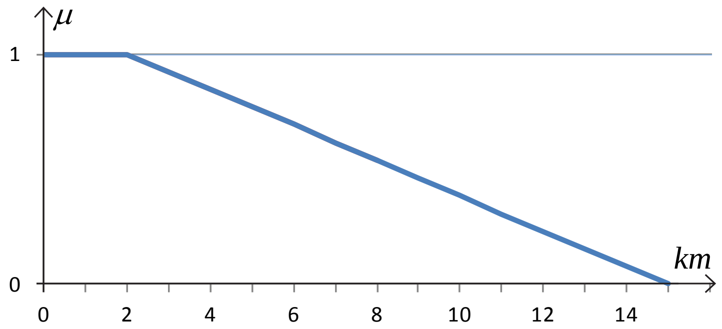


Figure 65: Distance evaluation for leisure and green amenities on level 3.

Morphological Rule

Distance between neighbouring cells decreases in a linear fashion (according to Von Neumann logic); for morphological rule see below.

Level 4 (Daily Level)

Services

- The presence of several amenities is taken into account (diversity δ_j) *with* evaluation of numbers n_j of the same category
- Different centres lying within a distance range are taken into account (3 km), usually by means of a linearly declining function ($\mu(d)$ = 1 up to 3km, linear decrease up to 10km, then $\mu(d)$ = 0
- Clusters are introduced (range: 800m)
- Distance d_{ij} from cell i (centroid) to cluster j is taken into account
- The formalization strictly follows that proposed by Tannier according to the MUP-city logic (Tannier, Vuidel, Houot, Frankhauser 2012). (*Zimmermann-Zysno operator combining the different effects as in MUP-city with other distance standards*).

Tannier, Vuidel, Houot, Frankhauser 2012

$$Y_{ij} = [\mu(n_j)^{\mu(\delta j)} \mu(d_{ij})]^{1-\mu(d_{ij})} \cdot [1-(1-\mu(n_j)^{\mu(\delta j)})(1-\mu(d_{ij})]^{\mu(d_{ij})} \quad [45a]$$

where:
cell = i
services = j
number of services = n_j
diversity (number of differernt types) for aggregation $j = \delta_j$
distance for every cell i and aggregation $j = d_{ij}$
accessibility for a cell i and aggregation $j = Y_{ij}$

The operator $\mu(S_4)$ evaluates the accessibility of the cell i to the set of the service clusters with daily frequentation:

$$\mu(S_4) = 1 - \prod_j (1 - Y_{ij}) \quad [48]$$

Green and Leisure Amenities

- The presence of several amenities is taken into account (diversity δ_j) *without* evaluation of numbers of the same category.
- No clusters.
- Distances d_i are taken into account: nearest distance to amenity for each category and mean distance for all categories.
- Green and leisure amentities are identified by their accessibility points. These points correspond to the centroid for *sports areas* etc..
- For area objects such as e.g. forests we take the intersection point between the shortest route between the gravity centre of the cell and the area object‘s boundary.

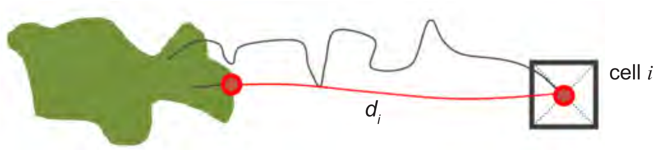


Figure 66: Processing distance d_i for green amenities on level 4.

- For leisure then we take the nearest leisure amenity; further all categories are then combined. The evaluation of distance again follows a linearly declining function.

$$\mu_i(L_4) = 1 \quad for\ d_i \leq 0.8km$$
$$\mu_i(L_4) = 2 - \frac{5}{4} d_i \quad for\ 0.8km < d_i \leq 1.6km \qquad [49]$$
$$\mu_i(L_4) = 0 \quad for\ d_i > 1.6km$$

where:
L_4 = green amenities on level 4
d_i = distance [km]
i = cell

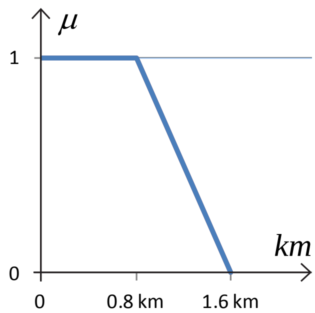


Figure 67: Distance evaluation for services on level 4.

Morphological Rule

Distance between neighbouring cells decreases in a linear fashion (according to Von Neumann logic); for morphological rule see below.

Combining the Criteria for Each MICRO Level

On the microscale global evaluation is of course only of interest for the cells which lie within the selected mesh. Thus, the only relevant rules are those which refer to the type of mesh selected. decreases in a linear fashion rules in awareness of the fact that only some of them will be used in a given context.

Amenities (services and facilities):

- F_4: Daily frequentation, services S_4 and leisure amenities L_4, morphological rules M_4
- F_3: Weekly frequentation, services S_3 and leisure amenities L_3, morphological rules M_3
- F_2: Monthly frequentation, services $S_2$and leisure amenities L_2
- F_1: Occasionally frequentation, services S_1 and leisure amenities L_1

Centrality levels:

- P_1: Important central place (e.g. Vienna; prime city) “Oberzentrum”
- P_2: Intermediate central place (town) “Mittelzentrum”
- P_3: Small central place “Unterzentrum”
- P_4: Petit central place (village, hamlet) “Kleinzentrum”

At each level the three or respectively two types of criteria (service, leisure and morphology evaluation) for M_4 and M_3 are weighted and the *arithmetic mean* is computed, i.e.

Level P_1

$$\begin{aligned}
A(P_1)[F_4] &= \mu(S_4) \cap \mu(L_4) \cap \mu(M_4) = 0.33\mu(S_4) + 0.33\mu(L_4) + 0.33\mu(M_4) \\
A(P_1)[F_3] &= \mu(S_3) \cap \mu(L_3) \cap \mu(M_3) = 0.4\mu(S_3) + 0.4\mu(L_3) + 0.2\mu(M_3) \\
A(P_1)[F_2] &= \mu(S_2) \cap \mu(L_2) = 0.4\mu(S_2) + 0.6\mu(L_2) \\
A(P_1)[F_1] &= \mu(S_1) \cap \mu(L_1) = 0.4\mu(S_1) + 0.6\mu(L_1)
\end{aligned} \quad [50]$$

Level P_2

$$\begin{aligned}
A(P_2)[F_4] &= \mu(S_4) \cap \mu(L_4) \cap \mu(M_4) = 0.33\mu(S_4) + 0.33\mu(L_4) + 0.33\mu(M_4) \\
A(P_2)[F_3] &= \mu(S_3) \cap \mu(L_3) \cap \mu(M_3) = 0.4\mu(S_3) + 0.4\mu(L_3) + 0.2\mu(M_3) \\
A(P_2)[F_2] &= \mu(S_2) \cap \mu(L_2) = 0.4\mu(S_2) + 0.6\mu(L_2) \\
A(P_2)[F_1] &= \mu(S_1) \cap \mu(L_1) = 0.4\mu(S_1) + 0.6\mu(L_1)
\end{aligned} \quad [51]$$

Level P_3

$$A(P_3)[F_4] = \mu(S_4) \cap \mu(L_4) \cap \mu(M_4) = 0.33\mu(S_4) + 0.33\mu(L_4) + 0.33\mu(M_4)$$
$$A(P_3)[F_3] = \mu(S_3) \cap \mu(L_3) \cap \mu(M_3) = 0.4\mu(S_3) + 0.4\mu(L_3) + 0.2\mu(M_3)$$
$$A(P_3)[F_2] = \mu(S_2) \cap \mu(L_2) = 0.45\mu(S_2) + 0.55\mu(L_2)$$
$$A(P_3)[F_1] = \mu(S_1) \cap \mu(L_1) = 0.45\mu(S_1) + 0.55\mu(L_1)$$
[53]

Level P_4

$$A(P_4)[F_4] = \mu(S_4) \cap \mu(L_4) \cap \mu(M_4) = 0.33\mu(S_4) + 0.33\mu(L_4) + 0.33\mu(M_4)$$
$$A(P_4)[F_3] = \mu(S_3) \cap \mu(L_3) \cap \mu(M_3) = 0.4\mu(S_3) + 0.3\mu(L_3) + 0.3\mu(M_3)$$
$$A(P_4)[F_2] = \mu(S_2) \cap \mu(L_2) = 0.4\mu(S_2) + 0.6\mu(L_2)$$
$$A(P_4)[F_1] = \mu(S_1) \cap \mu(L_1) = 0.4\mu(S_1) + 0.6\mu(L_1)$$
[54]

Combining the Levels for MICRO Level (Accessibility Rules)

The rules depend on the areas considered (area of level 1, 2, 3, 4 – occasionally, monthly, weekly and daily). The logic strictly follows the means defined by Tannier (2012; working paper) modified by Frankhauser, Czerkauer-Yamu (2012):
The accessibility *A* is hierarchically structured. From a functional point of view the explicit hierarchical approach allows a relational link to be made between frequentation of different amenities and the corresponding distances.

Oberzentrum P_1 to amenities F_4, F_3, F_2, F_1:

$$A(P_1) = 0.25A(P_1)[F_4] + 0.25A(P_1)[F_3] + 0.25A(P_1)[F_2] + 0.25A(P_1)[F_1] \quad [54]$$

Mittelzentrum P_2 to amenities F_4, F_3, F_2, F_1:

$$A(P_2) = 0.25A(P_2)[F_4] + 0.25A(P_2)[F_3] + 0.25A(P_2)[F_2] + 0.25A(P_2)[F_1] \quad [55]$$

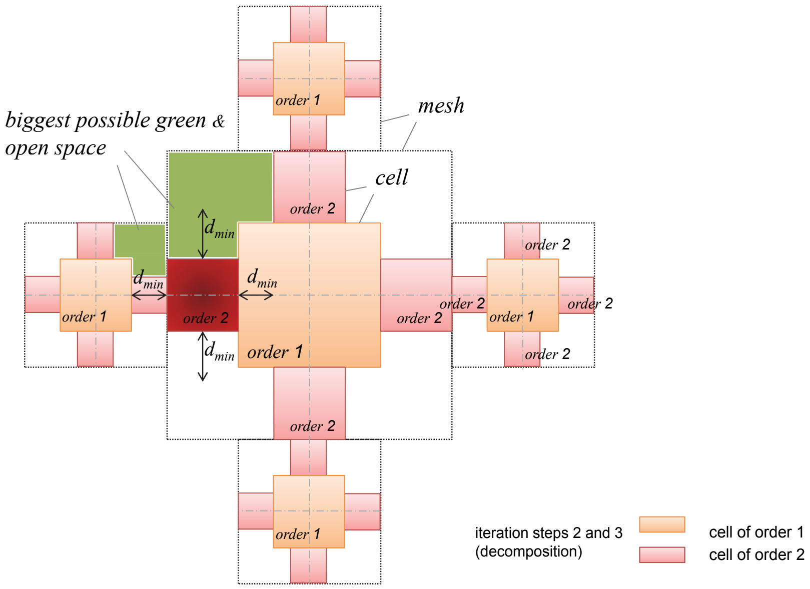
Unterzentrum P_3 to amenities F_4, F_3, F_2, F_1:

$$A(P_3) = 0.3A(P_3)[F_4] + 0.3A(P_3)[F_3] + 0.2A(P_3)[F_2] + 0.2A(P_3)[F_1] \quad [56]$$

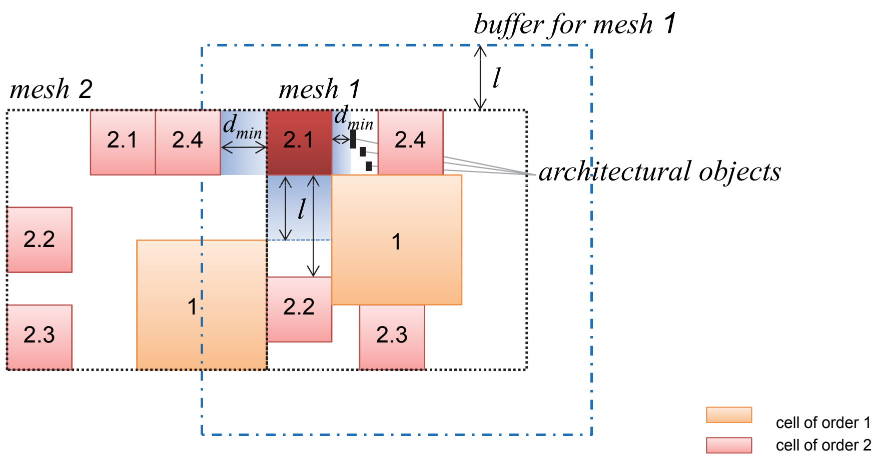
Kleinzentrum P_4 to amenities F_4, F_3, F_2, F_1:

$$A(P_4) = 0.5A(P_4)[F_4] + 0.25A(P_4)[F_3] + 0.1875A(P_4)[F_2] + 0.0625A(P_4)[F_1] \quad [57]$$

6.1.4. Morphological Rule – Lacunarity Rule including Landscape View Rule



a) With this theoretical configuration open and green spaces are the biggest as possible in the context of well connected spaces consistent through scale.



b) Evaluation for two equal sized meshes of d_{min} (2.1;2.2), d_{min}(2.1;2.4) = d_{min}(2.1;2.4)

Figure 68 (a, b): Morphological rule set for lacunarity including landscape view.

- We measure the minimum distances d_{min} of separate cells in proximity of same order (independent of their size). Thus, we measure distances between two cells of order 1 and distances of two cells of order 2.
- If one or more buildings are located between the two assessed cells, the minimum distance d_{min} is taken to the building located in closest proximity to the cell's border under scrutiny. The minimum distance is always taken in all directions.

- For the evaluation the logic of a Manhatten metric is used (x and y are equal).
- Within a mesh the distances are only evaluated with respect to the same order elements (at least for this simple version of the model with only two reduction factors). The neighbourhood of elements of different order are allowed to be adjacent
- For adjacent meshes the same rules apply, regardless of the cell's size (order takes priority over).
- The size of buffer corresponds to *l*. The buffer is defined by the base length of a "sub-cell" (order 2) within a mesh. The buffer *l* is potentially different for each assessed mesh.

N.b. The evaluation should take into consideration the base length of every architectural object (e.g. house) and the corresponding distance from the cell's border to the object. As the programming for this is not yet possible a simplified evaluation rule . In the absence of detailed information we take the mean value of the minimum distance d_{min} of all present distances to buildings and the best evaluation (l =1).
This takes account of the type of housing, e.g. a small single family house versus a linear housing block blocking the view. Thus, using the arithmetic mean we assume that there are still (remaining) open views to the surrounding landscape.

By applying the rule at different decomposition steps for different levels of analyses levels we take into account open and green space of decreasing size. Let us remind here that the size of open and green spaces is directly related to their frequence of use. Small open spaces are daily used, whereas medium sized ones are weekly and very big ones are monthly or rarely used.

Example: Element 2.1.

- Evaluation min (d(2.1;2.2), d(2.1;2.4) = d(2.1;2.4) evaluated according to linearly declining function:

$$\mu(d_{\min}) = \frac{d_{\min}}{l} \quad for \quad d_{\min} \leq l$$
$$\mu(d_{\min}) = 1 \quad for \quad d_{\min} > l \qquad [58]$$

In the event that neighbouring cells (belonging to different meshes) are of the same order but different size, the smallest cell size corresponds to *l*.

6.1.5. Definition of Distances and Information of the Fractalopolis Software

In the following we define criteria for determining the distances used in the previous evaluations. The best evaluated *metric* distances are chosen and used. The path time is computed and users can also retrieve this information. We now define the “metric“ according to the facility levels.

Level 1 (Occasional Level) and Level 2 (Monthly Level)

- Car accessibility via road network (including speed limits)
- Public transport network (PTN) (railway network)

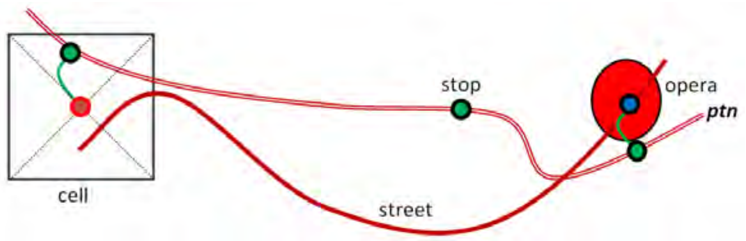


Figure 69: Depiction of the rule set for accessibility; green lines correspond to pedestrian access by using the street network.

Three options for evaluation:

- Car access
- PTN access
- Car and PTN access: best evaluation ist taken for evaluation function *(behaviour as usual)*

Level 3 (Weekly Level)

The weekly level incorporates different alternatives for evaluation:

- Car accessibility via road network
- PTN (regional bus network)

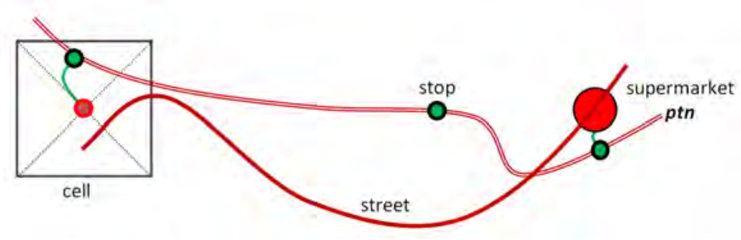


Figure 70: Depiction of the rule set for accessibility; green lines correspond to pedestrian access by using the street network.

Three options for evaluation:

- Car access
- PTN access
- Car and PTN access: best evaluation ist taken for evaluation function *(behaviour as usual)*

Level 4 (Daily Level)

Evaluation:

- Pedestrian accessibility by using the street network (according to Tannier, Vuidel, Frankhauser 2010)

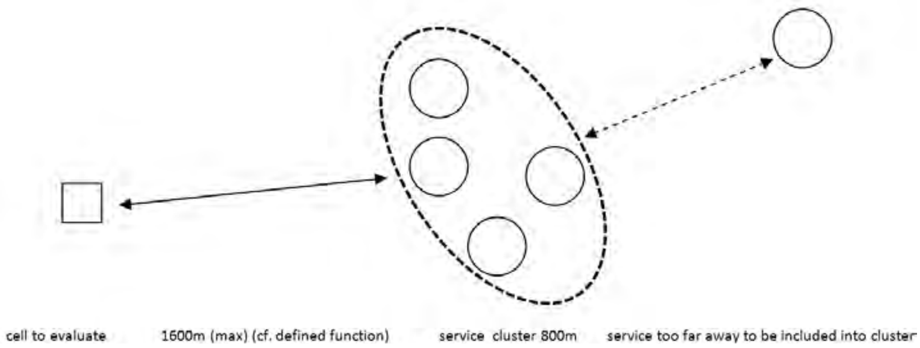


Figure 71: Depiction of the rule set for accessibility to clusters (modified; original Tannier 2012).

6.2. The Fractalopolis Software – A Simple Guide.

Based on the previous formalisation of Fractalopolis we will explain in the following how the software *Fractalopolis 0.6* [41] works and how the user can create multi-scale spatial scenarios on a macro and micro scale including accessibility and morphological evaluations. Please note, that the *Fractalopolis* software is an ongoing research.

[41] The software was programmed at ThéMA, Université de Franche-Comte, France by Gilles Vuidel.

Before we begin

Prepare shape files (ESRI format for geodata) containing areas and points including max. distances and definition of levels according to the formalisation for the area under scrutiny. For a minimum set you need to prepare the following layers:

For MACRO Level:

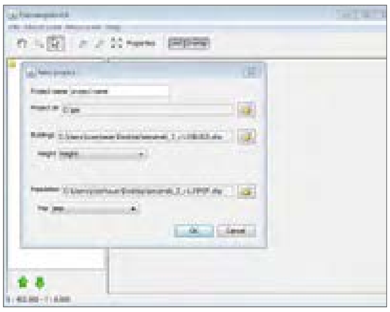
- *Built-up area*
- *Population (e.g. at municipal level)*
- *Highways and motorways*
- *Railway network*
- *Green areas*
- *Restricted zones*
  (these are zones where building is subject to special requirements, including landscape conservation zones and slope restrictions)
- *Water*

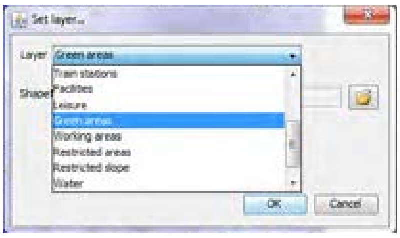
(-Hillshade and agriculture can be helpful)

For MICRO Level:

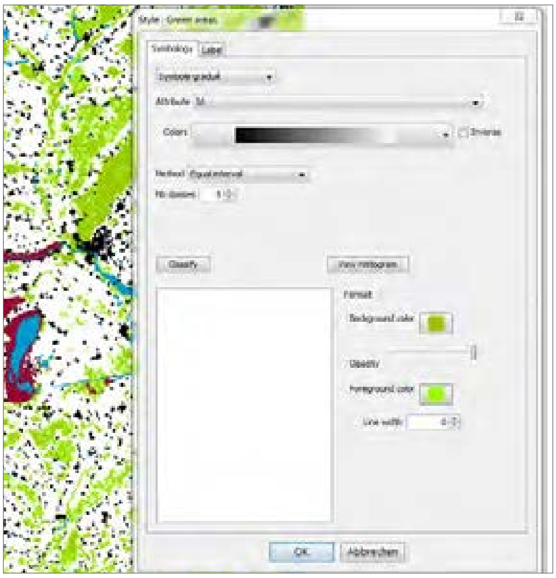
- *Detailed built-up area*
  (this will also serve as a basis for the 3D model)
- *Population (e.g. at municipal level)*
- *Road network (detailed)*
- *Railway network and stations*
- *Bus network and stops*
- *Green areas*
- *Services*
- *Leisure*
- *Restricted zones*
- *Water*

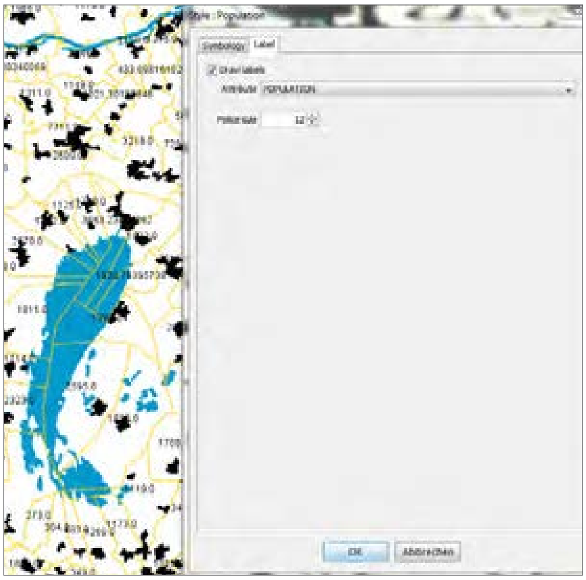
To create a *new project* from scratch the *built-up area* layer and the *population* layer have to be loaded. A folder will be created containing all loaded shape files including a project file. This helps to transfer projects in general. Additional layers can be added using *File – Set layer*.





Once the layers are loaded you have the possibility to change the *colour* for each indivudal layer and add *labels* by ticking the box *Draw labels*.

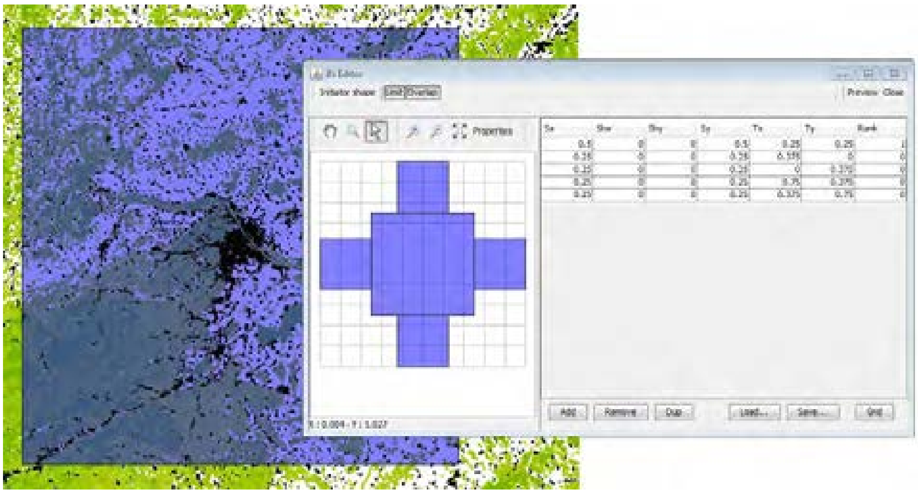




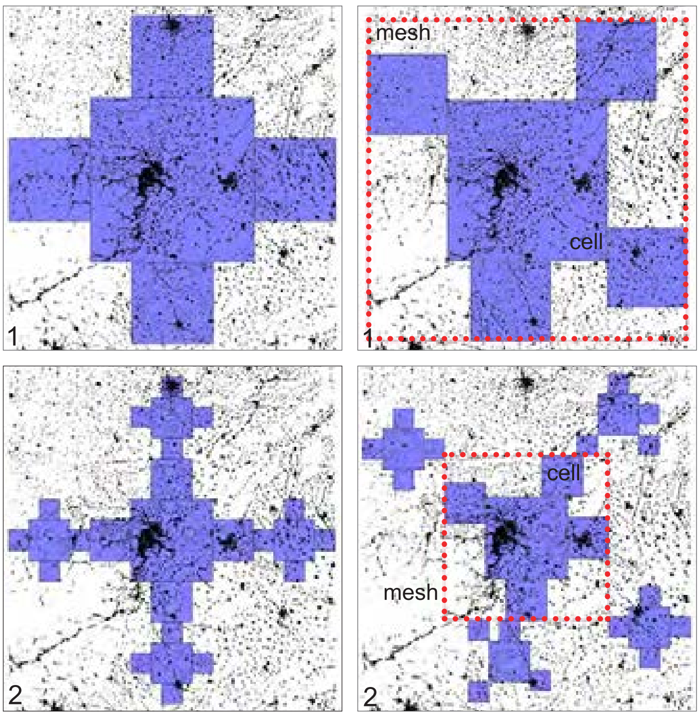
Once all layers are set the *fractal generator* can be defined (Iterated Function System – IFS Editor [42]). At the moment two different *ranks* can be calculated; rank 1 for centres and rank 0 for sub-centres and/or periphery. This has an impact on the population model. IFS can be set individually for macro and microscale.

[42] The IFSs are a method of constructing fractals.

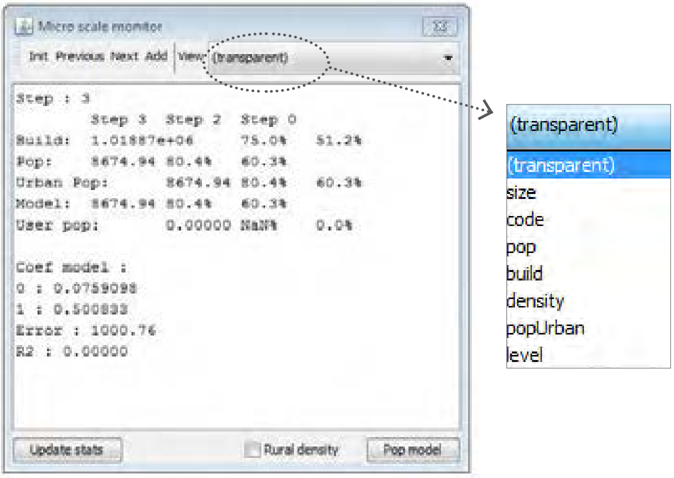
N.b. the fractal generator links to the Christallerian idea; the generated cells (iteration steps) will define the different sizes of potential development areas on an iteration level (multi-fractal logic).



From the very beginning you will have the initial figure (blue square; iteration step 0) defining the catchment area for the area under scrutiny. The initator can be varied in size and position, which will influence the scenarios. Below we show iteration steps 1 and 2 (for a theoretical multifractal see left images). (For an easy colouring of the layers you can move the initiator to the right within the window.) For developing planning scenarios, each cell can be moved within the mesh in order to indicate a potential strategic development area – either for an urban infill, consolidation, downsizing (by identifying the worst measures for accessibility measures to facilties and leisure), or extension of an area (by identifying the best accessibility measures). Further, any necessary economic, ecological and social enhancement (e.g. more shops for daily use; public transport stops; schools and kindergartens) can be discussed and analysed.



The iteration steps are obtained by opening the *macro scale monitor f*or macro scale and the *micro scale monitor* for micro scale using *menu – macro scale – monitor* and the same for micro scale. For the iteration steps simply click on *Add*. With *Next* and *Previous* you can browse through the iteration steps and make changes to your scenarios at any time. After going backwards and forwards and making changes you also need to update the statistics by clicking *Update stats*. By clicking on *Init* (initiator) you can remove all fractal steps. *Limits* helps you to stay within the catchment area when moving cells within a mesh, whereas *Overlap* prevents overlapping of cells.



This monitor provides a number of features. The most important features are always visible.

Step: Current iteration step; below this, information on the current step in relation to the previous step and the initiator (step 0) is displayed.

Build: Built-up area according to GIS files; percentage calculated between previous and current iteration step; percentage calculated from initiator

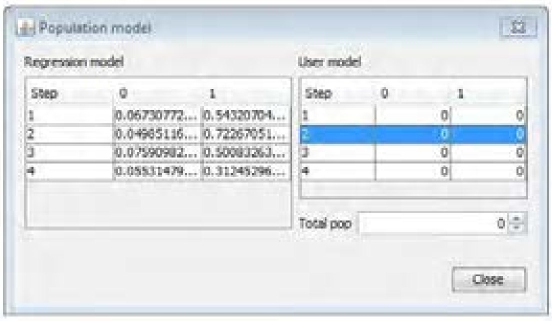
Pop: Real population of current interation step; percentage – same logic as before

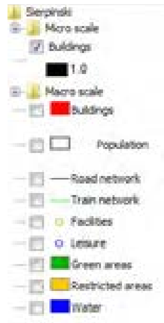
Urban Pop: Urban population; from this measure we know how much population is in the countryside (see population model); percentage – same logic as before

Model pop: is the population determined by the population model with coefficients estimated by regression.

User pop: is the population determined by the population model with coefficients given by the user.

View allows us to display a coloured image of the cells for a chosen feature, e.g. density. *Transparent view* is the default setting (blue cells). The monitor further offers a *Pop model*, which allows you to define a model population and redistribution of existing population for the different ranks.





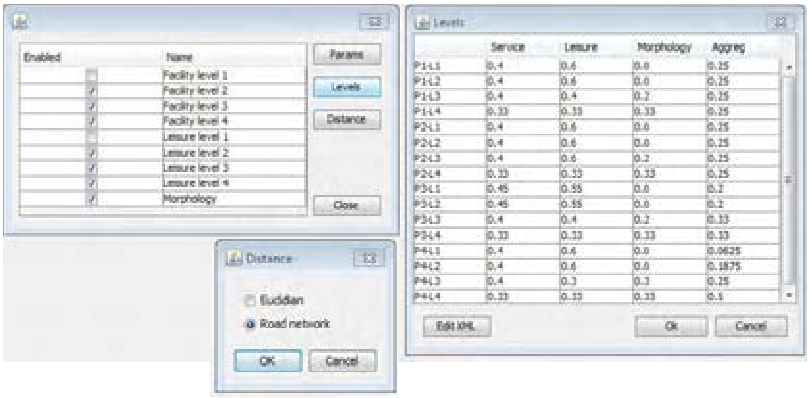
To change between *macro* and *micro scale*, choose a cell of interest at any iteration step on the macro scale and go to *menu – micro scale – create*. The micro scale monitor appears with the chosen cell as the new initiator for micro scale. Hence, a new IFS can be defined. If you do not define a new IFS for micro scale the previously defined IFS for macro scale will be used. On the vertical layer bar micro scale will be added.

(Experience shows that it makes sense to change the scale, macro to micro, at iteration step 3 or 4 by a given basic length of the initator on macro scale of appr. 200km.)

On macro scale *Fractalopolis* is a a normative model, whereas on micro scale it follows the logic of accessibility. Of course, accessibility can be calculated on macro and micro scale, though it is preferable and more useful to do it on the micro scale. (Note: We need to map the whole catchment area = initiator on macro scale for services and facilities as well as leisure and public transport)

Add all layers as mentioned above (see list). By clicking *update statistics* and *next* the accessibility evaluation will be colour coded from green (= 1) to red (= 0) in the scale monitor. In the scale monitor you can view different *accessibility evaluations* including the *morphological evaluation* and a *global accessiblity measure*. The accessibility distance measures, the combination of facilties as well as their preponderation (aggregation levels) and can be changed to reflect any metropolitan area under scrutiny. When browsing through the iteration steps the colour code corresponding to the evaluation on each level will be kept.

The simulation is useful down to an architectural scale (plot and block size). The scenarios can be exported as shapefiles, svg and TIFF files using *menu – file – export*. The export as shapefiles supports further handling and processing in GIS and also the creation of a *3D model*.



Accessibility parameters

Example of evaluation for a theoretical multifractal.

6.3. Hillier's Space Syntax [43]

The *Space Syntax Method* from Hillier (Hillier, Hanson 1984; Hillier 1996) is used herein to approach in combination with the decision support system *Fractalopolis* a planning support system.

[43] from Czerkauer 2007; revised 2012

Space Syntax[44] addresses the relationship between physical elements of a city and its social activity and the pattern of utilisation. Marcus (2007) defines the Space Syntax theory in a very understandable way when he explains that the main variable of urban form that is analysed within Space Syntax is *accessibility* and how the accessibility between spaces varies according to the changes in the *configuration* of urban form. This methodology considers space and the spatial structure as the fundamental concept.

[44] This research began in the 1970s at the Bartlett School of Architecture, University College London, under the direction of Bill Hillier. The original aim was the systematic testing of how design criteria have had an influence on rapid social decline (and ghettoisation) of postwar public housing buildings in Great Britain. Following on from this survey, the space syntax method was developed. (Rose, Schwander, Czerkauer et al. 2008)

There is a direct link between the urban structure and the pattern of activity, as the organisation of a city and its network of open spaces is created by the urban agglomeration of socio-spatial units. One of the major attributes is the relationship between movement – represented by connectivity and accessibility – and the spatial network, known as configuration.

Hillier 1996

Hillier, Hanson 1984

Marcus 2007

Space Syntax works with the concept of *graph theory* to describe relative centrality of single components using the basic tool of an *axial map* – as the minimal set of longest straight *lines of sight* or/and *movement* (axial line) that interconnects all open spaces. Marshall (2005) says that the axial line reflects the geometry of bounded space.

Marshall 2005

The axial line intersection of an axial map becomes the edge and the derived graph structure of the axial map is the *axial graph*. An axial map is a geometric model of an urban grid that transfers into a topological graph. This topological graph has the street network structure as its “underlying” property. As Hillier (2003) describes the city as a set of lines we can postulate the axial line logic as an abstraction of the urban network. He draws attention to the importance of connectivity and its topological arrangement into a network by the geometry of a system. What can be derived from this point is that the abstract connectivity (configuration) is more important than the position of space (composition) (Marshall 2005). What Space Syntax represents is a topological network to link urban structures with social activity through the idea of connectivity and accessibility.

Hillier 2003

The Idea of Centrality within Space Syntax Theory

Centrality has been revealed as a very important factor for understanding the structural characteristics of a complex relational network and further for implementing sustainable and sustaining planning strategies. It is also relevant to various spatial factors affecting social activity in cities. Centrality, or rather the cascade of centre and periphery, represents the topological dimension of a hierarchical scale of accessibility within a system. The higher the connectivity of the street pattern, ergo the accessibility, the more central a place is. The peak of a city is the highest connected agglomeration of socio-spatial units.

Different kinds of centrality are at work within urban agglomerations. Spatial and social concepts have to be distinguished. Spatial centrality supports social centrality. Metric centrality, as in Christaller's Central Place theory and Lösch's theory of Market Structures, implies the metric centre as the middle of an area where services, goods, and supply are located. Therefore, topological centrality as applied in space syntax theory implies the spatial integration of an area. It can be described as the configurational structure of the street network. Finally, a cultural centrality, defines the concentration of historical and cultural artefacts in an area (Van Nes 2007).

Lösch 1940

Van Nes 2007

Hillier (1999) argues that the centre of an urban agglomeration usually means a concentration and mix of land uses and activities in a prominent location. A concentration and mix of activities in a certain spatial position is carried out in relation to the whole settlement (Moreno Sierra 2009). Hence, where there is a centre, there is centrality. *Topological centrality* is linked to the urban fabric and its accessibility.

Hillier 1999

Moreno Sierra 2009

With regard to space syntax, centrality is defined through appropriate accessibility with the least possible changes in direction within the local or global urban environment. Hence, the integration of central places has a very high rank with respect to the whole system. The exclusion of other urban places as central places and the definition of one or more centres classifies a cascade. Thus, every city and region has its own topological hierarchy.

Centrality is also represented by a high movement flow of pedestrians. For example, historic centres in most towns have a good *movement economy* (Hillier 1996) in terms of socio-spatial impact. It refers to the socio-spatial impact. "Vital" centrality means the element of centrality which is led by retail, markets, catering and entertainment, and other activities which benefit unusually from movement.

Centrality appears to invoke spatial requiremententes over and above those related to other central functions such as administration, office employment or worship. The key proposal is that a distinctive spatial component is influenced by the movement economy process. The movement economy theory builds on the analysis of movement flows of a street network, influenced by the spatial configuration of the network itself.

Hillier 1996

We have to consider that two kinds of movement are at work. The first is *linear movement* from specific origins to specific destinations. In contrast to this, the second kind of movement is *moving around (strolling; cruising)*; movement within a local area, and relates to all origins and all destinations within that area. This process has the effect of optimising "metric distance", that is, minimising mean trip lengths from all points to all others within that area (Space Syntax Ltd. 2006). The organisation of settlements generates movement patterns, influencing land use choices and, furthermore, political planning decisions. These land use choices in turn influence local grids and so movement representing intensive use and density can be read of from the street fabric. Moreover, centres have the highest intensity of movement in an urban system. Through movement a cascade of more and less intensive movement emerges and therefore reflects a hierarchy.

Space Syntax Ltd. 2006

Centrality as a Process

We have to think of centrality not just simply as a state, but as a process with both spatial and functional aspects (Hillier 1999). Usually with the growth of settlements into large towns or to city level, a whole hierarchy of centres including sub-centres appears throughout the settlement. Through the everyday process of path selection behaviour, the spatial factor plays a critical role in the formation and location of prominent places and at the same time in developing and sustaining their intrinsic vital aspect. In fact, the constitution of centrality works through spatial configuration on *route choice* within a street network. This has an influence on land use location choices: so-called "attractors" appear, as in the urban layout as a whole.

Hillier 1999

Understanding centrality does not appear very problematic, because it seems clear and stable, if we for example think of historic centres with their "vital centrality". The area and its boundaries are well defined, and all we have to do is look at the spatial-economic layout. But as soon as we take time into account the whole idea of stable and clear centres seems to fade; the boundaries of centres do not remain in the same place over long periods. Through the growth of urban settlements centres may expand, contract or shift their focus. Most commonly, centres have the tendency to specialise in their function within the growth of a settlement, like e.g. in London, and sub-centres will interlink in the cascade of *centre* and *periphery*.

Various town centres can be defined as complexes of interdependent facilities, so that if you come to use one, it is easy to use others. The criterion for whether or not a development would be "part of the town centre" reflects this interdependence: if people come to use this, will they also use other facilities in the centre? Whether or not interdependency is effective depends on inter-accessibility: it must be possible to get from any facility to any other by a quick and easy route which stays within the town centre and which itself is lined with town centre facilities to maximize natural access to all facilities (Space Syntax Ltd. 2006). In other words, in centres it must be possible to explore, search and find relying on an underlying rule of wherever you go to, you can find an easy route to any other location within the centre, without going back over the same route. Inter-accessibility should be reflected in the spatial layout, not just on a local scale within the specific centre, but also on a global scale between the different centres. Centres will grow along major routes – as in Vienna along the historic supra-regional roads and boulevards – to some extent, and at the same time the integrity of the urban system will be conseerved. From a spatial viewpoint, centrality is a product of the global configuration of the road network, which identifies where the centre should be located, and the local process of street grid adaptation.

Space Syntax Ltd. 2006

Through the process of reallocation of functional aspects, individual mobility by car is an essential factor which influences central places. How does mobility affects centres and change them?

Stephen Read (2000) claims that with regard to configuration cities consist of different scales of hierarchy. These scales are layered, distinguished by the scales of mobility, and are designed to convey different scales of movement. He points out duet to the hierarchical configuration of the network there are different levels of carrying traffic over medium, longer and local distance. A historic centre supports pedestrian movement; an outlet centre or a shopping mall supports individual transport by car.

Read 2000

Hence, there are different types of centres for the diverse mobility scales that exists.

Read and van Nes point out, that those who complain that the centre has become specialised for parts of the lives we live have failed to understand that this cannot in reality be otherwise, given the fact that the city as it is lived in now is bigger and includes more, and more diverse networks and territory (Read 2006). Read 2006

The formerly important spatial centrality has been substituted by the centrality of the transport connection. And the closeness of these centres to the city still has more to do with prestige than with function. In a structural sense the effect is a new sub-centre centrality between an urban nucleus (very dense spatial structure) and the periphery. These sub-centres force a hyper-dimensional revaluation and up-valuation of the local area and at the same time degrade the “old” centre. On a global scale the population’s redistribution for e.g shopping and entertainment is more spread, following a global rather than a local logic. In an analytical sense the sub-centres substitute public space with an imitation of publicness in an enclosed spatial capsule that is an exclusive area. These places have a socially selective attitude, identified by exclusion through symbolic, economic and physical barriers. Artificial sub-centres of the same size are at the same hierarchical level, and as a result, competitors. This is the reason for a political and planning impact-supply with infrastructure, cultural institutions like schools, markets, pedestrian zones and junctions (access) to metro stations.

Read claims that in order to produce real (urban) centrality, locations need to be integrated at a wide range and variety of scale levels. Centrality and periphery is a product of layering and scales. This means that real (urban) centrality depends not only on the regional context, but also on the regional, city-wide and local scale (global to local). In other words, the location needs to be systematically connected to the more traditional urban scales as well as to the new ones (Read 2000). Read 2006

6.3.1. Methodology and Formalisation of Space Syntax

Spaces are linked together by a spatial relation. Their linkage consists of different attributes such as *adjacency*, *permeability*, *seperation*, and *segregation*. Therefore, in Hillier´s theory configuration refers to an interdependent relationship affected by the simultaneous co-presence of at least a third element and possibly all other elements in a complex system (Hillier 1996). To visualise the relation or configuration between spatial elements space syntax theory uses as a basic element a *graph* which is later transcribed into an *axial line* and further into an *axial map* [45].

Hillier 1996

[45] The definition of an *axial map* can be summarised thus: an axial map represents the continuous open space network as a matrix of the fewest, and longest, possible lines of sight and movement that can be drawn along the streets and public spaces of a system, without leaving any street segment or space left out of the network. Each street's network position relative to all other streets is analysed using a computer program which considers each line as a node in a graph and calculates the depth (the fewest steps to every other line in the system (Greene et al. 2000, 62f.). In other words, the axial map represents urban space that it is possible to visually overlook and physically access (Marcus 2007).

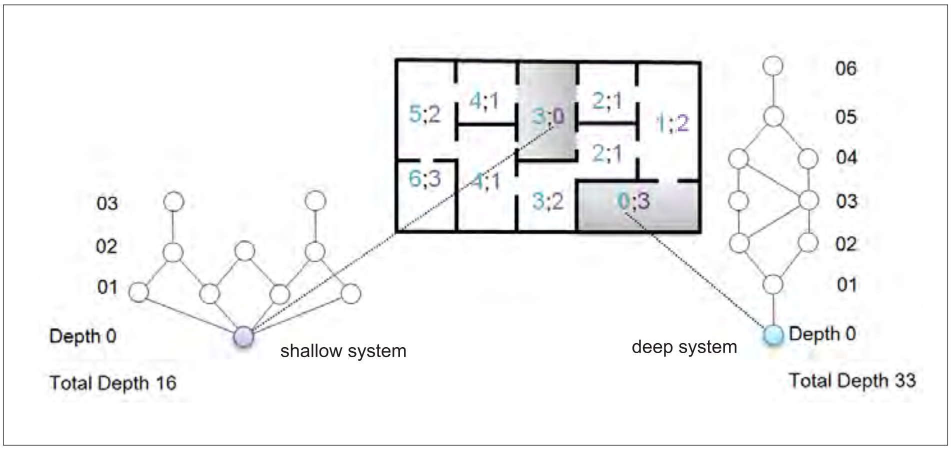


Figure 72: Spatial depth from different root nodes (depth 0) in a system. From the j-graph (justified graph) *total depth* can be calculated by the sum of all possible steps from a given starting point (from Czerkauer-Yamu 2012; original: Rose, Schwander, Czerkauer et al. 2008). The left graph depicts a shallow system which is indicated by three syntactic steps whereas the right image depicts in contrast a deep system indicated by six syntactic steps. The "deeper" the system the greater the total depth.

Rose, Schwander, Czerkauer et al. 2008

The influence of shape has an impact on distribution is fundamental to the study of spatial systems. In general, the distribution of *depth* underlies architectural and geometrical effects. The problem of *total depth (TD)* is that it is influenced by the shape of the calculated system, making it impossible to compare different spatial systems. Thus, the value of depth is normalised so it is possible to express the numerical value of total depth independently of the size of a spatial system. As the j-graph represents the structure of graphs it leads to the demand for a standardised format for comparative analysis.

The space syntax analysis uses three main categories of measures:

- numeric measures,
- metric measures and
- configurational measures.

Numeric measures are metric measures such as length and width, and also numbers of axial lines. Configurational measures describe the relationship of spaces to each other. Configurational measures can be divided into local and global measures. Local measures quantify the relationships of nodes that are closely connected, for example in 3 or 5 syntactic steps and thus quantify the characteristics of spatial neighbourhoods. In contrast, global measures evaluate the overall characteristics of a graph as a whole. Greene et al. (2000) point out that the importance of configurational measures is that they strongly correlate with pedestrian and vehicular movement (c.f. movement economy).

Greene et al. 2000

In the following we will describe and explain the development from the configurational measures of total depth and mean depth to *integration* that is used for the empirical analyses of this research.

Total Depth (TD)

Is the sum of all possible steps of a system.

$$TD = \sum_{i=1}^{n} s_i \quad [59]$$

where:
TD = total depth
S_i = all possible syntactic steps of a graph or axial map

Mean Depth (MD)

From the idea of total depth a value called *mean depth* can be differentiated. Mean depth is the average depth of a certain space within each possible j-graph drawn for the urban system in question.

$$MD = \frac{TD}{k-1} \quad [60]$$

where:
MD = mean depth
TD = total depth
k = number of cells/nodes in a graph including root node

Mean depth is equivalent to the total depth relativised to the number of axial lines or nodes of the system and represents the average steps needed to reach any of the axial lines of the system.

Relative Asymmetry (RA)

Relations of depth necessarily involve the notion of asymmetry, since mean depth varies with the root to some extent. Relative asymmetry is a normalisation (0-1) of mean depth; with low values indicating a space from which the system is shallow, that is a space which tends to integrate the system, and high values indicating a space which tends to be segregated from the system. The normalisation enables comparison of different spatial systems. Major and Hillier explain that RA only measures depth relations in the system and a tree with that distribution will be the same as a ring system with the same distribution of spaces as the shape is not taken into account (Major, Hillier et al. 1998). The following formular is taken from Hillier and Hanson; no precise mathematical derivation is given (Hillier and Hanson 1984, 108).

Major, Hillier 1984

$$RA = \frac{2(MD-1)}{k-2} \qquad [61]$$

where:
RA= relative asymmetry
MD = mean depth
k = total number of spaces

Real Relative Asymmetry (RRA)

If we wish to make comparisons across systems which differ significantly in size, we must make one or more transformations to eliminate the considerable effect that size can have on the level – though not the distribution – of RA values in a real system. In effect, what we do is compare the RA value we have with the RA value for the “root” (the space at the bottom of a justified map) of a “diamond-shaped” pattern. This has nothing to do with a geometric shape. It simply means a justified map in which there are k spaces at mean depth level, k/2 at one level above and k/4 at two levels above and below, and so on until there is one space at the shallowest (the root) and deepest points (Hillier and Hanson 1984, 111ff).

Hillier, Hanson 1984

RA is influenced by the size of the system. Therefore RRA provides a relativisation that allows comparison of depth between different-sized spatial systems.

$$RRA = \frac{RA}{D_k} \qquad [62]$$

where:
RRA = real relative asymmetry
RA = relative asymmetry
D_k = diamond value for k spaces
k = number of spaces

D represents the distribution and k the size of the system – it follows, that D_k is a value representing a value-based number of spaces in the system. In order to eliminate the effects of size (as with RA) every case is compared with a graph of a diamond of that number of spaces (for D-values see The social logic of space, Hillier, Hanson 1984, pp.112).

Hillier, Hanson 1984

Integration (INT)

High RRA values mean greater depth, which implies less activity and segregation. So, the reciprocal of RRA – represented by the integration value – is used for a syntactic analysis. High integration values represent more integrated spaces whereas low integration values indicate more segregated places. This correlates well with the idea of movement.Integration enables measurement of the relative accessibility of a space within a system. Hillier and Hanson describe integration as a global measure of depth, relativised in such a way that differently sized systems can be directlycompared to one another directly (Hillier, Hanson 1984).

$$INT = \frac{1}{RRA} \qquad [63]$$

where:
INT = integration
RRA = real relative asymmetry

Integration can be calculated as a *global* or *local* measure. Global measures calculates integration for the whole system whereas a local measure is restricted to finite syntactic steps and therefore a specific spatial neighbourhood. Radius measures enable compartmentalisation of the global character of depth at any pre-selected depth status. Generally speaking, they are systematised in local and global measures. Radius measures are strongly used in correspondance with the integration analysis.
The local measure, e.g. radius 3 (R3 as defined by Hillier) is, as a shallow one, very useful. It is the root node and two topological steps in any direction. That means that R3 analyses space in terms of it being reachable within two additional topological steps. In R3 or *local integration* analysis important streets for a certain area (neighbourhood, quarter) on a local scale are identified. In addition, experiments with Radius 4, 5 and onwards should

be done to test the best-fit behaviour, because the size and configuration of the system always has an impact on the analysis.

The opposite measure to the local integration is the *global integration* or radius infinity (Int N). It reveals the relationship of spatial pattern to the focus of the whole spatial system. Radius N examines the whole spatial system – instead of focusing on local areas, defined by e.g. Radius 3 or two topological steps, it describes the relationship of all points to all points, regardless of their distance or the number of topological steps to each other. Radius N helps to analyse the whole system and gives a very good dimension of the spatial pattern or fabric of a city. Global measures correlate with long distance-journeys and are strongly linked to vehicular movement. In other words, radius N represents the urban system on a macro scale and highlights centrality in an urban agglomeration.

In the analysis of radius N the "*edge effect*" comes into play. Configurational measures have an adequate buffer of nodes around them in order to produce correct and clean results. The edge effect results from those areas, that have no accurate buffer zone around them. This produces artificially low results which are not precise or accurate. Using local measures such as radius 3 minimizes the edge effect, but still does not eliminate it. To minimise the edge effect for a whole spatial system a measure called radius-radius (RadR) or Super Grid (Rose, private information 2006) has been devised. This analysis tool works on the level of mean depth in the sense that the topological steps of mean depth are taken and calculated as an integration from the highest integrated axial line of a system. Radius-radius is different for every system.

Rose 2006

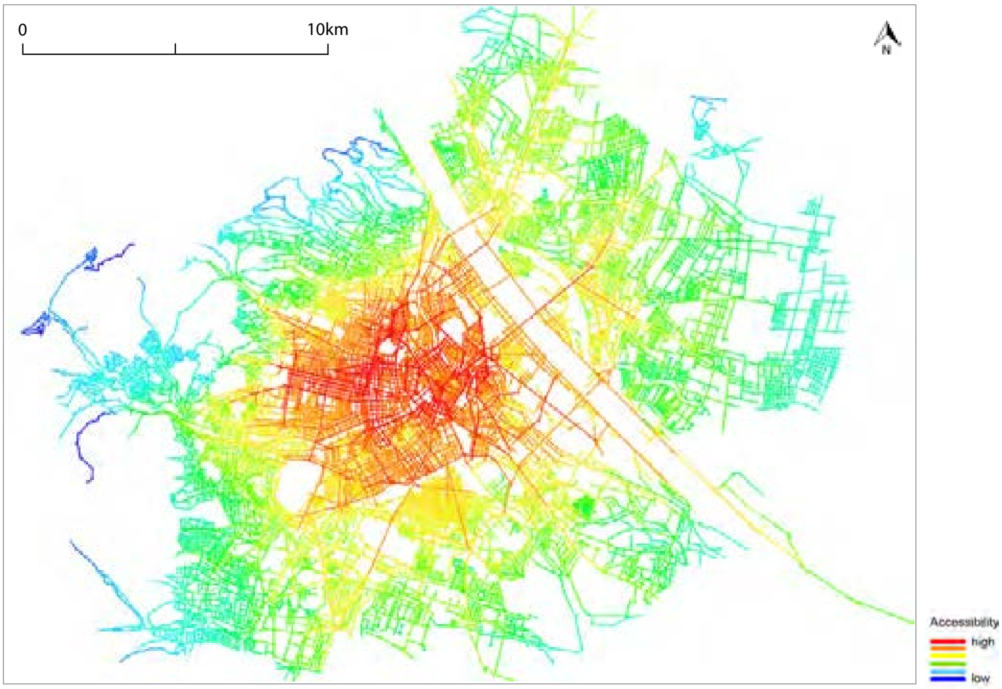


Figure 73: Integration N (cirywide centrality), Vienna 2006
(administrative boundary) (from Czerkauer 2007:77).

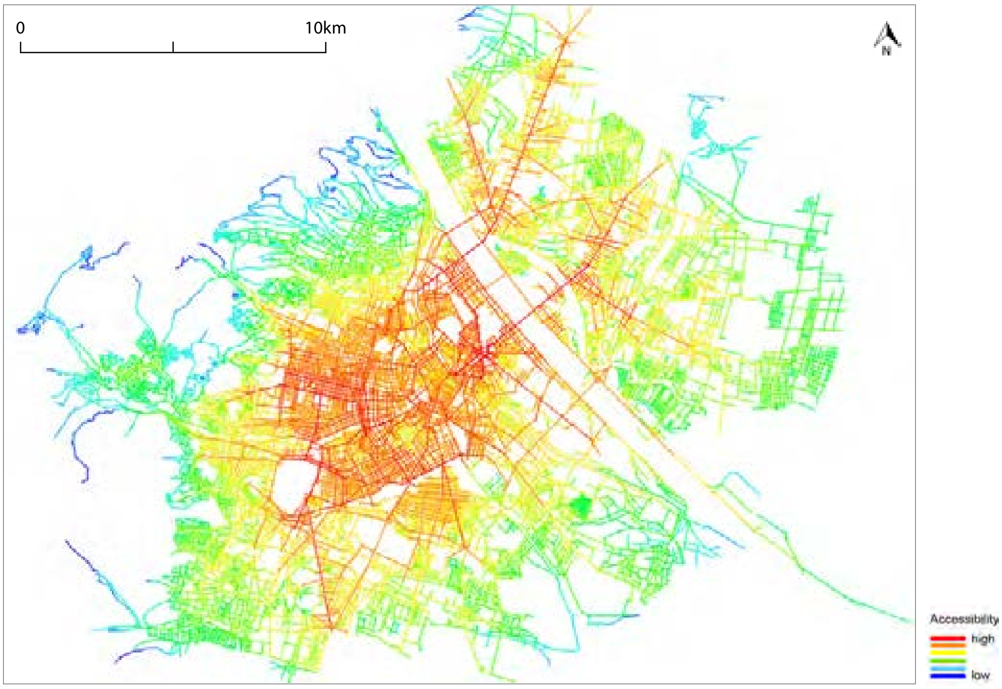


Figure 74: Integration Integration RAD 13 (centrality), Vienna 2006
(administrative boundary) (from Czerkauer 2007:78).

6.3.2. Angular Segment Analysis (ASA; Route Choice) – Potential Through- Movement [46]

Streets are junctions between landmarks (e.g. skyscraper, cathedral, radio tower) and display a real or imaginary line including shifts in directions. These are indicated by crossings (intersections), which Lynch defines as the point of decision; if a road is seen as a continous path – regardless of its shifts and curves – that should be chosen or not (Lynch 1960).

[46] Czerkauer 2007, p.157ff; revised 2012

Lynch 1960

He says that the paths, once identifiable, have continuity as well, which is an obvious functional necessity. People regularly depended upon this quality, with the actual characteristics being less important. Paths which simply have a satisfactory degree of track continuity are selected [...]. These can be followed by the stranger, albeit with difficulty [...]. In general it can be said that other kinds of characteristics along a continuous track are also continuous, despite actual changes. People tend to think of path destinations and origin points: they like to know where paths come from and where they lead. Paths with clear and well-known origins and destinations have stronger identities, helped tie the city together […], (Lynch 1960, p. 52ff), (cf. Humpert – Gangler, Esefeld 2007). We have to be aware that the *Gestaltqualität* plays a key role when choosing a pedestrian path (cf. Flâneur, Bummler, Spaziergänger – Benjamin 1983).

Lynch 1960

Gangler, Esefeld 2007

Benjamin 1983

Within the process of spatial cognition people decode spatial information. Using what are known as *cognitive maps*, people define their position in their environment and also their routes through the network. Cognitive mapping allows orientation within a spatial system. The idea of continousness is important for orientation.

Alongside the adaption of continuousness the cognitive knowledge of the network has an influence on the route choice. When driving accross the whole city, people will tend to recognise the street pattern in terms of main roads. In the case of pedestrian movement the network will be read on a small-scale structure. There is even a difference between tourists and locals. Not knowing the network so well, a tourist will choose the path with the least angles for the best orientation; the local the shortest Euclidian path (Hillier 1994; Turner 2000, 2001).

Hillier 1994

Turner 2000, 2001

Montello summarizes two categories of distance: *cognitive distance*, which concerns people's belief about distance where the destination cannot be seen; and *perceptual distance*, which concerns beliefs about directly observable destinations (Montello 1991).

Montello 1991

People tend to think of route choice in terms of cognitive distance, but network users very often make perceptual decisions and not cognitive ones. Hence cognitive distance appears to be inconsistent. The usage of the network is based upon the interaction of these two ways of navigating a network. Before starting a journey, first the route will first be chosen using knowledge of the city's cognitive map; and secondly, decisions are made in situ by means of perceptual indicators. This situation can occur in rush hours when people get stuck in a traffic jamand then start using side streets with less traffic beside the well-known direct path. Further, a driver's choice can be influenced by the socio-demographic layout of the built environment (e.g. households characteristics, education, age, gender, income, number of cars in family, etc. – Jan et al. 2000). Jan et al. 2000

Sadalla and Magal (1980) found out for the estimation of lengths of paths that if a trip has fewer turns, even if the physical distance is longer, people perceive it as being shorter. Hillier (2005) argues that the least-angled path is best and metrically shortest paths the worst. He goes on to explain that people navigate with a mental mode or architectural mode of distances, but with a geometric mental mode of connectivities. This is not a simple account of distances, and has major implications for how cities are designed and planned. Thus, for route choice analysis a route is divided into segments. Each segment is perceived as a single element of indeterminate length, but turns themselves are remembered, ergo a *weighted graph* (Sadalla, Magal 1980; Turner, Dalton 2007).

Sadalla, Magal 1980

Hillier 2005

Turner, Dalton 2007

A conclusion can be summarized on the basis Lynch already noted in the 1960s: the idea of continuousness correlates to the number and degree of angles. The key concept is the idea of as few turns as possible to achieve a route from origin to destination. The cascade is determined by the quantification of how likely it is that the selected space is part of the trip between origin and destination. By visualising the cascade of a path beeing chosen for a route, a *hierarchical flow pattern* can be derived.

Betweenness Centrality versus Centrality – Route Choice versus Integration

In the field of space syntax, angular analysis is also known as *betweenness centrality*. In contrast, integration is the topological measure of centrality. So, what distinguishes angular analysis from integration? Angular analysis consists of a weighted graph to calculate the syntactic metrics. It is the prediction of simulation of movement through, and occupancy of space. Choice, a space syntax term of angular analysis, quantifies how likely it is that the selected space is part of the trip for all the possible combinations of origin and destination. In contrast, integration is a non-weighted standard measure.

The idea of integrating angles into the calculation of street systems appeared with the discovery of various interesting phenomena. There are two major indicators:

In general, it is easier for people to place themselves when the grid is not deformed than when it is. People linearise routes in order to have shallower turns toward their goals. In the case of angles people tend to round angles to 90 degrees. The subject memory of turns is better with right-angles, so when there is a doubt, a turn is rounded to 90 degrees for a better placement of oneself for choosing a route for a trip in the urban network (Turner 2001). Turner 2001

Three types of human turns exist in this regard (Conroy 2001): Conroy 2001

- no turn
- fork
- right angle

Hence, segment analysis or angular analysis is about the absolute change of direction (Turner 2000) in moving (pedestrian, vehicle, etc.) from A to B. The basic idea is the minimum change of direction. Hence, the distinction is between minimum angular path (MAP), (Turner 2000) and the minimum distance path (Euclidean measure) between two points. Turner 2000

As already mentioned, the tourist will mostly follow the minimum angular path and the local the Euclidean path (distance). The major impact of angular analysis is to use the way people orientate themselves (cognitive assumptions of networks by angles, linearising routes, etc.) to visualise the choice of routes in a street network.

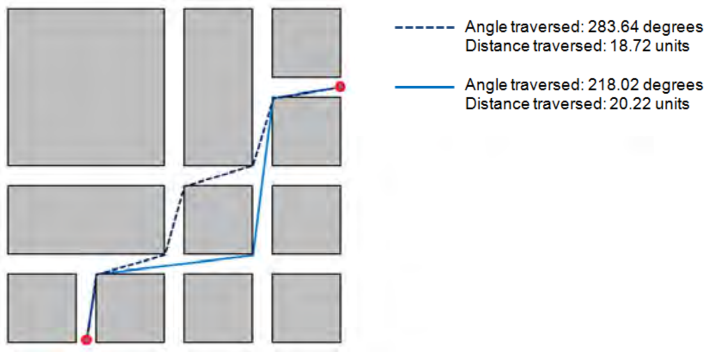


Figure 75: Minimum Euclidean path and minimum angular path between two points (from Turner 2000; redrawn).

For the segment analysis a weighted graph is calculated. The weighted sum of the edges is calculated and each edge is weighted by the angle of connection. In the calculation of a path from A to B, integration would be normally calculated. Therefore, we have to look back to the proposed question of the distinction between angular analysis and integration:

Integration is a measure of depth and focuses on the correlation of movement and mean depth (see global and local measures of space syntax). It has to be noted, that researchers assume the integration measure with regard to centrality as an indicator of how people move around. Axial Integration is the causal factor of movement. As discussed above, some turns are more important to pedestrians than others, conditioned by the human cognition (this approach also presupposes a topological quality of the built environment). Turner points out that a slight shift of 15 degrees is not considered a turn (Turner 2000); Humpert (Gangler, Esefeld 2007) proposes a 30 degree angle as being influential for a shift.
This links to Lynch's continuous path theory and supports the importance of different angles to the human mind (Lynch 1960) in the context of orientation. Axial Integration works with topological steps; every turn is equal and coherent to one topological step. A single axial line defines one syntactic step in a non-weighted calculation. One key outcome is that the results of standard axial mean depth and angular mean depth, both calculated for line A, are completely different.

Turner 2000

Gangler, Esefeld 2007

Lynch 1960

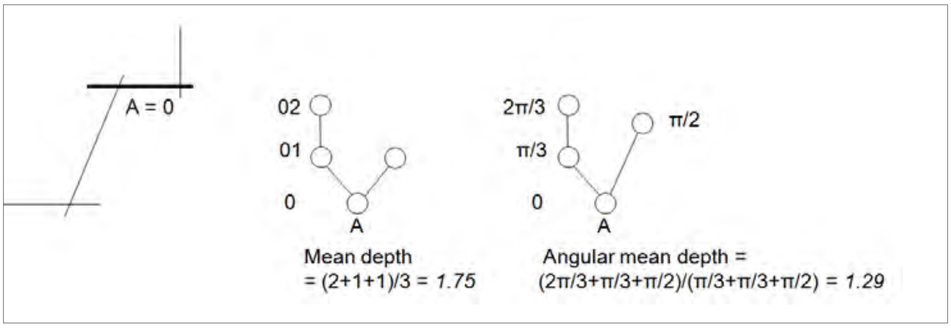


Figure 76: (This image is a continuation of figure 106 for total depth and mean depth.) Integration versus angular analysis for mean depth (from Turner 2001; redrawn). The results of the shown figures have no units: the use of degrees or any other measure for angles has no consequence for the result of mean depth.

It still has to be considered, that mean depth and angular mean depth are two different views of a system. Mean depth is an analysis of how deep or shallow a system is. The shallower a system the better connected and easier to move around it is. Integration as 1/MD or 1/RRA enables the measurement of the relative accessibility of space within a system and links to the idea of centrality. The more central an area is, the better the accessibility. Therefore angular analysis enables the illustration of a hierarchical impact of in-betweenness centrality. This links to the choice of routes. The origin and destination of a journey is important – the major inquiry to an analytical request.

Formally, angular analysis weights any j-graph by the angle (in radiants) of each connecting pair of axial lines. To calculate angular mean depth, the shortest angular path from every axial line to every other axial line in the system is calculated. The angular mean depth L_a^α for line a is the sum of the shortest angular paths over the sum of all angular intersections in the the system. It is not the number of lines in the system, for reasons which will become apparent (Turner 2001).

Turner 2001

$$L_a^\alpha = \frac{\sum b \in V(L)^{l_{ab}}}{\sum e \in E(L)^{w_e}} \quad [64]$$

where:

l_{ab} = shortest angular path between lines *a* and *b*

$V(L)$ = set of all axial lines in the system

w_e = weight (i.e. angle) of each individual connection

$E(L)$ = set of all edges in the system

In conclusion, it should be pointed out that lines which are cut in the middle have no impact on the result. They can simply be cut in two and calculated as usual, because the splitting of a line into two segments does not change the total angle of the whole line. In this case the calculation of mean depth will have the same result.

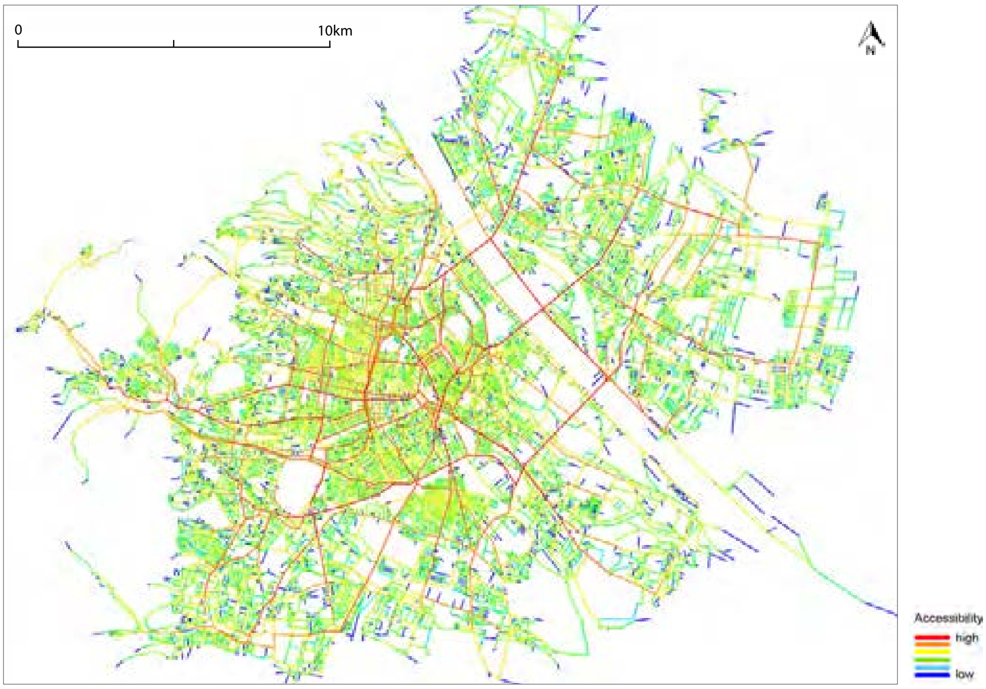


Figure 77: Choice N [log+2], Vienna 2006 (administrative boundary)
(from Czerkauer 2007:161)

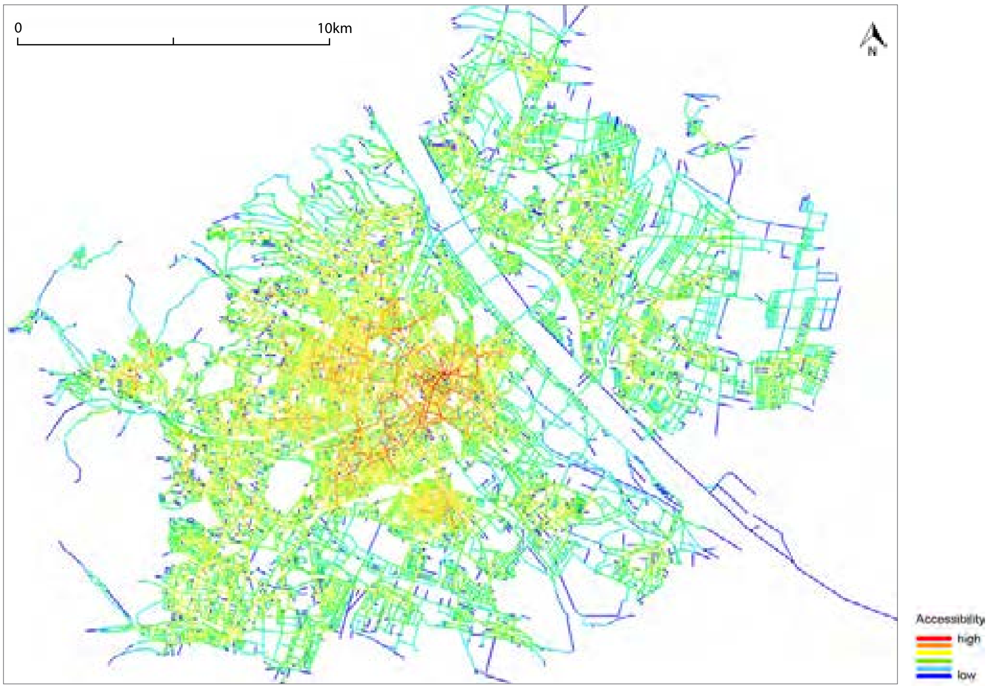


Figure 78: Choice 1200m [log+2], Vienna 2006 (administrative boundary)
(from Czerkauer 2007:appendix)

6.3.3. Space Syntax in a Critical Light [47]

[47] Czerkauer-Yamu, Voigt 2011, pp.126; Czerkauer-Yamu revised 2012

Like every theory, Space Syntax, too, has generated criticism and controversial views. In the following we would like to review two major topics (building heights and land use) of the famous scholarly debate between Carlo Ratti and Bill Hillier & Alan Penn (2004).

Does Space Syntax deal with building heights?

Carlo Ratti (2004) argues that the axial map discards all 3D information, as building height never appears in Space Syntax analysis. He stresses the fact that in contrast to Hillier's hypothesis of a more or less equally loaded grid with buildings (termed as natural movement) (Hillier 1993 in: Ratti 2004), an urban grid is rarely loaded in a uniform way. Building heights change within the city, modifying pedestrian movement. Ratti goes on to say that "a similar effect is produced by bus stops, underground stations, and the characteristics of streets, such as their width" (Ratti 2004, 492).

Ratti 2004

Hillier, Penn 2004

He also admits that the widths of streets are partially taken into account in the axial map. Further, Ratti states that building height would not matter if Hillier's argument that urban attractors are a mere consequence of configuration ("tallest buildings appear in the most integrated parts of the town") applied to the built environment. He underlines that especially with planned cities, this argument may not be applicable, as planning decisions are often based on social, economic and technical reasons – in contrast to the configuration of a street network. Further, functions (i.e. car parks) can generate higher pedestrian movement rates than the original configuration of the network (integration, choice) would suggest.

Hillier 1993

Hillier and Penn respond to Ratti by explaining that Space Syntax has no difficulty at all in dealing with such factors as building height, pointing out that this factor is implemented in the regression model rather than in the spatial model. They emphasise their position by referring to a study done in five areas in London (Penn et al. 1998) which showed that building height was important for pedestrian movement at the level of area, though not at the level of individual road segment, but that the effect of building height was minor compared with configurational variables (Hillier, Penn, 2004, 504).

Penn et al. 1998

However, the trend in planning practice and research is towards a systemic planning approach combining geo-referenced data sets, topological and topographical factors with 3D and 4D spatial models (see also: planning support system – PSS). Lynch argues that "way-finding is the original function of the environmental image […]" (1960, 125); his notation of the city in the context of the visual ordering principle (imaginary trip) is based on five elements: path, edge, district, node, and landmark. Thus, the third dimension is an essential element of way-finding. Considering Ratti's argument about the non-homogeneous distribution of building heights within a town or city, we return to Lynch's landmarks. Landmarks gives orientation within an urban system regardless of their location (prominent or non-prominent location). In general, way-finding is achieved through the perception of direction, distance and vertical height. Thus, incorporating the third dimension into the spatial Space Syntax model would add important value in developing a holistic tool.

Lynch 1960

Does space syntax take land use into account?

In the context of land use, Ratti shares Batty's opinion (2002) and quotes him as follows: "[Space Syntax] accessibility measures, although providing indices associated with forecasting trip volumes, are not based on models which simulate processes of movement and thus do not provide methods for predicting the impact of location changes on patterns of pedestrian flow. In short although these indices can show changes in flow due to changes in geometry and location of entire streets, they are unable to account for comprehensive movement patterns which link facilities at different locations to one another." (Batty et al. 1998, 3 in: Ratti 2004, 492f). Batty argues in favour of the use of an agent-based model (ABM).

Batty 2002

Batty 1998

Ratti 2004

In contrast, Hillier (1999) offers a model in which locations are weighted in such a way that an additional local grid (i.e. shopping mall) is added to the street network (axial map). This, of course, will change the value of integration as the gravity of the street network changes due to the additional number of elements added. Ratti sees Hillier's model in a critical light, arguing that "the procedure, however, seems quite ambiguous, as it arbitrarily assimilates an indoor commercial centre to a real street network. Furthermore, it does not provide any method to quantify these fictitious additions to the urban grid, leaving the possibility of unconscious

Hillier 1999

postrationalism – whereby it is the axial map analysis that mirrors movement and not vice versa.” (Ratti 2004, 493).

Ratti 2004

Hillier and Penn agree with Ratti in the sense that the axial map does not technically integrate land use factors (author’s note: economic attractiveness measures). They argue that there is a good scientific reason for it, as technically it is quite simple to calibrate lines with land use (improving r^2).
For a theoretical understanding of cities as well as practical importance (where should shops be put?), both see a higher value investigating of the impact of configuration and movement on land uses and, further, the formation of centres and sub-centres. Further, Hillier and Penn argue that in Space Syntax theory, land use is a dependent variable: spatial configuration influences movement and, further, can be expected to influence land use. They support this hypothesis by offering an extensive empirical investigation by Hiller (1999, 2000), (Hillier & Penn 2004, 506).

Hillier 1999, 2000

Hillier, Penn 2004

Seeing the discussion of land use in the light of a “goal following” approach (agent-based modelling) that asks the question “How does a specific location of a shop influence movement?”, Batty is right in saying that agent-based modelling (ABM) can better manage to investigate and answer this question. Let us remind ourselves that ABM is a behaviouristic approach.
Raford highlights the difference between space syntax and agent-based models very clearly when he says that “as a statistical model it (Space Syntax) is relatively simple and robust, allowing for quick analysis of a range of cases and outcomes. But it is fundamentally static and falls short of many of the advantages that ABM provides, particularly dynamic activity over time, complex agent interaction, goal following, social learning, and emergent behaviour (Manson 2006, Miller and Page 2007, Epstein 2006, Gimblet 2002, Batty and Jiang 1999; in: Raford 2010, 243).

Manson 2006
Miller, Page 2007
Epstein 2006
Gimblet 2002
Batty, Jiang 1999

We agree with Raford that a research tool integrating space syntax with agent-based approaches is a promising direction for future research, as it is a more flexible way of exploring the role of space and accessibility in a variety of dynamic processes such as land use change, urban transportation, shopping, crime, and other forms of social behaviour (Raford 2010, 243).
It should be emphasized that Space Syntax is mainly interesting in a structural sense.

Raford 2010

What we have seen with Space Syntax is that it supports, to a great degree, an awareness-raising process. Space syntax helps to give new insights on urban functionality by visualizing spatial relationships. In the light of strategic planning and design, it can help us gain an insight into specific problems of an area and their possible solutions. Further, it can be used in participation processes by planners, local authorities and the public. Space Syntax is a support tool for urban analysis to enable informed decisions. It can also add value to planning support systems (PSS).

The constraints and opportunities of Space Syntax are as follows:

- It is a topological model having the ability to link urban structures with social activity through the idea of connectivity and accessibility.
- It is relatively simple and robust, allowing for quick analysis of a range of cases and outcomes.
- It adds value to the strategic and design process: strategic issues, goals approach, scenario approach, direct approach, strategy development, description of the future, and post-evaluation.
- The axial map does not technically integrate land use factors.
- It is a static model falling short of the advantages that ABM provides (dynamic activity over time, complex agent interaction, goal following, social learning, and emergent behaviour).
- It discards all 3D information, such as building height.

Finally, Hillier argues (1993) that Space Syntax offers no more than a powerful aid to a designer's intuition and intentions and it helps them to understand what they are doing. It provides information of access ensured by the network and mode of movement.

Hillier 1993

6.4. Strategic Visibility

Lynch's theory (1960) supports the idea of "legibility" of urban systems[48]. Legibility is the clarity of the cityscape (Morello, Ratti 2009, 838) – how easily individual parts or elements can be organised mentally to a coherent pattern. The easier the *mental map* can be derived from the built environment, the easier way-finding and orientation is (see also Cullens's serial vision from 1961). Thus, the topological relationship between elements of the "real world" (Mayerhofer, Walchhofer et al. 2009) links "legibility" of urban space to way-finding and orientation. "Good" visibility further influences the overall quality of cities.

Lynch 1960

[48] Lynch describes five visual elements: path, landmark, edge, node and district.

Morello, Ratti 2009

Cullen 1961

Mayerhofer, Walchhofer et al. 2009

Hillier adds the notion of "intelligibility" for his Space Syntax theory. He defines intelligibility as [...] the essence of urban form that is spatially structured and functionally driven. Between structure and function is the notion of intelligibility, defined as the degree to which what can be seen and experienced locally in the system allows the large-scale system to be learnt without conscious effort. Structure, intelligibility and function permit us to see the town as social process [...] (Hillier, 1996; revised 2007, 171).

Hillier 1996

Furthermore, Benedikt (1979) describes the idea of and *isovist*. Turner, Doxa et al. (2001) argue that Tandy (1967) appears to have been the originator of the term isovist.

Benedikt 1979

Tandy 1967

Turner, Doxa et al.,2001)

An isovist can be briefly explained as a *visual record* of what can be seen in a 360 degree angle from a given point. The theory of an isovist is closely related to the idea of visual perception and spatial description (see also Lynch's theory). An isovist represents the relationship between an individual's location and the whole spatial system. The visual record is taken at average eye height.

Batty summarises an isovist as [...] a field of vision from which various geometrical properties, such as area and parameter, can be calculated. Isovists can be defined for every vantage point, constituting an environment, and the spatial union of any particular geometrical property defines a particular isovist field (Batty 2001, 123).

Batty 2001

$$j \in Z_{i\,;}\; j = 1, 2, .., n_i \qquad [65]$$

where:

Z_i = generic field associated with the vantge point or vertix i

n_i = total number of points in Z_i including the vantage vertix i

Figure 79: (left) Point isovist (Vienna's historic core);
(right) Axial isovist: Isovists taken when moving (from every street crossing along the imaginary axial line). This is based on Cullen's term of serial vision (1961). Serial vision is transposed into in Hillier's theory as the axial isovist. Cullen 1961
Fundamental properties of a 2D isovist are: area of isovist, perimeter of isovist, solid perimeter, solid perimeter to perimeter ratio, maximum radial distance, minimum radial distance and average radial distance.

In the context of an isovist Lynch's visual elements can be reinterpreted.
For Lynch *paths* (boulevards, main streets) are channels for potential movement with a strong visual character. They contain a kinesthetic quality and provide clear foci of origin and destination. In this context a 2D isovist it can give information on static and movingviews (see Figure 112; point isovist and Cullen's serial vision), verify visibility and movement (axial line) and produce continuous information about the space from the viewpoint of the observer (Morello and Ratti 2009). In contrast, a *node* (intersection of streets, concentration of actitivity) is by Lynch's defintion a key point in wayfinding and orientation. Seen from the viewpoint of an intersection of streets, a node links urban information and therefore intensifies information. It enhances the creation of a *mental map* for the observer. A mental map is a subjective, internal image of space reorganising the upfront homogenious space for orientation and wayfinding. Task is to create an internal orientation network based on e.g. visual elements or urban sound. This is where Lynch's *landmarks* (e.g. a prominent building with a figure-background contrast) come into play. Landmarks are important as they are physical elements which are unique, significant and memorable (Lynch 1960,78) in their context. They are an important factum for wayfinding and orientation as they mark the built environment.

Morello and Ratti 2009

Lynch 1960

Morello and Ratti 2009

Morello and Ratti proppse a technique for measuring 3D visibility using the idea of voxels and based on of Lynch (Morello, Ratti 2009, pp.846):

- *Paths*
  Count on a pixel per pixel basis the number of visible voxels along the path, in order to establish a constant visual recurrence of built masses.

- *Districts*
  Compute the number of visible voxels that appear on each pixel of open space and verify if their distribution reveals any homogeneity scale of the district on a larger scale.

- *Edges*
  Compute the number of visible voxels that appear on each pixel of open space and verify if isolines reveal edges.

- *Landmarks*
  Verify visibility (occlusivity) of the landmark far away and from close distance (at the base); verify the homogeneous visibility of the object from far away; calculate the rate of visibility from street level through isovisimatrix.

For 3D isovists see also Derix, Gamlesaeter, Carranza 2008.

Visibility Graph Analysis (VGA)

As described before, Hillier and Hanson (1984) introduced the axial lines for an analysis of spatial layouts based on graph theory. Let us recall that axial lines represent lines of sight and movement. An intersecting set of axial lines, in more detail – the fewest longest lines of a spatial system – form an axial map which represents all nontrivial rings of circulation (Turner et al. 2001) in a system. Each axial line is a vertex in the system and each intersection a node. Axial lines support a description of how an urban system can be traversed by syntatic steps, i.e. how many changes in the system are required to reach any space from any other space in the system. From this comes the concept of an *all-line axial map*. Hillier and Penn explain that the all-line axial map is as an automated graph representation [...] in which all the lines form a tangent between any pair of mutually visible vertices drawn (Hillier and Penn 1992 in: Turner, Doxa et al. 2001,106). Desyllas and Duxbury argue that the technique has the limitation that the sampling of lines of sight is entirely dependent on the complexity of the polygons used in processing. He argues further that this means that any graph based on the all-line axial map is "weighted" towards areas that have complicated [...] polygons (Desyllas and Duxbury 2001, 27.6). It means that more complex polygons will have more vertices and thus more lines whereas in contrast less complex polygons with fewer vertices will have less lines.

Hillier, Hanson 1984

Turner et al. 2001

Turner, Doxa 2001

Desyllas, Duxbury 2001

Still, the all-line axial map gives an helpful overview to a more detailed analysis in terms of the field of vision as it splits a homogeneous field of view into "sub-fields" represented by a set of axial lines and further provides information (numerical and colour coded) for every axial line.

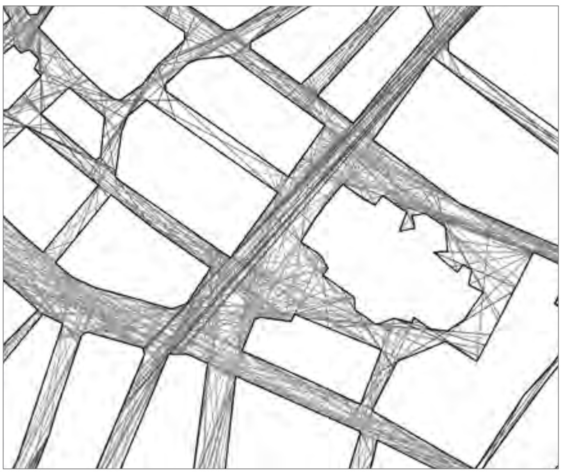


Figure 80: All-line axial map for Vienna's historic centre (zoom).

Hillier derives a graph-based representation based on Watts and Strogatz's (1998) small world analysis (see chapter 2.1.) leading to a visibility graph analysis (VGA).

Watts and Strogatz 1998

The method developed at the VR Centre of the Built Environment, University College London, involves taking a selection of points accross a space and forming graph edges between those points if they are mututally visible, to form a visibility graph. (http://www.vr.ucl.ac.uk/research/vga/; accessed 2012-16-02). Inspired by Hillier and Hanson the visibility graph analysis (a cell-based calculation) mostly concentrates on "visual integration"[49] of a point, ergo a cell – a topological measure of centrality. Further, measures based on the Watts and Strogatz's (1998) "small world" as the clustering coefficient (a measure for local density of edges) were introduced by the space syntax group (see also Turner et al. 2001).

Turner et al. 2001

Also people like de Floriani (1994), Braaksma and Cook (1980), Krüger et al. (1979) already worked with similar techniques and concepts of a visibility graph.

De Floriani 1994
Braaksma and Cook 1980
Krüger et al. 1979

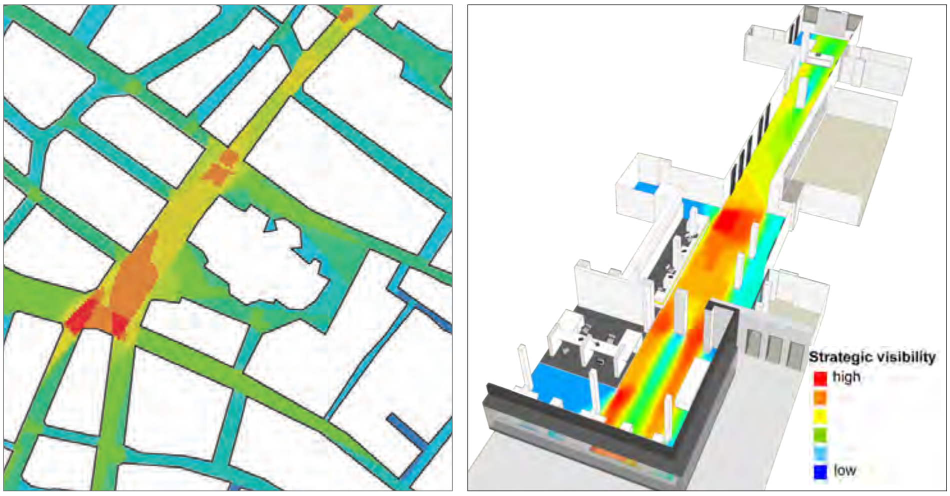


Figure 81: Visibility graph analysis; left: VGA on an urban scale (from Czerkauer-Yamu 2012); right VGA combined with a 3D model on an architectural scale (Bauamt Munich), (from Gosset, Czerkauer 2008 [SSx Ltd.]).

With VGA the question of "how many points can be seen from a specific location?" can be answered. The higher the strategic visibility, the more central the point (cell).

[49] Visual integration works with the same concept as axial integration. Integration is a normalised, relativised, inversed measure of a system's mean depth. Hillier and Hanson describe integration as a global measure of depth, relativised in such a way that differentlysized systems can be directly compared to one another (Hillier, Hanson, 1984).

6.5. 3D Modelling and Visualization

In general, spatial modelling and simulation allow a complex reality to be depicted in a simple manner in order to explore and evaluate a priori interventions and their spatial impacts (Voigt 2011).
3D models and visualisations are commonly used to overcome lack of communication between different parties (e.g. laypeople, general public and planners) as they can translate conventional drawings into a format that is more easily understood (Pietsch 1999, Hall 1996). Lack of communication and lack of mutual understanding regarding spatial problems can lead to an inconsistency in the planning and design process. Hence, a 3D visualzation often works as a communication tool and can be seen as a supporting tool for a decision-making process (Roupé, Johansson 2010).
Pietsch (2000) highlights that Tony Hall (Anglia Polytechnic University, England) found out in a study he undertook from 1991-92 that the development control process of visualizations[50] (Pietsch refers here to a 3D visualization model) of small-scale projects provided the most interesting results and discussions compared to the visualization of large-scale projects. On the other hand Al-Douri cites Huang et al. (2001) and Shiffer (1995) who state that the impact of 2D and 3D visualizations on the decision-making process is only relevant in large geographical areas (in Al-Douri 2010, 77).

The discussion about *objectivity* is inherently interwoven with the use of 3D models and visualizations. Beside the ideal of independent 3D modeller, 3D objects, based on the fact that the model is a geometric object in a software program, promise the possibility of many available viewpoints including the control over the parameters. Many viewpoints and parameter control (interactive models) is also part of presentations in a virtual reality (VR) environment[51]. The problem with this view, as also represented by Hall (1992), is that exactly these various viewpoints hinder objectivity and support a subjective view of the scenario under scrutiny. Data themselves remain objective, but through manipulation and processing they can generate subjective images of the a priori objective model.

Voigt 2011

Pietsch 1999
Hall 1996

Roupé, Johansson 2010

Pietsch 2000

Al-Douri 2010

[50] Pietsch says that the term visualisation can refer to tradititonal drawings, maps, perspectives, 3D physical scale models, computer visualization models, and scientific visualisation models, chiefly 3D with reference to two-dimensional (2D) forms. Pietsch 2000, 521

Huang et al. 2001
Shiffer 1995
Hall 1992
Al-Douri 2010

[51] For example the spatial simulation lab [SRL:SIM] at Vienna University of Technology, The interdisciplinary research centre deals with digital technologies for space and the built environment. http://simlab.tuwien.ac.at

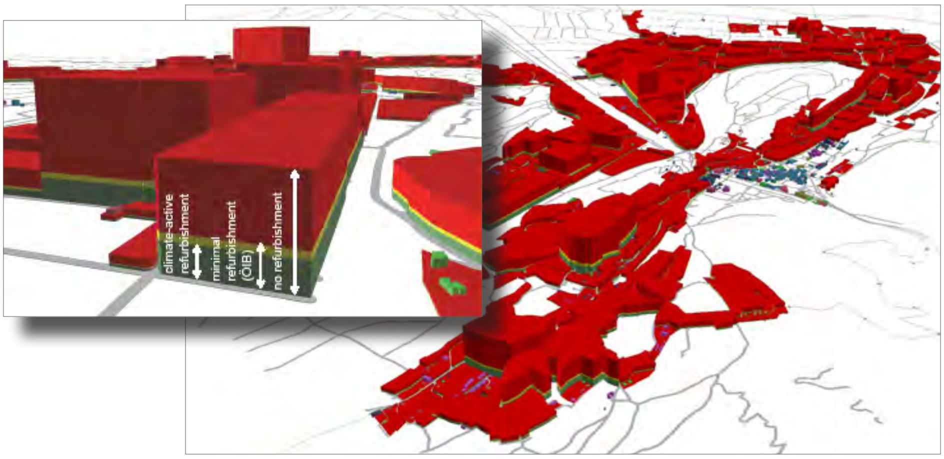


Figure 82: Example of a 3D visualization: heating demand for the city of Feldkirch per building block and year (Austrian Federal Land Vorarlberg) in [MWh/block a]. Three different scenarios are shown (clima-active refurbishment, minimal refurbisment, no refurbishment). All of them are proportional to costs and Co_2 emission (from Brus, Czerkauer-Yamu 2012).

Two factors makes 3D models and their presentation in a virtual reality (VR) environment so interesting to work with the on one hand, the transparency of data and the awareness-raising process induced by the multi-scale variety of viewpoints; secondly, the allowness to interrogate a database.

The added value of 3D models and visualisations as well as simulations is that they can create a new dynamic in discussions and collaborative urban design processes. Thus, we can summarise that modelling and simulation-assisted experimentation with the built environment can be regarded as an essential contribution to the configuration of our living environment. There is a great need for supporting complex planning and decision-making processes with state of the art modelling and simulation equipment and ideas. The following criteria can be applied (Voigt et al. 2009): Voigt et al. 2009

- optimum clarity and comprehensibility for laypersons and experts (planners) (Sheppard 1989) Sheppard 1989
- support of team decision-making processes and planning processes in general (Schönwandt 1999). Actors involved in the planning proces can exchange and discuss ideas. Schönwandt 1999
- combination of planning- and project-related information (quantitative and qualitative information, visual and numerical information), synoptic presentation (synthesizing overview)
- real-time simulation; VR tools and environments

PART FOUR:

CASE STUDY and SCENARIO DEVELOPMENT

Vienna-Bratislava Metropolitan Region
(The Vienna Case)

About this Chapter

This part deals with the application and option testing of the decision support system *Fractalopolis* as well as its interlinkage with other analyses to form a spatial planning support system. The case study is the Vienna-Bratislava metropolitan region, which forms part of the Centrope region.
As an introduction to the case study we present the historic, spatial and demographic context of the Vienna-Bratislava metropolitan region as well as discussing the cities of Vienna and Bratislava themselves. The focal point for masterplanning strategies is Bruck an der Leitha, which acts as a stepping stone between the two cities.
The case study is divided into four major parts:

- historical context, population change and commuting of the Vienna metropolitan region;
- pre-assessment of the Vienna-Bratislava metropolitan region on a global scale (using Space Syntax);
- scenario development and option testing from a global to a local scale (using Fractalopolis). Identification of planning options (and approaches) including 3D visualizations (this shows the range of possibilities for which the DSS Fractalopolis can be used and illustrates its flexibility as a tool that can be adjusted to any spatial system);
- strategic masterplanning (incl. option testing) for two selected areas in Bruck an der Leitha on the basis of the Fractalopolis accessibility evaluation and Space Syntax masterplanning principles, with two population scenarios including 3D visualizations.

In order to carry out the case study a geo-referenced relational database with a total of approx. 89,000 entries was established (services & faciltities and leisure; see appendix).
The concluding chapter discusses the completed research and presents an outlook on ongoing research. Finally, the epilogue reflects on digital methods and techniques in the context of planning, concluding that:
Spatial modelling and simulation allow a complex reality to be shown in simplified form, in order that interventions and their spatial impacts can be explored in advance. Spatial models and simulations need to be representative, precise, clear and vivid, attractive and comprehensible (Sheppard 1989).

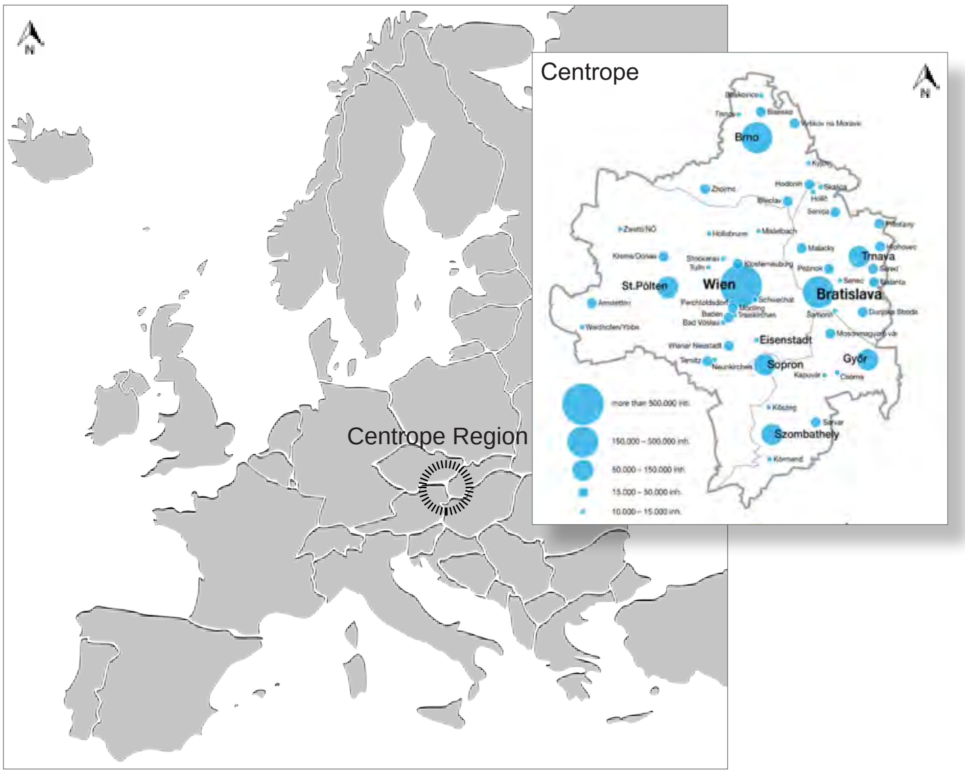
CHAPTER SEVEN:
GETTING TO KNOW THE AREA UNDER SCRUTINY

7.1. Centrope

The economic and political changes in Central and Eastern Europe since the late 1980s have fundamentally changed the European landscape and the framework for economic activity in major parts of the continent (Altzinger and Maier 1996). The fall of the Iron Curtain in 1989 was the starting point of the *Centrope Region*. This European Region was founded in 2003, grouping regions of four countries: the federal states of Lower Austria, Burgenland, South Movaria, Trnava Region, Bratislava Region, Komitat Vas, and Györ-Moson-Sopron. Its aim is coordination and cooperation in economic, infrastructural, educational, and cultural questions with the pre-eminent goal of strengthening the economic and tourism region (PGO[52] 2008). Centrope is one of the most important transnational economic areas on the former Eastern borders of the European Union. Centrope comprises eight regions, four EU members and 6.5m inhabitants. Further, the region offers high accessibility and benefits from the closeness of two capital cities: *Vienna* and *Bratislava* (German: *Preßburg*; Slavik: *Prešporok*; the name Bratislava has been used since 1920); the so-called “Twin Cities”.

Altzinger, Maier 1996

[52] PGO (Planungsgemeinschaft Ost) is a joint organisation of the federal administrations of the federal states of Burgenland, Lower Austria and Vienna. Its aim is the coordination and preparation of spatial issues and activities relevant to Austrian’s Eastern region.



Map 1: Centrope Region
(original: www.centrope.com, accessed 2008;
detailed map source: www.b2match.at, accessed 2012)

8.2. Vienna-Bratislava Metropolitan Region

The Vienna-Bratislava Metropolitan region is an urban and economic core of the Centrope region (Achleitner 2007) and is strongly influenced by restructuring of the former socialist countries. The entry of Austria into the EU in 1995 and the EU's 2004 eastern enlargement including the accession of Slovakia was the next stepping stone for this region. With Slovakia's accession to the Schengen Agreement in 2007 the last barrier between Austria and Slovakia fell.

Achleitner 2007

The Vienna-Bratislava metropolitan region has a surface area of around 30,000 sq.km and is currently home to 4.5 million inhabitants (2012). It encompasses the three *Austrian Länder* of Vienna, Lower Austria and Burgenland and the two Slovak regions of Bratislava and Trnava. The Slovak part makes up roughly one quarter of both area and population. All three *Austrian Länder* that constitute the Vienna Metropolitan Region are independent states. They autonomously decide matters that fall within their sphere of competence (e.g. construction of local transport infrastructure, environment, spatial planning), (ODPM[53] 2006, pp131). The population growth in this region of 0.2 per cent between 1991 and 2001 slightly below the Austrian average but higher than the Slovak average. Migration from other countries explains the population growth in this region.

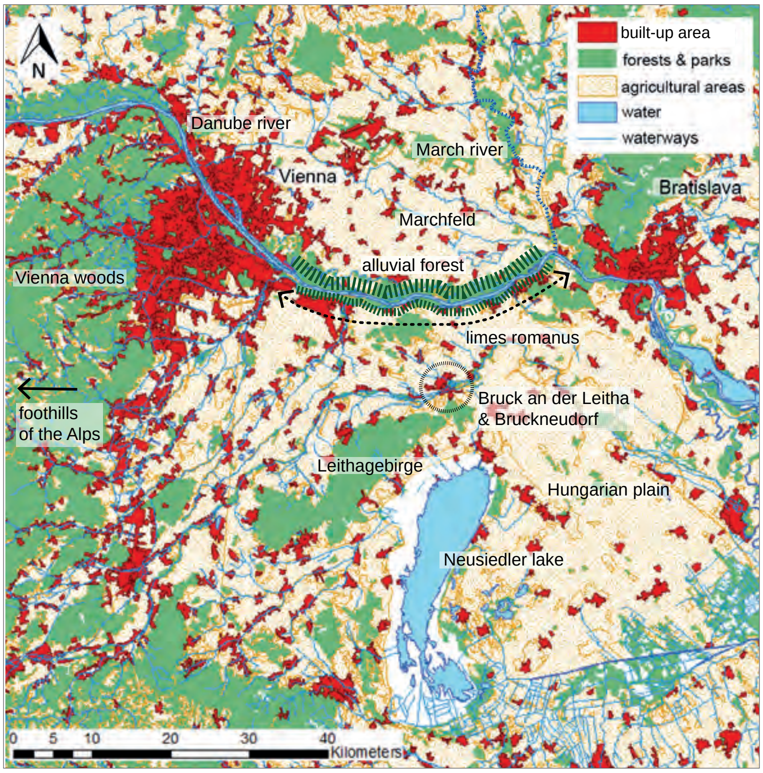
[53]Office of the Deputy Prime Minister, UK Parliament.

	Austria			Slovakia	
	Burgen-land	Lower Austria	Vienna	Bratislava	Trnava
Area (km ²)	3,965.5	19,177.7	414.7	2,052.6	4,147.2
Population (2010)	283,965	1,607,976	1,698,822	622,706	561,525
Share Females (%)	51.1	51.0	52.2	52.5	51.2
Share aged 15 or less (%)	13.5	15.0	14.2	13.1	13.9
Share aged 65+ (%)	19.7	18.7	16.9	12.8	12.5
aged Population 2030* (2010=100)	94.2	101.7	113.8	85.6	85.6

Table 5: Population forecast for Centrope and the Vienna-Bratislava metropolitan region (from Österreichisches Institut für Wirtschaftsforschung 2011:16; source: Cambridge Econometrics; data at NUTS2 level; modified)

The core of Centrope is the Vienna-Bratislava Metropolitan Region. It is economically and politically unique – nowhere else in Europe are there two capitals with such an important bridge-building function between East and West. Due to its heterogeneity, this region is interesting and contradictory at the same time. It has a heterogeneous topography based on the interrelation of unique natural resources worthy of protection with agricultural and industrial areas.

Topographic benchmarks are the rivers Danube and March. The Danube marks the natural barrier between the southern part, used as a transit corridor between the two cities, and the northern agricultural one – the Marchfeld. In general, the area between Vienna and Bratislava is dominated by agriculture.



Map 2: Morphological layout of the Vienna-Bratislava metropolitan region. An obvious feature is the strip development of the southern axis (data: Austrian Institute of Technology (AIT) 2010; Corine Land Cover 2009).

The region's main challenge is the Donauauen (Danube Wetlands) National Park, which complicates any plans to build a motorway link to efficiently bridge the northern part (Marchfeld) and the southern transit area of the Danube efficiently (Knoll 2005). Knoll 2005

The Donauauen National Park (created 1996) is the biggest contiguous alluvial forest in Central Europe and stretches between Vienna and the Marchfeld on the border between Austria and Slovakia. It is approximately 36km long and 4 km wide at its broadest point. The March River is the natural boundary to Slovakia. To the south of Vienna we find the Viennese Basin bordered by the Alps in the West and the Carpathian Mountains in the East.

On the other hand, the main advantage of the Vienna-Bratislava Metropolitan Region is its diversity. Geographical, cultural, linguistic, and economic conditions are based on their historic background, not too far from each other and further have common ground, providing the region with a good development potential.

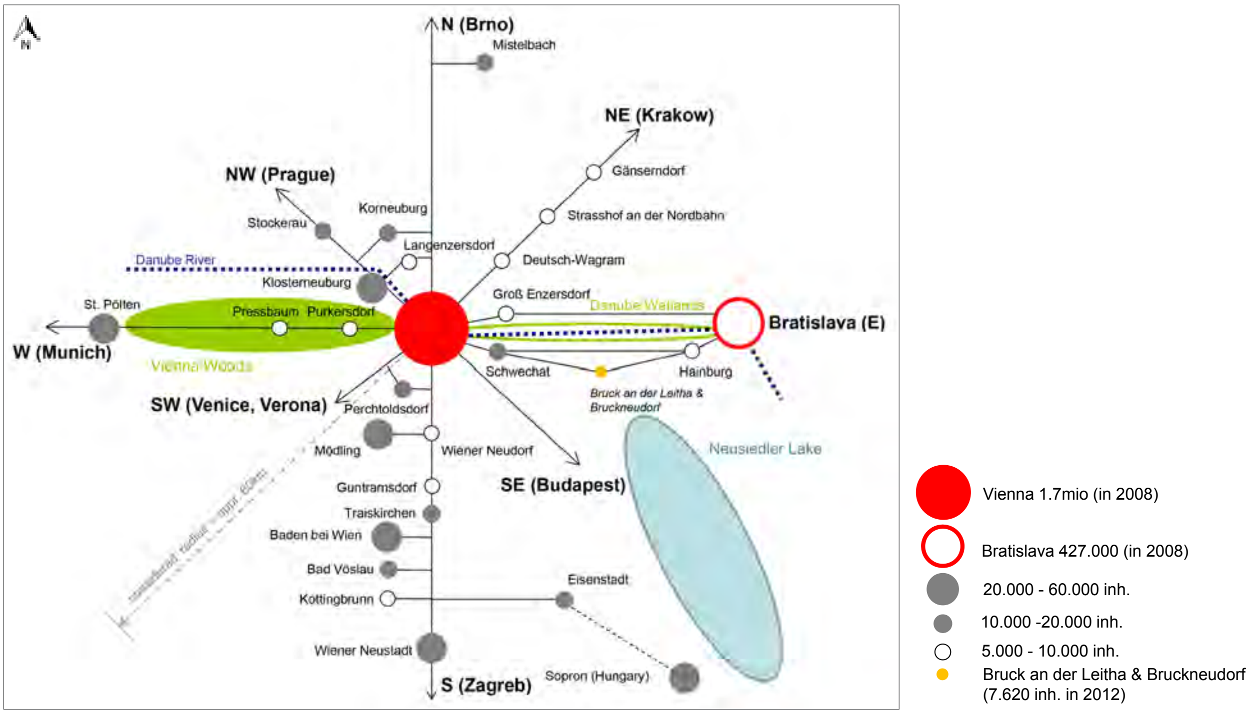


Figure 83: Strategic sketch of the Vienna metropolitan region within a radius of approx. 60km. The area between Vienna and Bratislava south of the Danube river is suitable for development, whereas the west axis is restricted for development due to the Vienna woods. The chosen area for the case study (south of the Danube river) offers high diversity in landscape (Neusiedler lake, Schneeberg, Semmering) and thus a wide range for leisure and sports activities while at the same time is in close proximity to Vienna and Bratislava.

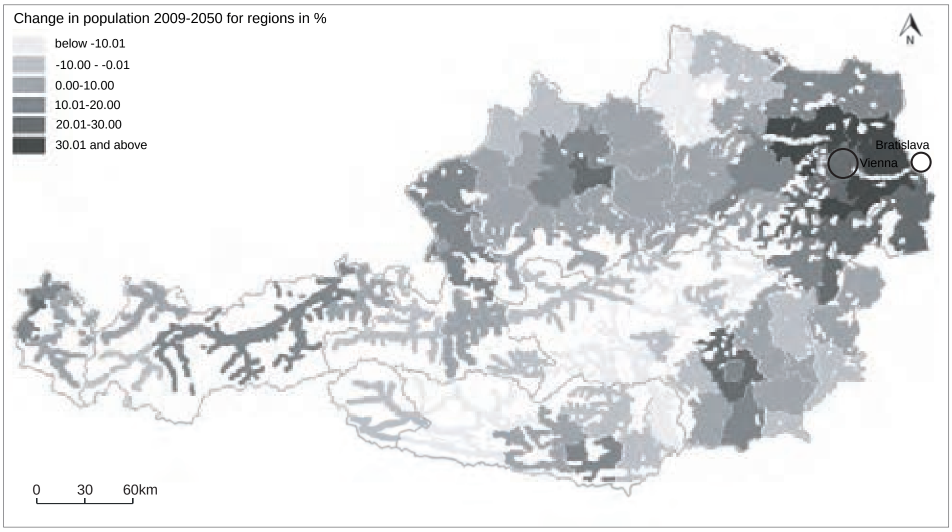
The strategic sketch (Figure 83) above gives information on which agglomerations with a certain population can be found along the axes. Further, the next important strategic towns and cities along the axes are indicated. We can already identify that Vienna’s south axis is highly developed whereas there is a lack of development between Vienna and Bratislava (which can be developed). Dense agglomerations along the south axis have their roots in topographical, historic, political and economic circumstances. Vienna’s development axes not only connect the urban hubs Vienna and Bratislava but also interact with and provide access to cities in all directions like *Munich*, *Venice*, *Verona*, *Prague*, *Krakow*, *Bratislava*, and *Budapest*. If we scale down from the regional approach and look in more detail at Vienna’s regional axes we also find interesting historic developments and conditions which have had a lasting influence on the settlements along and in close proximity to them.

7.3. Population Change, Forecast and Commuting

Due to Austria's accession to the European Union the position of Vienna has transformed due to the fall of the Iron Curtain in 1989. Vienna is no longer a geographically isolated city in an isolated state as it was after the break-up of the former Austro-Hungarian Empire (Lichtenberger 1997).
Recent past development has shown (1991-2001) that Vienna as the prime city is still an urban hub for the region, but the functional relationship between Vienna and its hinterland has changed. Various communities have developed dynamically with regards to amenities, culture, infrastructure and level of employment. This phenomenon can especially be observed along the older suburbanisation axis in the south and in different sub-areas in the south east region as well as in the county of Neusiedl (south of Bruck an der Leitha). This progress enabled the hinterland to functionally separate itself from the direct dependency of the prime city Vienna and to become autonomous and attractive. As a consequence the intraregional mobility pattern has changed and the in-between spaces of old urbanisation axes are more vital. Therefore, the hinterland is more attractive for services and industries and became a settlement zone. The direct migration (compared to indirect migration: Vienna's hinterland) has increased. This is a clear indication for the overall attractivity of the Vienna-Bratislava metropolitan region (PGO 2008).

Lichtenberger 1997

PGO 2008



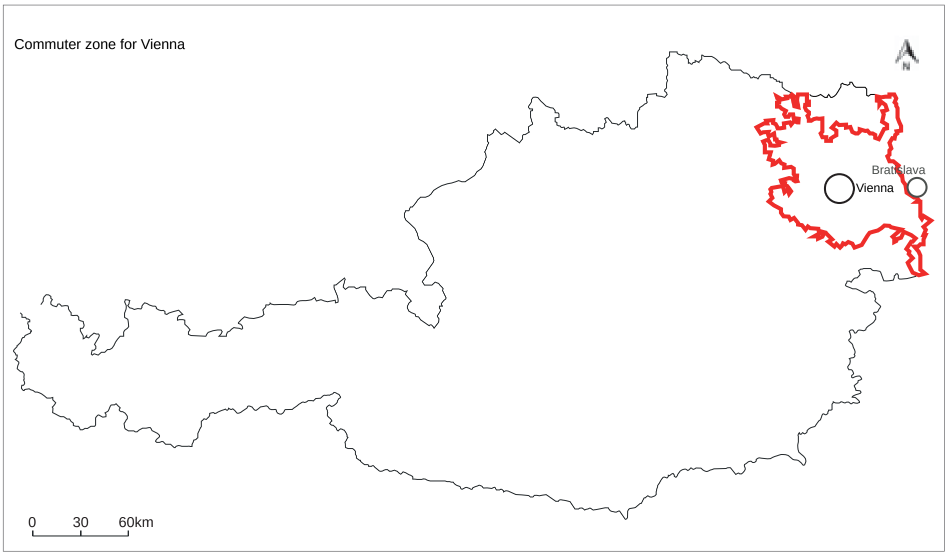
Map 3: Change in population (2009-2050) in Austria. Regions with strongest change in population until 2050 include Vienna Umland-Süd with 36.2% and North Burgenland with 24.7% (ÖROK 2012:80). The strong change in population demands changes in the spatial system (source data: Statistik Austria; original map: ÖROK 2010:79; modified).

The tendency towards a denser population of Vienna’s surrounding area (cf. ÖROK 2012; Austria‘s migration balance 1960-2009 and forecast 2009-2050))indicates the need for a structural intervention in order to influence the population growth in a sustainable way. Uncontrolled growth can generate higher traffic and a uniform distribution of agglomerations (urban sprawl). The aim is to generate a settlement pattern next to strategic traffic axes to give people the opportunity to act in a sustainable manner (public transport, more efficient connections, shorter journeys by car).

Commuting

Suburbanisation combined with workplaces in Vienna generates a higher number of commuters. Fassmann explains the commuter’s preferences when driving to and from work when he says that radial traffic flow dominates over tangential routes. Even when commuters have to use tangential routes they mostly use hierarchically higher ranked routes in order to cover long distances by radials (Fassmann et al. 2009). In general, commuters’ behaviour provides important information on mobility behaviour of a city, hinterland and region. Mobility behaviour addresses the functional extension and intermeshing of a network. Commuters to and from work show a classical mobility pattern between city and urban hinterland.

Fassmann et al. 2009



Map 4: Commuter zone for Vienna (data: Statistik Austria 2001)

The data for inbound and outbound commuters (Table 6) show that Bruck an der Leitha should be developed (population and economy). The aim is to avoid the excess of outbound commuters.

Axis	County	Inbound Commuters 2001	Outbound Commuters 2001	Balance
	Greater Vienna	679.025	551.528	127.497
	Vienna Metropolitan Area	38.407	35.012	3.395
south axis	Baden	28.457	42.432	-13.975
	Mödling	48.541	40.234	8.307
	Wr. Neustadt	17.220	7.675	9.545
east axis	Bruck an der Leitha	6.325	13.496	-7.171
	Neusiedl am See	7.403	17.985	-10.582
west axis	St. Pölten Metropolitan Area	2.588	6.676	-4.088
north axis	Mistelbach	7.214	12.336	-5.122
north-east axis	Gänserndorf	11.641	24.678	-13.037

Table 6: Inbound and outbound commuters per county in 2001
(original: Fassmann et al. 2009:137; modified)

7.4. Historic Context and Lasting Influences on Nowadays Conditions

Already in former days, the Vienna-Bratislava metropolitan region was, thanks to its location, a dynamic development area and a transport hub of two important trading routes – the famous *Amber Road* (from the Roman town Carnuntum across the Marchfeld to the Baltic Sea) and the *Roman limes* along the Danube from west to east. Before World War II several villages like Bruck an der Leitha and Hainburg were flourishing, benefiting from the infrastructure of Vienna and Bratislava and their proximity to the two cities.

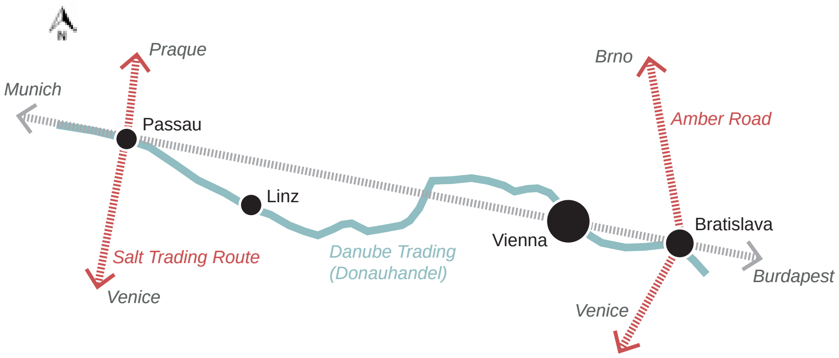


Figure 84: Regional trading cohesion in a historic context.

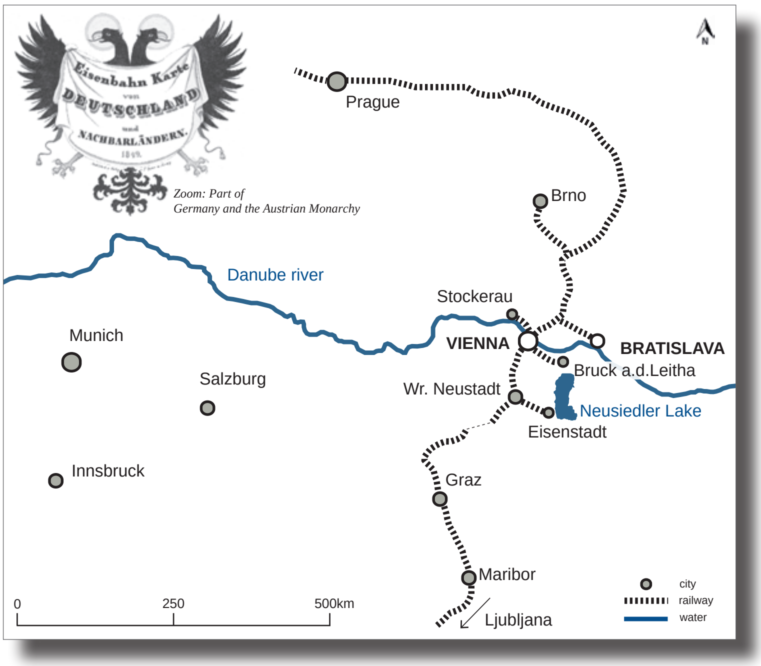
The parameters of landscape, history and planning concepts have constituted the regional layout of the Vienna-Bratislava Region.

Vienna's regional *south axis* lies within a *thermal region*. Important cities along this route (like Mödling, Baden or Bad Vöslau) have sulphur springs known in Roman times as *Itinerarium Antonini* (Wikipedia 2010). During the reign of Emperor Claudius *Baden bei Wien* was named Aquae (German: water, whereas the German word baden means "to bath"). It was later a permanent summer residence of the Holy Roman Emperor of the German Nation, Franz I (Franz II Joseph Karl, *Florence 1768, †Vienna 1835). In contrast, *Mödling* was historically the residence of a side arm of the Babenberger family. During the 20th century Mödling established its position as transport hub (train and bus) and has since attracted for industries of all kinds. Mödling remains a stepping stone between Vienna and Wr. Neustadt today.

Wr. Neustadt was established by the Babenberger Duke Leopold V in 1194. He invested the ransom for the English King Richard Lionheart to develop the city (Nova Civita). Its major task was to act as a fortification against Hungary. In the 15th century it was the main residence of the Holy Roman Emperor of the German Nation Friedrich III (Friedrich IV, *Innsbruck 1415, †Linz 1493). Nowadays, Wr. Neustadt is one of the most important and biggest railway hubs in Austria, connecting destinations such as Vienna, Budapest, Venice, Rom, Zagreb or Maribor.
The *Danube River* flows in the direction Vienna-Bratislava and marks the *east axis*. Historically, it was the most important factor for the development of this region, not only influencing the development within the Danube region, but also the whole Central European area. The Danube area always been a link between different European cultures, religions and ethnic groups. Natural barriers determined conditions for settlement and transport connections. One main historic development axis between Vienna and Bratislava was along the frontier of the Roman Empire (limes) parallel to the south bank of the Danube.

In contrast, if we observe the axis *Vienna – St. Pölten – Munich* to the *west* we find restricted development potential based on a natural boundary – the Vienna Woods, which are also part of the broken green belt around Vienna. Natural boundaries play crucial roles in regional developments. Based on restricted space for housing in combination with proximity to vast woods and gentle hills the price of land is above average in this area, attracting wealthy people and families. Let us recall that the west axis is part of the Danube trading route.

The *axis to the north* and the area north of the Danube river is nowadays not weakly developed and sparsely populated. Historically it was part of the important amber trading route connecting Vienna with Brno – the second largest city of the Czech Republic and historic centre of Moravia (German: Brünn; original: Brno). The trading route represented by a historic main railway route is still in use today (see railway map from 1849).



Map 5: Abstraction of Germany's railway routes (zoom) including neighbouring countries in 1849. Main routes in 1849 were Vienna-Brno, Vienna-Prague, Vienna-Bratislava, Vienna-Bruck an der Leitha, Vienna-Mariobor-Ljubljana (Leibach), (basic map source: www.landkartenindex.de, accessed 10/2011).

The Cities of Vienna and Bratislava

The *city of Vienna* has a long urban tradition. The first appearance of human settlements in the area of today's Vienna can be traced back to 10,000 BC. Its first urban layout can be detected in 1 BC when Vienna was founded as *Vindobona*, a Roman camp beside the Danube river. It was one of many along the *limes romanus*[76] of the Roman Empire. Later, Vienna was the capital of the Austro-Hungarian Empire under the reign of the Habsburgs. With a population of more than 2 million (Figure 6, p.24), Vienna around 1900 was the fourth largest city in the world (Czerkauer 2007). Nowadays, Vienna's population as the capital of the Republic of Austria is below the 2,000,000 mark (1.7 m in 2008 with an area of 419km²).

Like Vienna, *Bratislava* also lies along the *limes* only approx. 55km east of Vienna (straight-line distance from: Vienna's historic centre to Bratislava`s historic centre). Bratislava's city border in the West is in most areas congruent with Slovakia's national border.

[54] Along the limes romanus moden-day cities and villages were founded like Vindobona (Vienna), Carnuntum (next to Hainburg, Lower Austria), Gerulata (next to Rusovce in proximity to Bratislava), and Aquincium (Budapest).

Roman names:
Vienna = Vindobona;
Schwechat = Ala Nova;
Maria Ellend-Regelsbrunn;
Carnuntum = Petronell-Carnuntum;
Gerulata = Bratislava.

This reflects the intensive functional relationship between Vienna and Bratislava already in Roman times.

The first humans settled in the area of today's Bratislava in around 3,000 BC (at the end of the Late Stone Age); the first settlements are thought to have been founded in founded supposably 2,500 BC. In 5 BC Celts founded an empire with its administrative centre on the castle hill of Bratislava.
Later, the Romans founded a small military camp at today's Bratislava (castle hill) in 2 BC.
During the Austro-Hungarian Empire Bratislava was one of the most important economic and administrative centres of the monarchy. Further, from the 16th to the 18th century (again in 1848) it was the capital of the kingdom of Hungary. Today, Bratislava is the capital of the Slovak Republic with a population of approx. 430,000 and an area of 368km² (in 2008).
Bratislava lies at the crossing point of the Danube River with the historic, *Amber Road*, a historic trading route leading from St. Petersburg to Venice and connecting the Baltic Sea with the Mediterranean Sea.

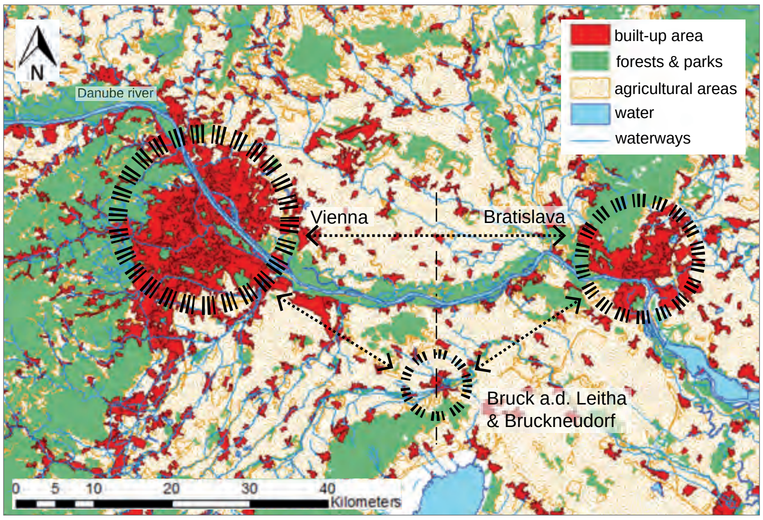
Strategically, Vienna and Bratislava were not only connected by the Danube River as an west-east trading route, but also were well supplied by the Amber Road (Bratislava) and the Salt Trading Route (Passau) both intersecting in Venice. This historically important circumstance has had an influence on their modern-day infrastructure and connectivity to other European cities. Due to political circumstances (Iron Curtain) the naturally evolved (self-organised) interaction between Vienna, Prague and Bratislava was interrupted during the 20th century, being re-established at the end of the 20th, beginning of the 21st century.

The Stepping Stone – Bruck an der Leitha over Time

In Roman times Bruck an der Leitha was the focal point of the important trading routes from the Baltic Sea to Italy; located next to Carnuntum Bruck an der Leitha was the crossing point of the Danube trading route and the amber route. Thus, the Roman military was permanently based there in order to safeguard and secure this important route.
The predecessor of Bruck was the small Roman town *Quadrata* (square). In 1043 the Leitha river was the political border between the Babenbergian Ostmark (Ostarrichi) and the Kingdom of Hungary; until 1921 this border was contested. In 1316 King Friedrich II. granted Bruck the license to sell self-grown wine in all Ländern. Despite the border (Austria and Hungary) Bruck was the focal point of the whole economic area from the Neusiedler See (Lake Neusiedl) reaching until the Hungarian kingdom.

Statistik Austria 2012

Nowadays Bruck an der Leitha (Lower Austria) is a small town with a population of 7,620 (in 2012; source: Statistik Austria) and an area of 23.68 km² with a density of 323.9 people/km². Neighbouring Bruckneudorf nowadays belongs to the Austrian Land Burgenland (former West Hungary) with a population of 2,889 and an area of 36.64 km² having a density of 78.85 people/km² (in 2012; source: Statistik Austria).
Spatially the two towns (Bruck a.d. Leitha and Bruckneudorf) form a single agglomeration and are located in proximity to both Vienna and Bratislava. Thus, Bruck an der Leitha and Bruckneudorf form a stepping stone between the twin cities of Vienna and Bratislava.



Map 6: Spatial location relation between Vienna, Bratislava and Bruck an der Leitha (Lower Austria) and Bruckneudorf (Burgenland).

CHAPTER EIGHT: CASE STUDY

8.1. Pre-assessment with Space Syntax

The pre-assessment of the Vienna-Bratislava metropolitan regions supports to validate the choice of Bruck an der Leitha as a priority development zone between Vienna and Bratislava South of the Danube river. Thus, the pre-assessment analyses further identify the feasibility of a possible development.
The convenient travel time between Vienna and Bratislava is approx. 60 minutes and from Vienna to Bruck a.d. Leitha approx. 30 minutes by car. Advantageous location factors, a moderate price spectrum for land and agricultural attractivity increases the possibility of regional growth.

Public transport also has to be adapted to the needs of teenagers and elderly people as they are often not part of the "car-community". This is often problematic in rural zones where public transport is inadequate for to the needs of the population.

In this regiona, most towns and villages are located a moderate distance from a regional or supra-regional centre – with a surprisingly advantage for individual transport. However, we have to consider that certain locations are not as attractive to people as others due to of functions (shopping, schools, hospitals, post offices, etc.).

The Space Syntax analysis herin used for the pre-assessment of the Vienna-Bratislava metropolitan region in the context of the before described *strategic planning approach* is *Choice* (or potential through-movement or segment angular analysis ASA) and *Integration* in segment map (least angle closeness). Choice highlights the *potential through-movement* which indicates how likely you are to pass through space on routes between all other pairs of segments. It depicts a hierarchy of the network; Integration (centrality) measures how easy it is to get to a segment from all others – *to-movement*.

Illustration: Level of Detail of the Street Network Used for the Accessibility Analysis

Figure 85: Street network graph for Vienna 2012

Figure 86: Street network graph for Bratislava 2012

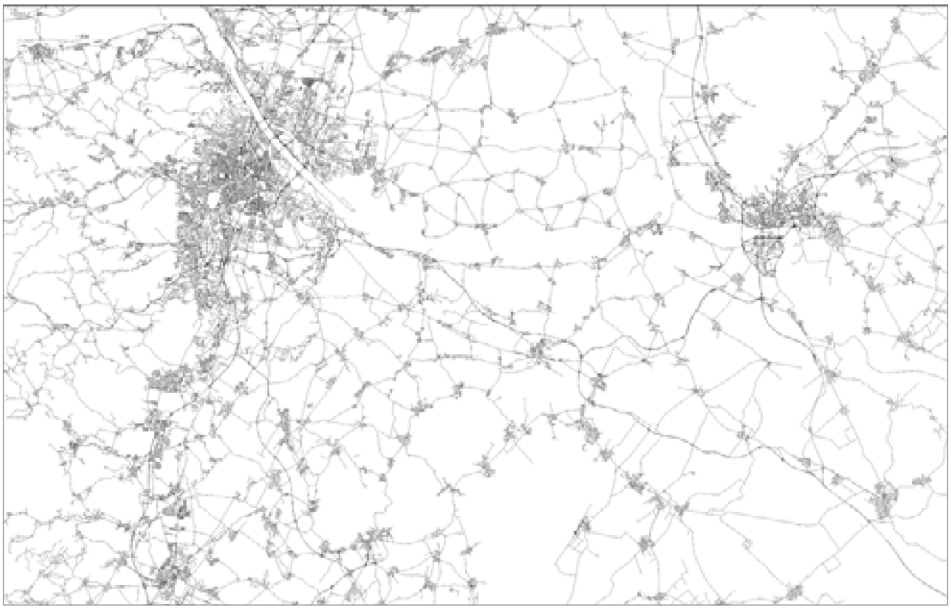
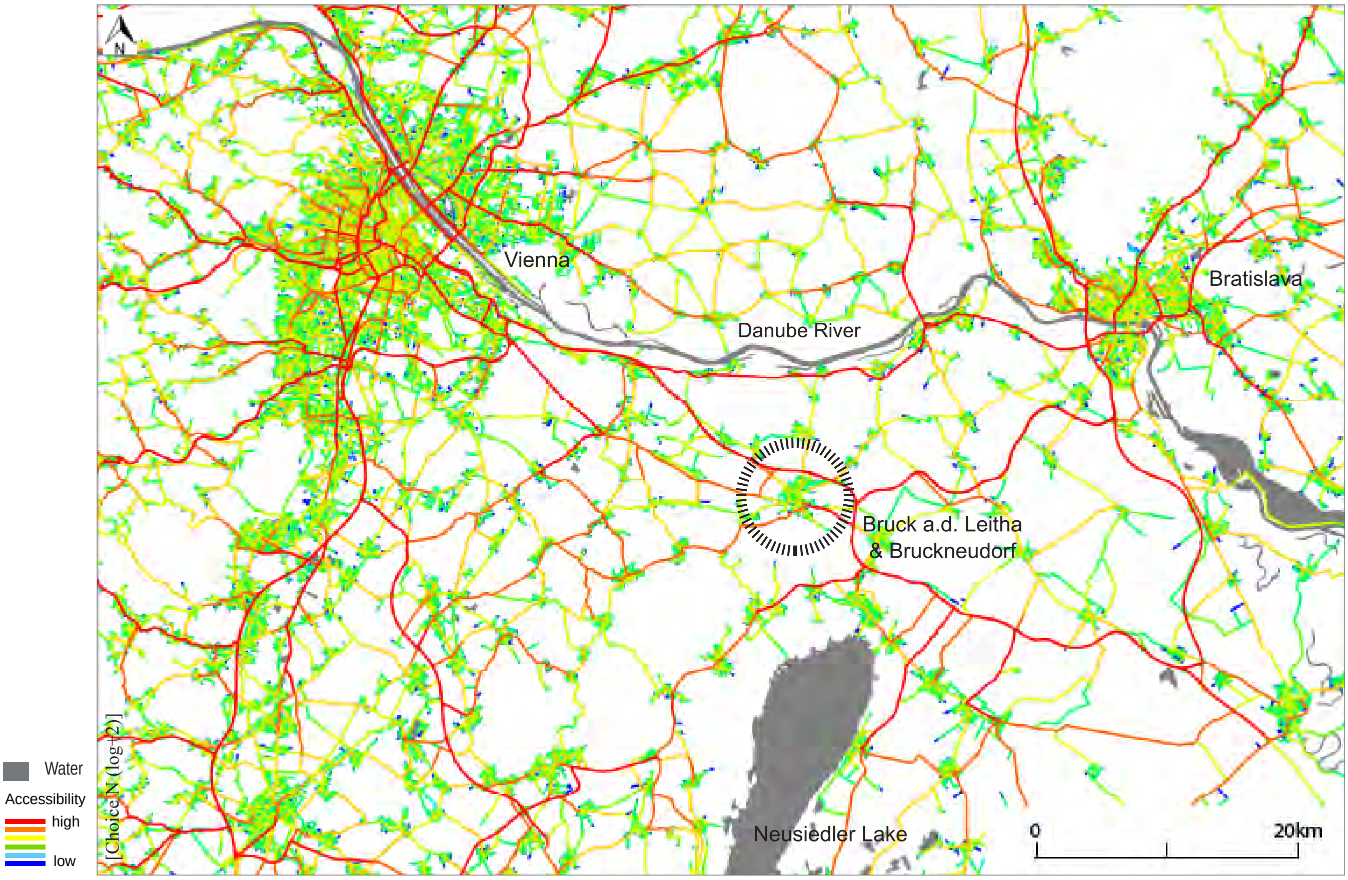
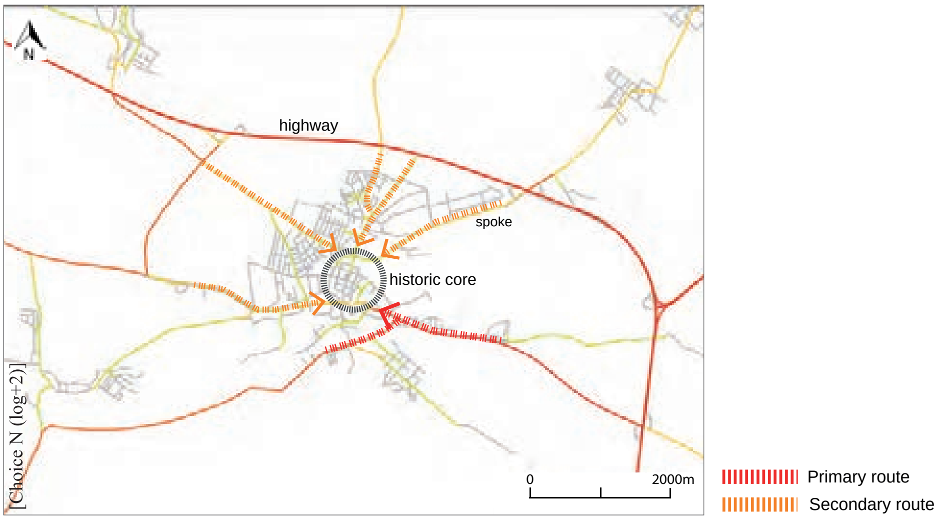


Figure 87: Street network graph for for the Vienna-Bratislava metropolitan region 2012 in the same resolution as for Vienna and Bratislava.



Map 7: Regional accessibility [Choice N (log+2)]

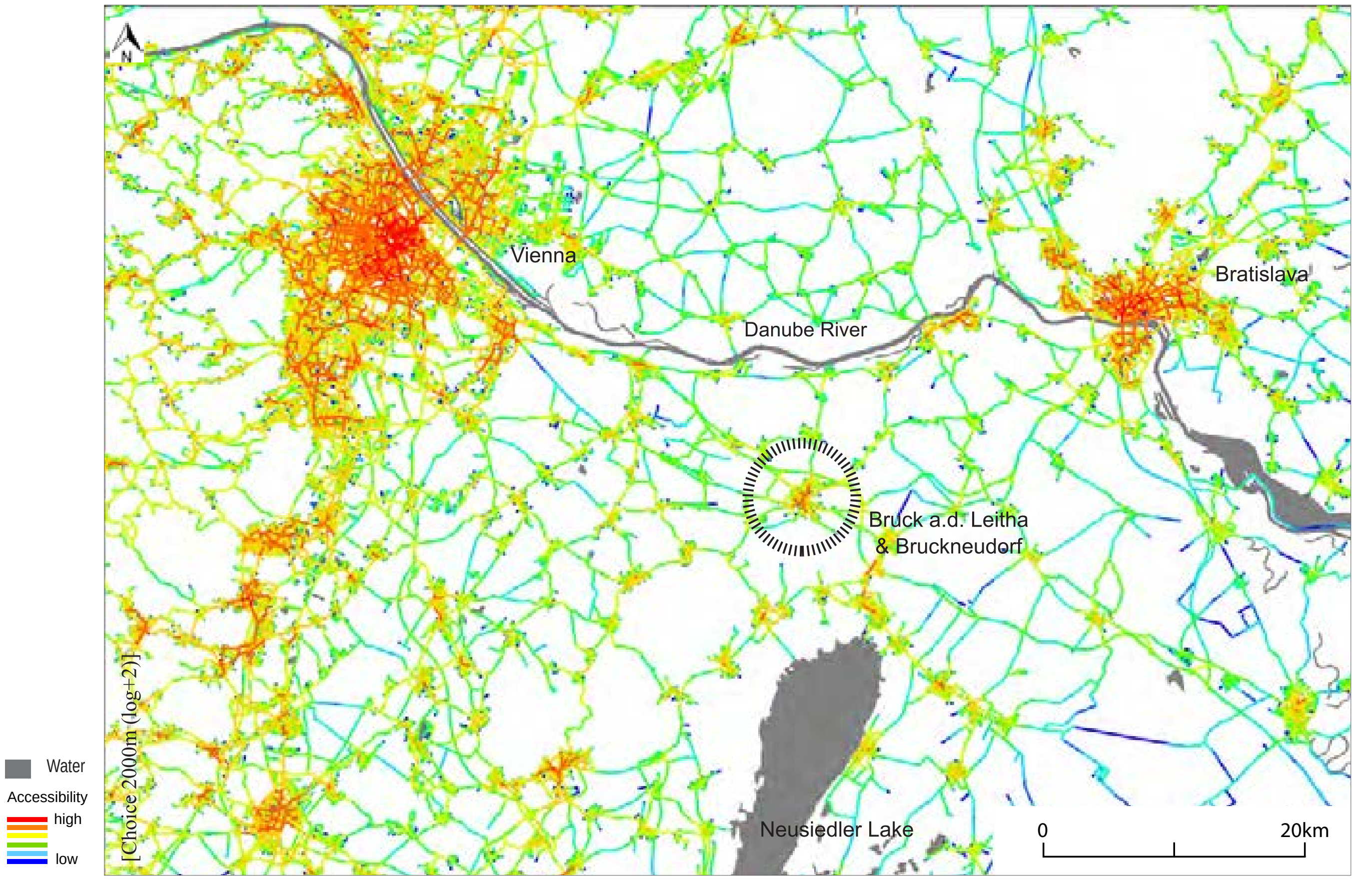
R*egional accessibility* shows that Bruck an der Leitha is located next to highly accessible regional routes from the A4 (East highway; Ostauto-bahn).



Map 8: Urban context map for Bruck an der Leitha & Bruckneudorf

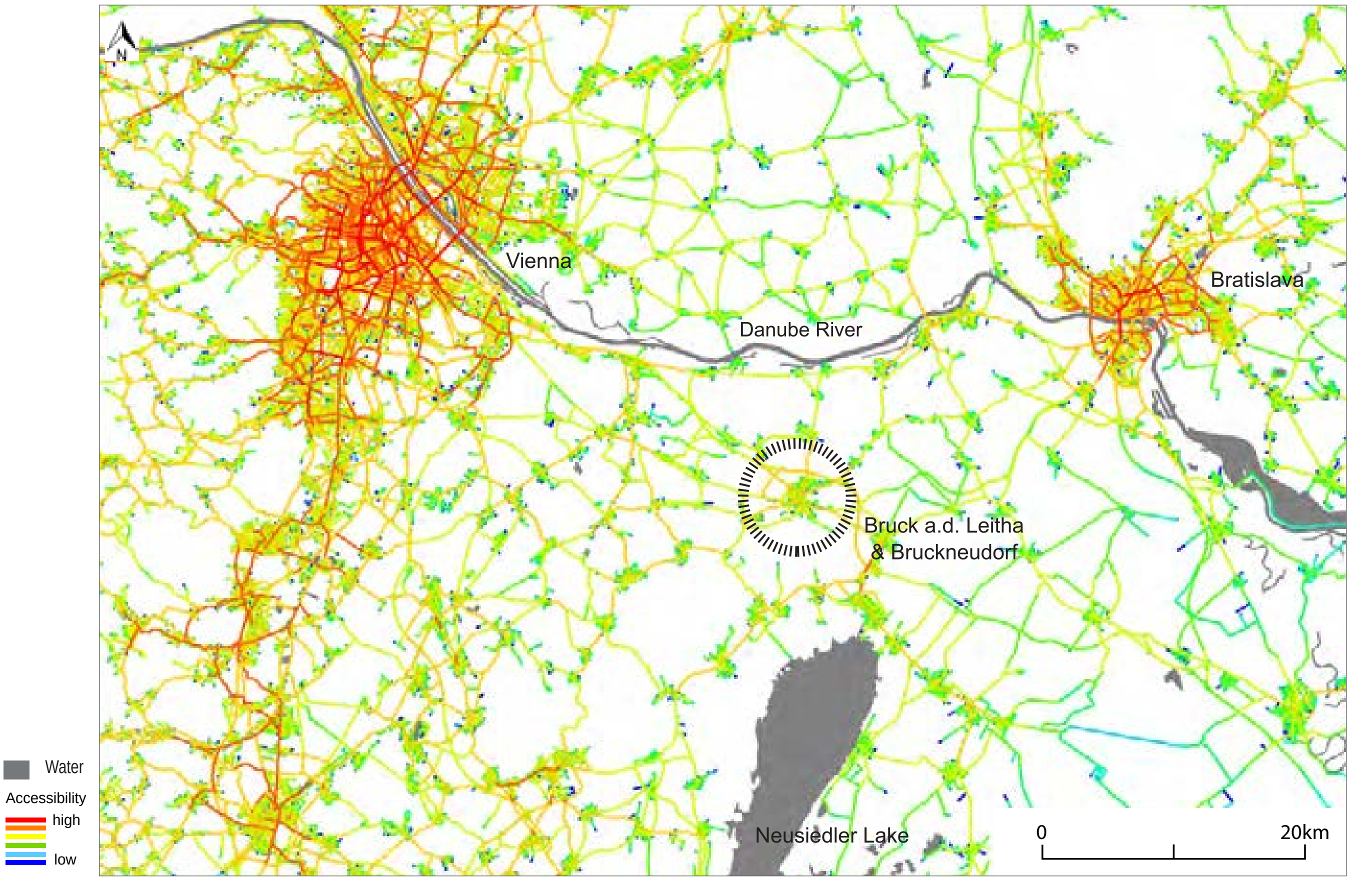
[Choice N (log+2)]

The *urban context map* (Map 8) on a regional scale highlights a radial system of secondary routes with mostly primary routes as orbitals (highway). The highway replaces classical, historically evolved orbital streets. Further, it highlights the classical pattern of a deformed wheel.
The *deformed wheel pattern* is typical for historic evolved cities and towns and can be found with most cities and towns. It has strong *spokes* linking the centre to the edge in all directions (star-shaped city form).
The normally strong rim of lines is overtaken by the highway passing tangentially Bruck a.d. Leitha. It offers good potential for development as the network is in its basic constitution efficient.This is further confirmed by local accessibility (see Map 9 below).



Map 9: Local accessibility of the Vienna-Bratislava metropolitan region [Choice 2000m (log+2)].

The *local choice* analyses (Map 9) also depicts local centres based on the through movement. Where segments with high ranges of integration and choice overlap it indicates places for good economy as they are places with high centrality and high movement flows. In the local accessibility analysis we can identify the centre Bruck an der Leitha.



Map 10: Intermediate accessibility of the Vienna-Bratislava metropolitan region [Choice 7000m (log+2)].

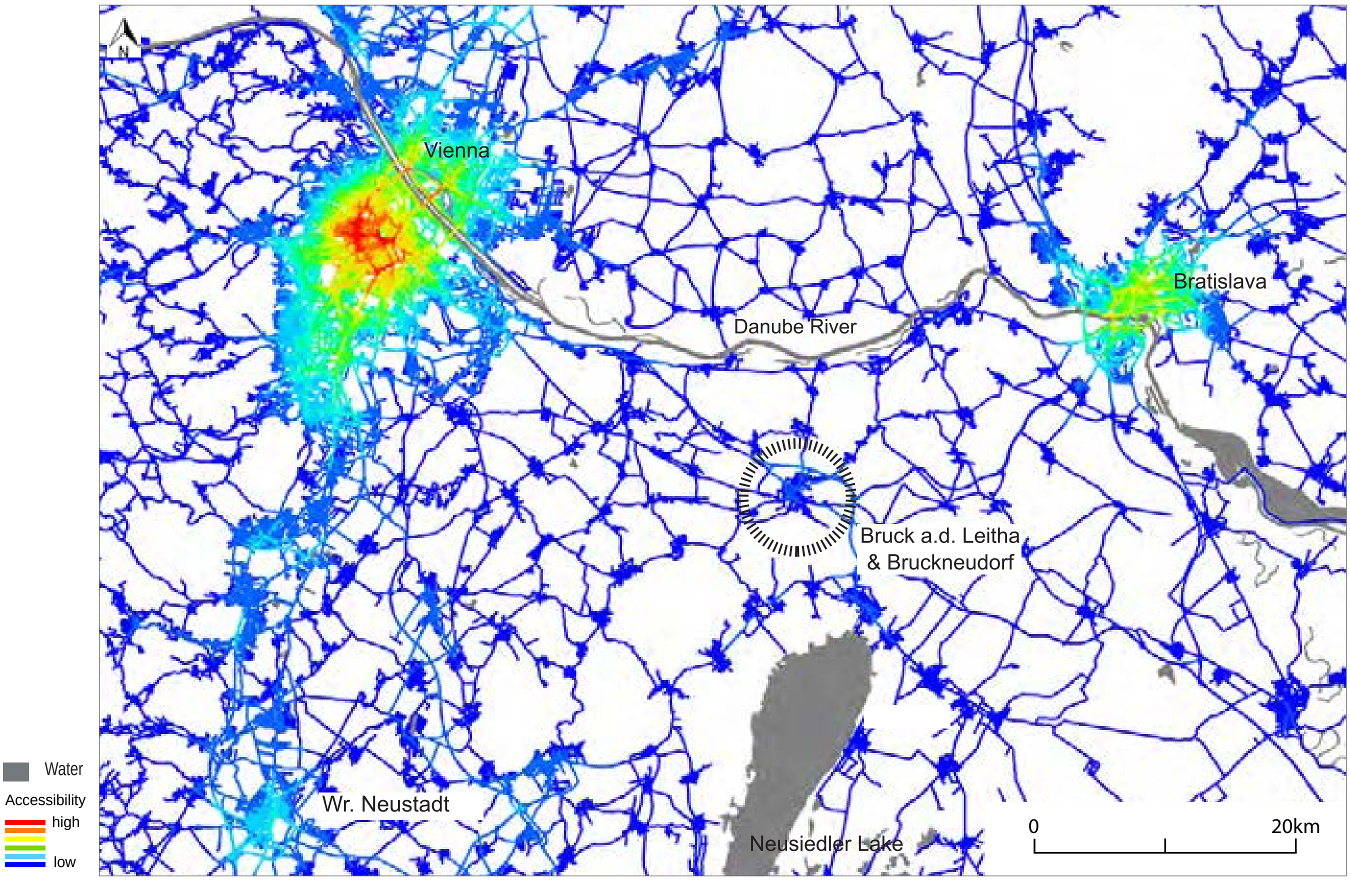
On an *intermediate accessibility scale* (Map 10) Bruck an der Leitha is not highlighted within the regional context. This depicts that Bruck is very local embedded and not globally within the Vienna-Bratislava metropolitan region. Thus, on an intermediate scale accessibility should be improved. Further, the well developed south axis becomes prominent.

Conclusion

Bruck an der Leitha (including Bruckneudorf) is globally well accessible on a local scale. Also the street network of the historic core (local scale) is functional and well accessible. Hence, no restructuring actions of the spatial structure has to be carried out.

On an intermediate scale Bruck an der Leitha's street network configuration can be improved. Due to the herein shown scenarios (case study p. 216 ff; building constructions increasing population) the network configuration will change and thus enhance accessibility on an intermediate scale.

N.b. Let us remind, that with the geometrical idea of a fractal city, the network is a sub-set of the built pattern.



Map 11: Local centrality in segment map [Int 5000m in segment map].

Local centrality shows very well the hierarchy of centrality - Vienna as the prime centre and Bratislava as the secondary centre with Wr. Neustadt as the tertiary centre. St. Pölten as the tertiary centre by population is not considered in the analyses as it is not strongly influencing the Vienna-Bratislava metropolitan region.

Thus, for the Fractalopolis analyses the centroid of the initiator will be placed on central Vienna.

8.2. Scenario Development and Option Testing with Fractalopolis DSS including 3D Visualization

It will be recalled that the *Fractalopolis* software supports the idea of developable areas and non-developable areas. Everything, which is not developed is assumed to be leisure (if not already built-up).
The application herein will discuss the built pattern and population on macro scale; and built pattern, population and accessibility on micro scale.

The fractal rule is as follows:

- Continuity of built-up (developable) zone
- Continuity of open space
- Interweaving/ intermeshing of both

Below are two examples for defining the IFS:

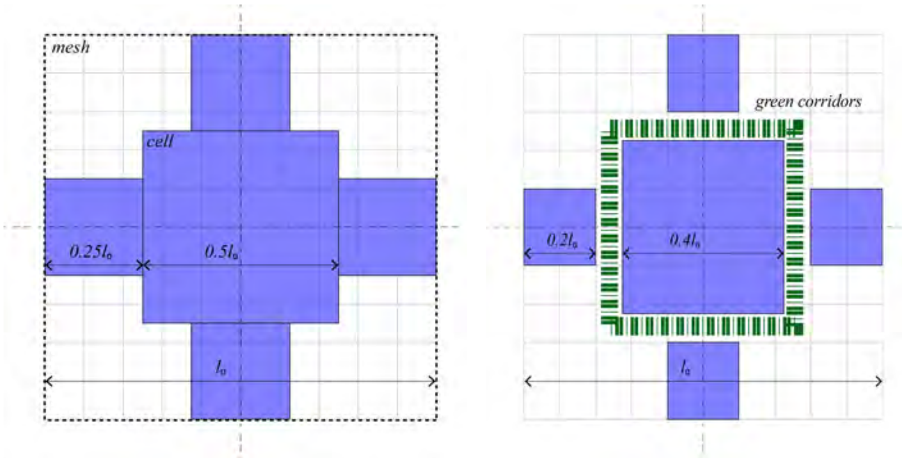


Figure 88: IFS definition for Sierpinski (left) and Founier dust (right).

For the spatial scenario set we will use the underlying logic of a *Sierpinski carpet*. We use the logic of Sierpinski in order to avoid fragmentation and urban sprawl. Indeed the elements of a Sierpinski carpet are connected in a topological sense. Nevertheless, the hierarchy of non-built areas is preserved.
Moreover, based on the shift of elements (cells within a mesh) on each level (iteration step; decomposition) we can provide intra-urban green lacunae to avoid a “fractal linear town”. By introducing a multi-fractal and not a mono-fractal Sierpinski carpet we increase the local built-up concentration of built-up mass which allows to avoid the construction of a “fractal linear town”.

The scenario[55] set will be tested based on the strategic planning approach of *informed decision-making*. The procedure will be as follows:

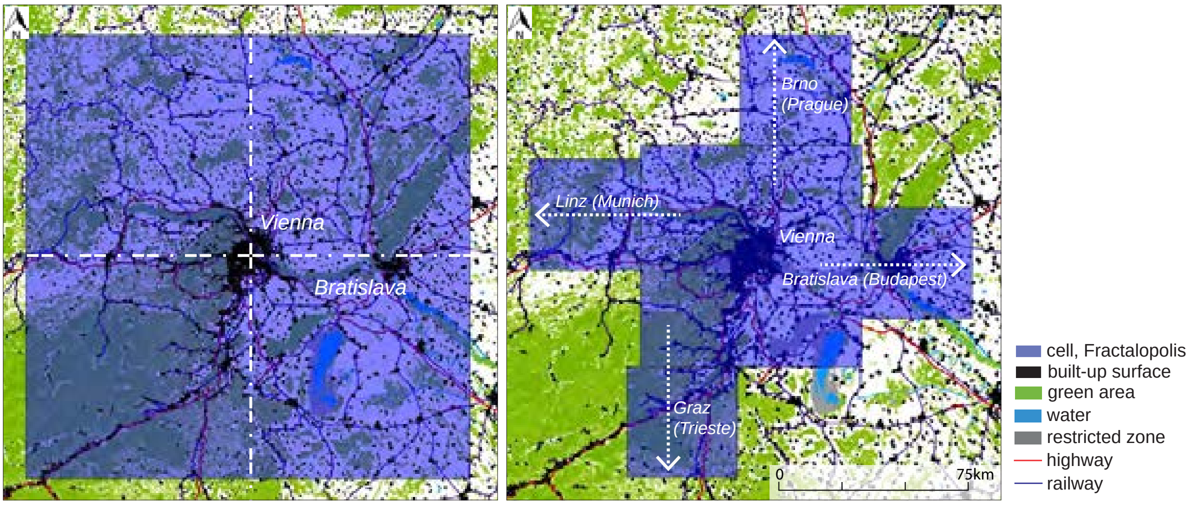
A.) Development of scenario (macro and micro scale)
B.) Accessibility evaluation – services and leisure (micro scale)
C.) Population model
D.) Option testing and evaluation with Space Syntax
E.) Strategic visibility
F.) 3D model

[55] For the case study we developed georeferenced database with a total of around 90,000 entries (services and facilties; leisure, public transport)

On the *macro* scale the scenarios will not be evaluated in terms of accessibility as the scale is too coarse grained for meaningful accessibility measures (all evaluations will be good as the catchment areas are big); even formulated in the accessibility rules. The focus of the decision-making process for scenarios is the knowledge of the area. Further, no morphological rule exists.

All following images without scale for the benefits of illustration.

Sierpinski ***MACRO*** *(iteration steps 0-3)*

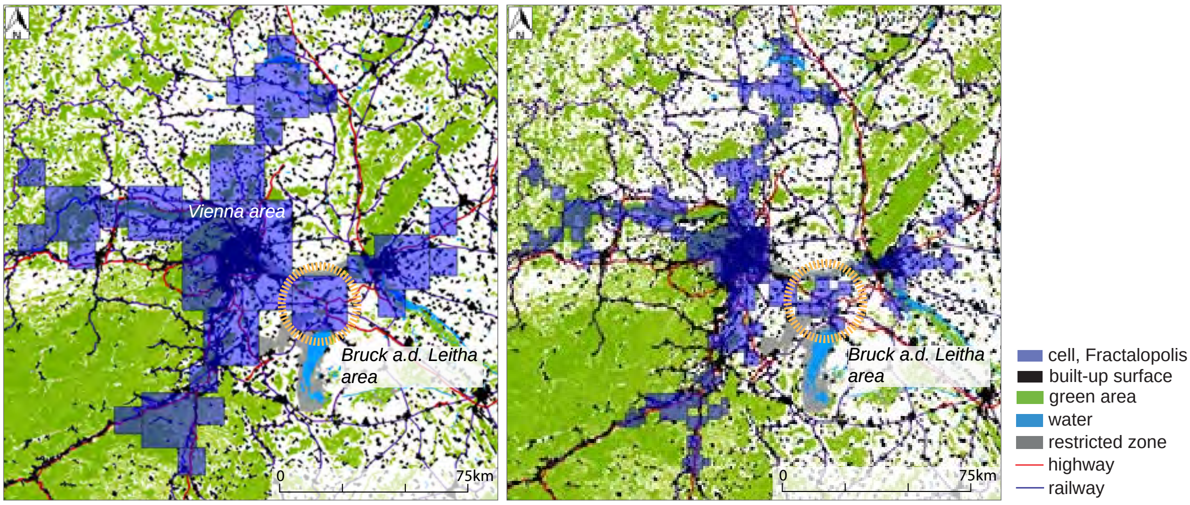


Iteration step 0 (initiator)
base length cell: 174.87km

Iteration step 1
base length main cell: 87.44km;
each sub cell: 43.72km

Figure 89

Planning strategy is to strengthen the axes to Brno (north), Graz (south), Linz (west) and to develop a consistent axis south of the Danube river between Vienna and Bratislava; local sub-centres are also part of the planning strategy. The topography is considered (restricted slope zones) as well as the empirical knowledge about this study area (e.g. local economic advantages and disadvantages, local natural constraints, current development trends).



Iteration step 2
cell sizes from 43.72km to 10.93km

Iteration step 3
cells` sizes from 21.89km to 2.73km

Figure 90

Levels of hierarchy – iteration steps 0-3

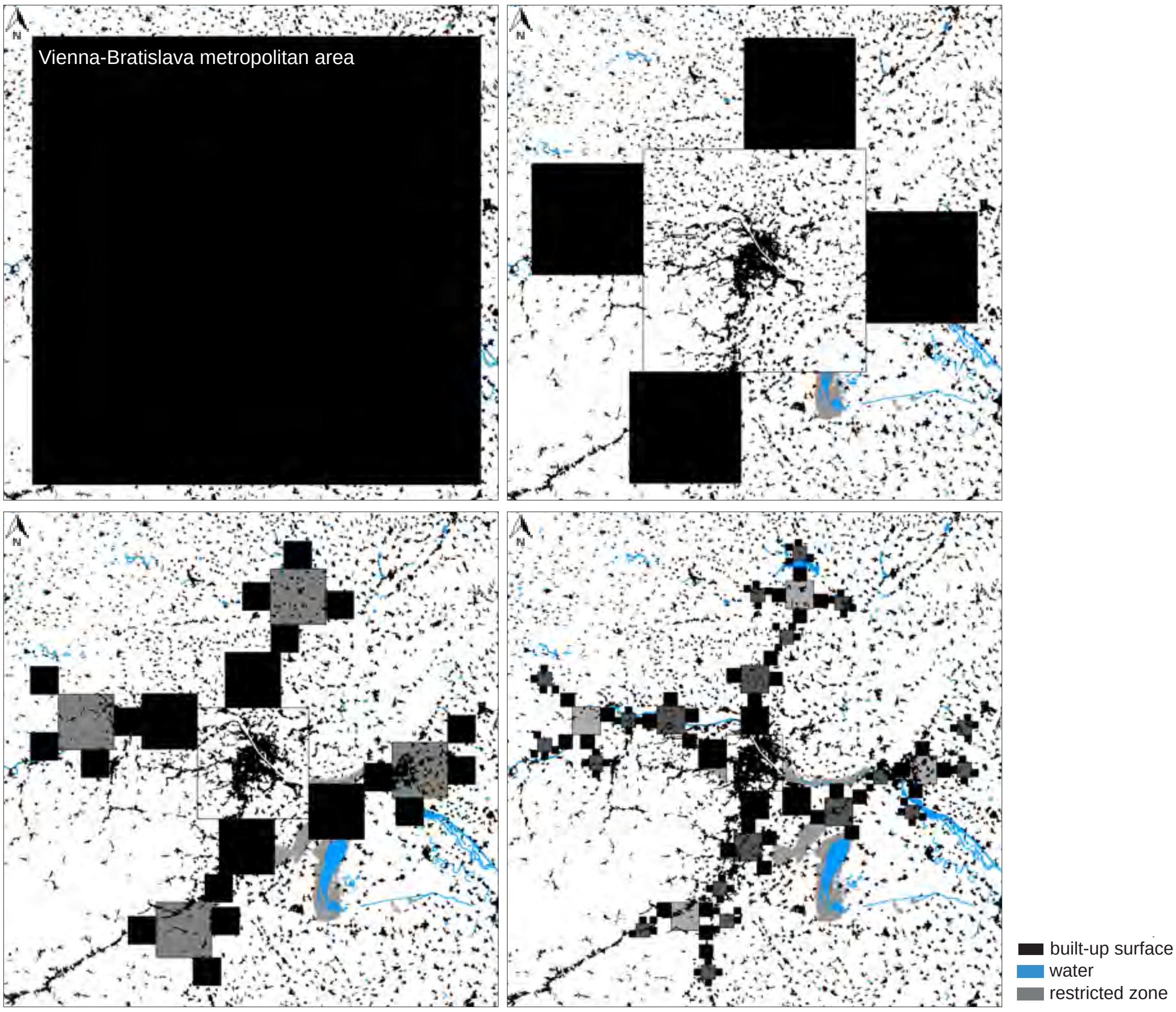


Figure 91

The proposed level of hierarchy depicts very clearly the multi-fractal logic for each iteration step.

Population model at iteration step 2

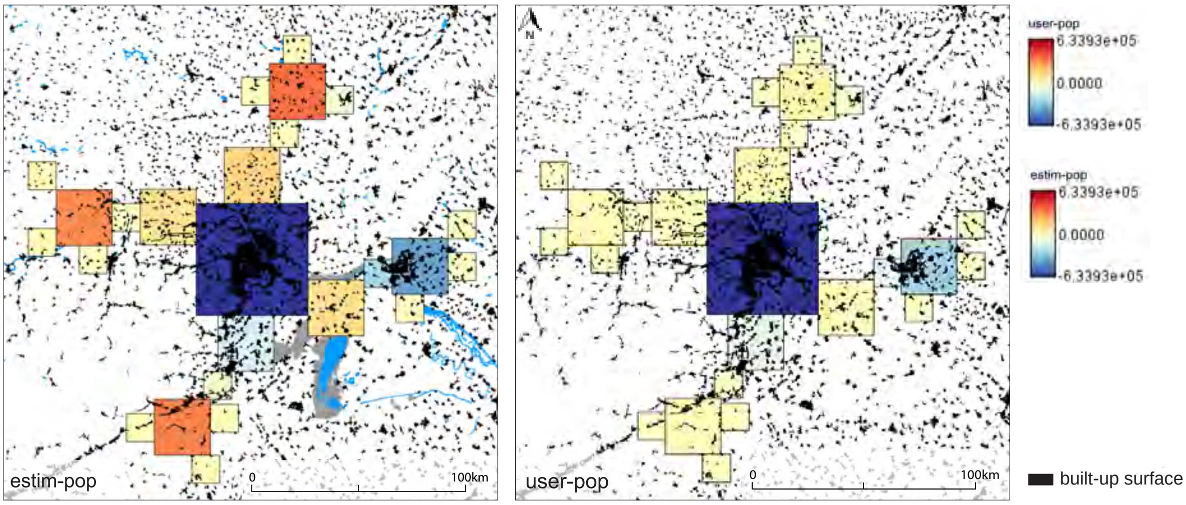
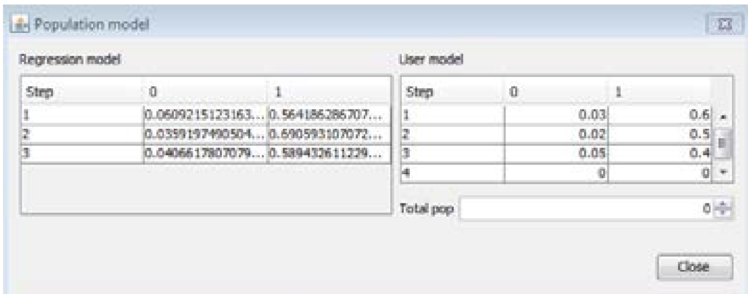


Image left: Estimated population (model) minus real population (data base); right: better adjustment to real population distribution (right). Left: The estimated population is based on empirical data of the region (arithmetic mean – see population model); right: The model is calculated based on a user model (artificial parameters) to highlight the possibility of a scenario development (see parameters for the user model below). The scenario is adapted to the weak exisiting Christaller hierarchy in the metropolitan area.

Figure 92



Population model

Regression model

Step	0	1
1	0.0609215123163...	0.564186286707...
2	0.0359197490504...	0.690593107072...
3	0.0406617807079...	0.589432611229...

User model

Step	0	1
1	0.03	0.6
2	0.02	0.5
3	0.05	0.4
4	0	0

Total pop 0

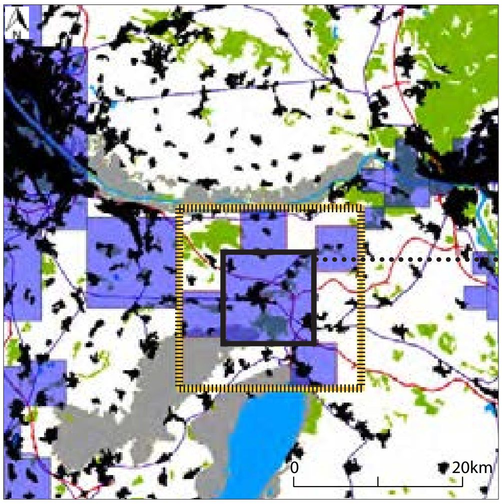
Close

It will be recalled that for the estimated population model we combine a surface model (multifractal model) with a weighting logic (ponderation). The model uses an iterative estimation method (see population model; chapter 6.1.2.). The distribution of the population is linked to the locations of the individual squares (scenario development). Centres having the same function are equally weighted.

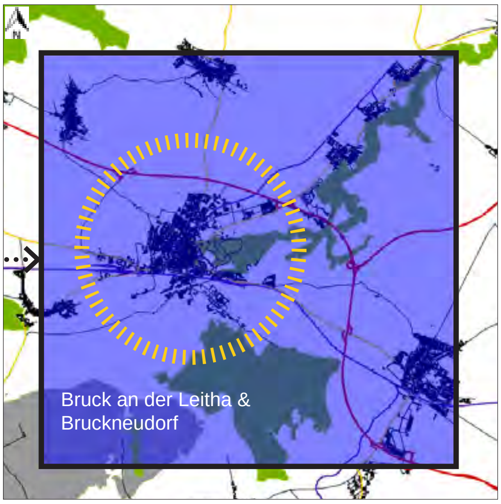
The model translates a predefined hierarchical spatial distribution of population. In the study area the hierarchy is almost inexisting. Nearly all population is concentrated in Vienna and Bratislava (Figure 124, image left). It is possible to represent such a weak hierarchy using Fractalopolis software (image right). By doing this, the bicentral concentration of population in Vienna and Bratislava is depicted stronger. For the spatial scenario on micro scale we in increase the number of population of Bruck a.d. Leitha to reach the number of inhabitants estimated by the model.

*Sierpinski **MICRO** (iteration steps 0-4)*

The micro scale is a more accurate reflection of a real-world situation as it also includes in addition to the population model a functional approach, the *accessibility* evaluation. The planning strategy on a micro scale focuses on *Bruck an der Leitha*.

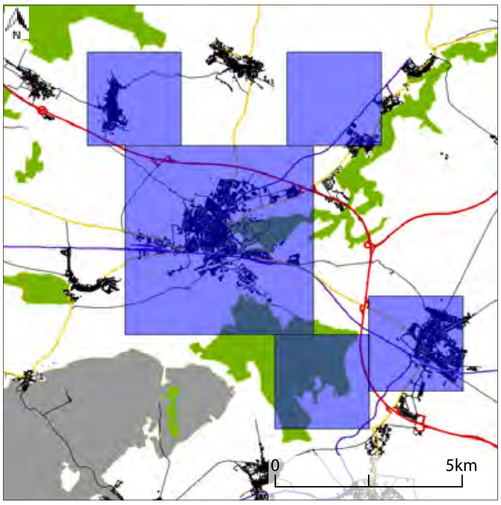


Chosen area (mesh) for micro scale



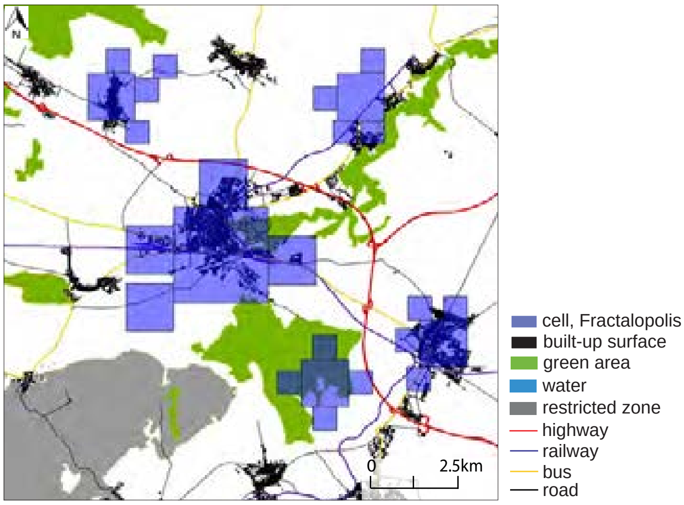
Iteration step 0 (initiator)

base length cell: 10.93km



Iteration step 1

base length main cell: 5.46km
each sub cell: 2.73km



Iteration step 2

cells` sizes from 2.73km to 0.68km

Figure 93

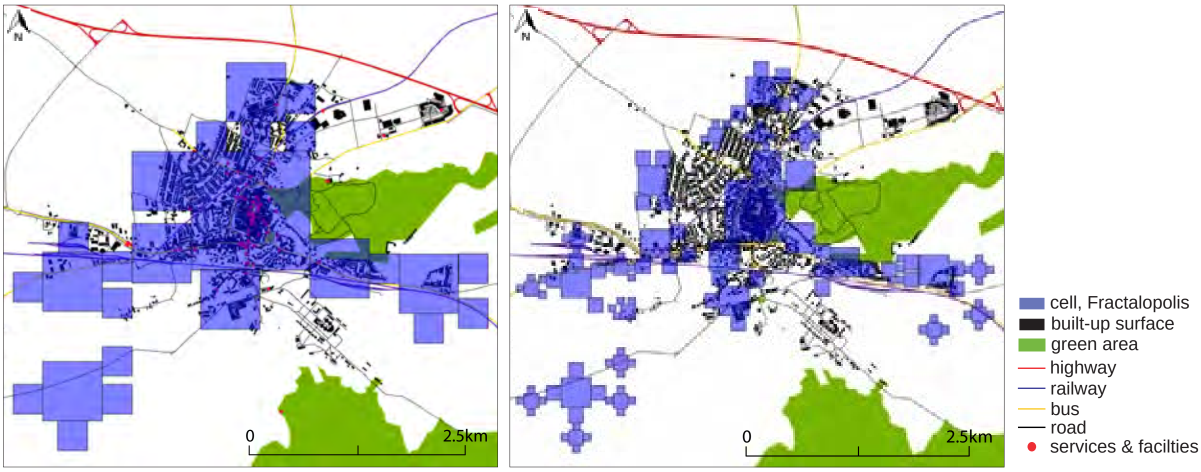


Figure 94

Iteration step 3

cell sizes from 1.37km to 170m

Iteration step 4

cell sizes from 683m to 43m

For the urban scenario the following *planning types* are identified:

A. Inner development (urban infill) and revitalisation of historic centres
B. Extension of historic (sub-)centres
C. Grid intensification of residential areas
D. Extension of residential areas
E. New development

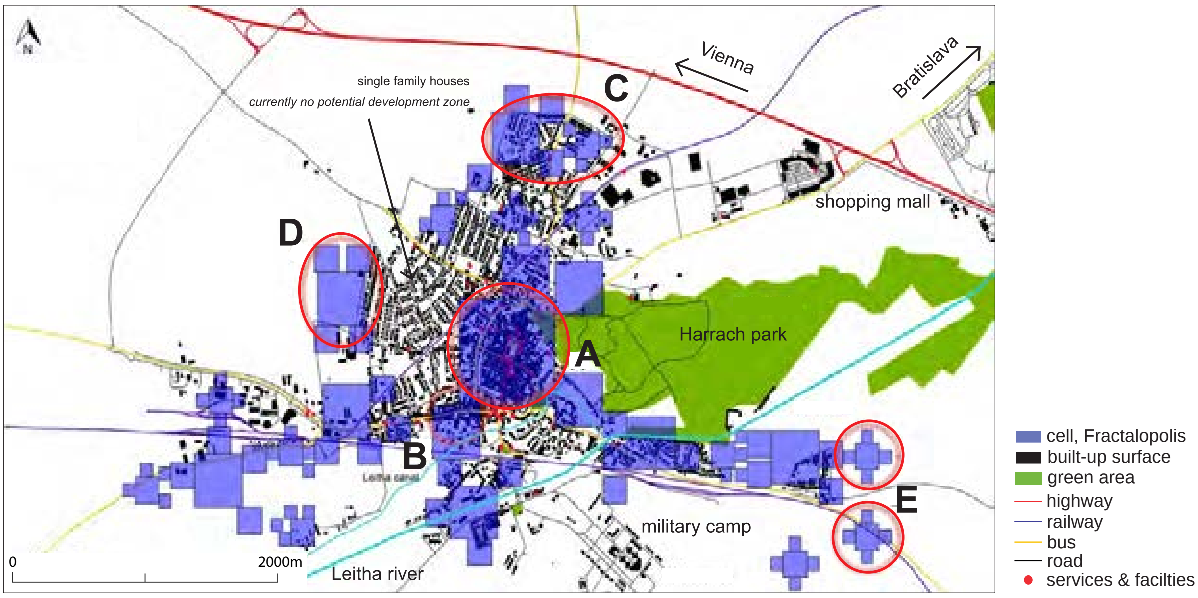


Figure 95
Planning types

Main shopping street Kirchengasse (area A):

The main inner city shopping street Kirchengasse has many empty shops.

Historic (sub-)centre Altstadt (area B):

The historic sub-centre shows a dense street front (images above) and very sparsely developed rear areas (images below).

Residential area (area C):

The residential area at the northern edge of Bruck an der Leitha has many empty individual plots and groups of plots.

Residential area (area D):

The residential area west of the historic core is a typical single family house settlement with a clear boundary.

Non-developed area (area E):

Bruck's shopping mall

The town has its own shopping mall.
The small Esprit shop in the inner city shopping street is closed whereas the shopping mall has a mega store of this brand.

Harrach park (English landscape garden) and Schloss Prugg (11th century):

Evaluation on Micro Scale – GIS Data Base for the Case Study

For this research a GIS data base was established containing in sum 22,839 entries for services and facilties and 67,368 entries for leisure and green open space (including automated processed access points for parks and forests). Further, information on morphology (built-up surface), street network, water, forests & parks, agricultural areas, restricted zones, public transport (bus, train) and population was added. For gathering the information several data sources were combined, manually adapted and completed (e.g. Corine Land Cover, Herold, Statistik Austria, Bing Maps, Google Earth, WMTS, Open Street Map data).Where there was a lack in data, the data are collected according to the need of the case study on a local scale (Bruck a.d. Leitha and neighbouring towns). Thus, the data base includes coarse grained and fine grained data sets (see below)[56]. The data base is used for the evaluation of the scenarios on micro scale.

[56]The data base makes no claim to be complete.

Services and Facilties (22,839 entries)

Occassional = Monthly Frequentation

University, research institution	110
Central place administration (ministry, court, embassy)	88
Cultural centre (opera, theatre, museum)	496
Shopping malls, shopping cities	8
Hospital and health centre	4 (Bruck, neighbouring towns)
DIY and garden centre	86
Casino	7
Gas station	1,349

Weekly Frequentation

Post office	978
Secondary school	99
Bank office	1,388
Hairdresser	40 (Bruck, neighbouring towns)
Florist	49 (Bruck, neighbouring towns)
Café, restaurant, bar	9,721
Pharmacy	989
Bicycle shop	241
Car repair	1,230
Supermarket	49 (Bruck, neighbouring towns)
Clothes shop (shopping malls excluded)	20 (Bruck, neighbouring towns)
Beauty salon (in wellness centre)	4
Dentist	131 (Bruck, neighbouring towns)
Cinema	107
Household shops	12

Local cultural centre	43
Drugstore	26 (Bruck, neighbouring towns)
Place of worship	2,358
Library	180
Local administration (e.g. municipal office, social facilties)	517
Farmer‘s market	35
Sports centre (competitive leisure services; e.g. gym)	42 (Bruck, neighbouring towns)
Spa centre	4

Daily Frequentation

Corner shop, organic store	1 (Bruck)
Primary school	449
Kindergarten and crèche	566
Newsagent and tobacconist	38
Bakery	63
Butcher (in supermarket)	49 (Bruck, neighbouring towns)
General doctor	497 (Bruck, neighbouring towns, cities)
Cash machine	679

Leisure and Green Open Space (9720 entries plus automated produced access points = 67,368 entries)

Occassional = Monthly Frequentation

Skiing lift	3
Water sport (windsurfing, kitesurfing, sailing)	15
Golf	13
Swimming (Lake)	15
Recreation area, forests, moor and heatland (>150ha)	1965
UNESCO world heritage (landscape)	1

Weekly Frequentation

Tennis	40
Soccer	15 (Bruck, neighbouring towns)
Public swimming pool	47
parks, recreation areas (2-150ha)	5868

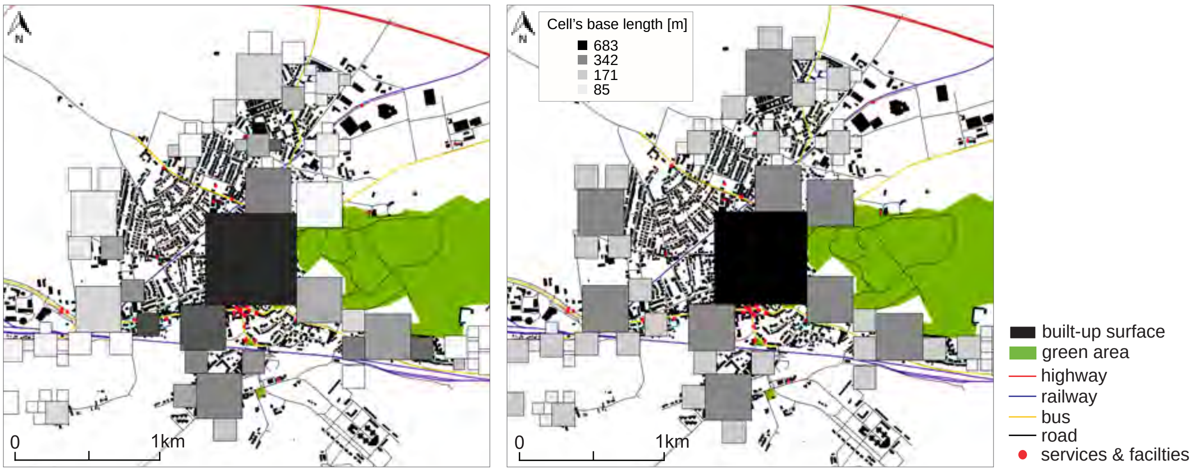
Daily Frequentation

Playground	1(Bruck)
Dog exercise area	not existing in Bruck
Small park (Beserlpark), park, green area (0-2ha)	1737

Urban Scenarios – Evaluation

N.b.The following analyses are all zoomed to the area of interest.

Density (iteration step 4)



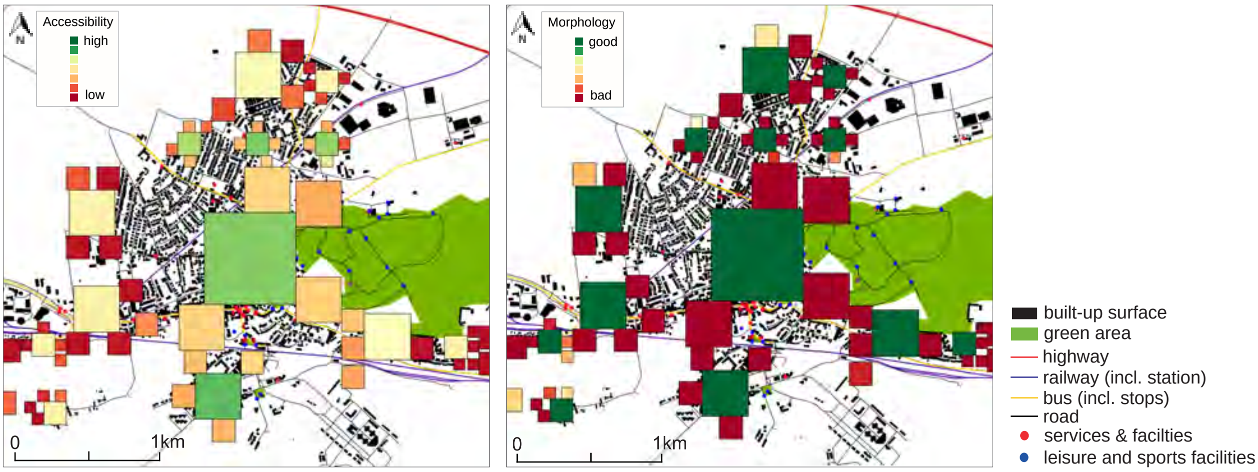
Density [people/km²] Sizes of cells – base length in [m]

Figure 96

Density[57] [people/km²] (figure left) highlights a decrease from the city centre to the periphery. Image right shows the corresponding cell sizes.

[57] Density tool under development.

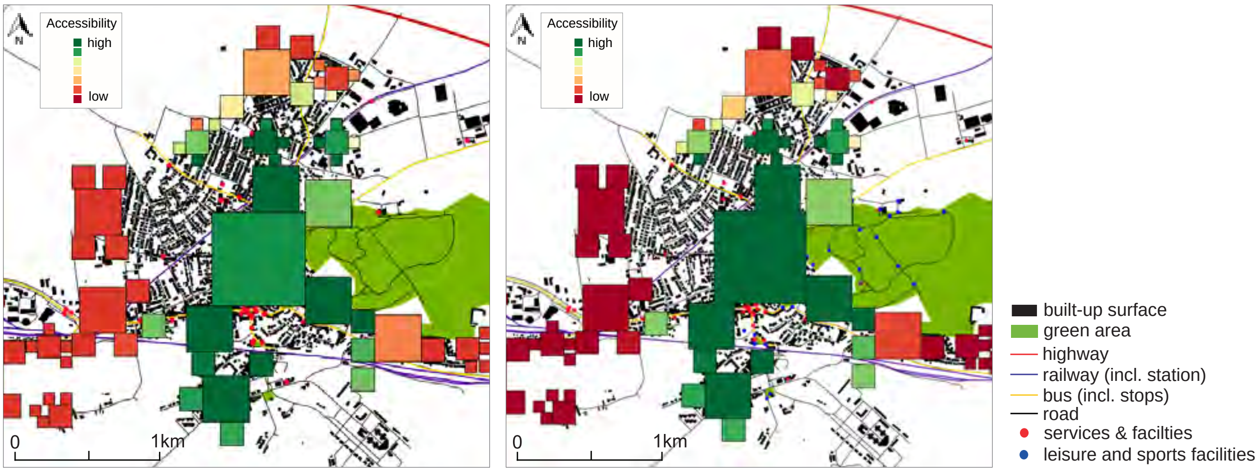
Accessibility and Morphology (iteration step 4)



Global accessibility incl. morphological rule Morphological rule

Figure 97

The image to the left depicts the global evaluation (accessibility to services and leisure on a daily, weekly, monthly and occasional level including morphological rule). The historic centre is evaluated as good due to the existence of local shops and close proximity to Harrach park. Sub-cells to the north are in close proximity to the shopping mall and public transport stops. The green cell in the south belongs to the core of Bruckneudorf (good access to local shops and leisure and transport). What can be detected from the global analyses is that the morphological rule has a strong influence.

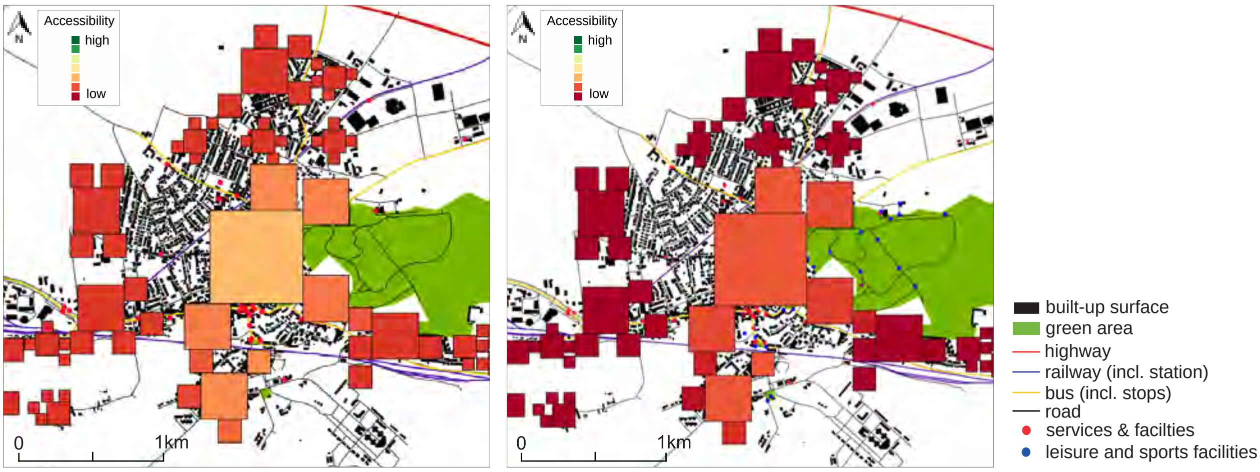


Global accessibiliy - facilities
(daily, weekly, monthly, occasional)

Local accessibility - daily facilities

Figure 98

Based on the set aggregation level daily facilties have a strong influence on the evaluation. Monthly and occassional facilties are evaluated as bad. This is due to the fact that Bruck an der Leitha is a small town in a rural area depending mainly on daily (and weekly facilities). The planning scenario designates Bruck as a centre of level three. The first two hierarchical levels are assigned to Vienna. Important for Bruck is a good evaluation on level three and four (daily and weekly facilities).



Global accessibility - leisure
(daily, weekly, monthly, occassional)

Local accessibility - daily leisure

Figure 99

The evaluation of local accessibility (daily leisure) is an illustration that the not so good evaluation of daily leisure is influenced by the circumstance that the data base includes sports facilities and green areas (points and areas with defined access points). The agricultural landscape around Bruck an der Leitha is not considered. The analyses highlights that for this case study services take priority over leisure as Bruck is embedded in a rural neighbourhood.

We have to be aware that the morphological rule already defines the size of green spaces in a specific manner (e.g. Sierpinski manner).

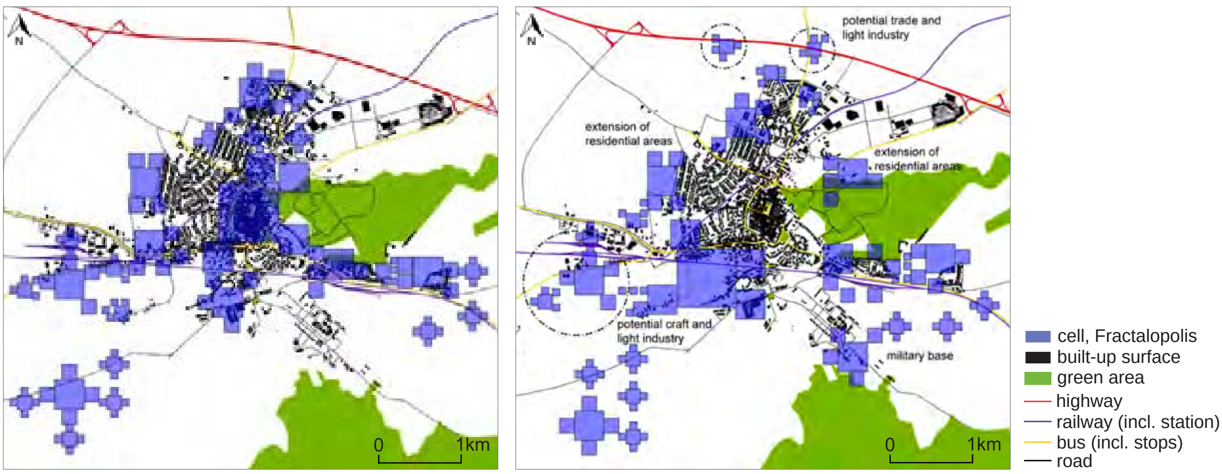
Considering the herein used classification for green spaces we use as an underlying basis ANGSt (Accessible Natural Greenspace Guidance NE265) adjusted to the Vienna-Bratislava metropolitan region – relating to the conceptional Christallerian logic. So far, some problems with the practical implementation of this logic occure (f.e. daily and weekly use of a park as it can be identified in the analyses with Harrach park). The classification needs to be extended in the data base for green spaces which are poly-functional according to their frequentation (e.g. code 4 = daily use, 3 = weekly use; 5 = daily and weekly use).

Option Testing with the Fractalopolis Decision Support System

The decision support system Fractalopolis can be adjusted to individual spatial and economic situations and thus opens up a spectrum of variants for option testing. This can be done by either:

- Relocation of cells and meshes
- Change of accessibility distances and diversity functions on all levels including cluster size
- Change of weighting and aggregation of services and leisure
- Combination of accessibilites for evaluation
- Consideration or not of morphological rule
- Implementation of additional facilities and leisure on all scales
- Change of restricted areas (e.g. slope constraint for development)
- Change of population parameters

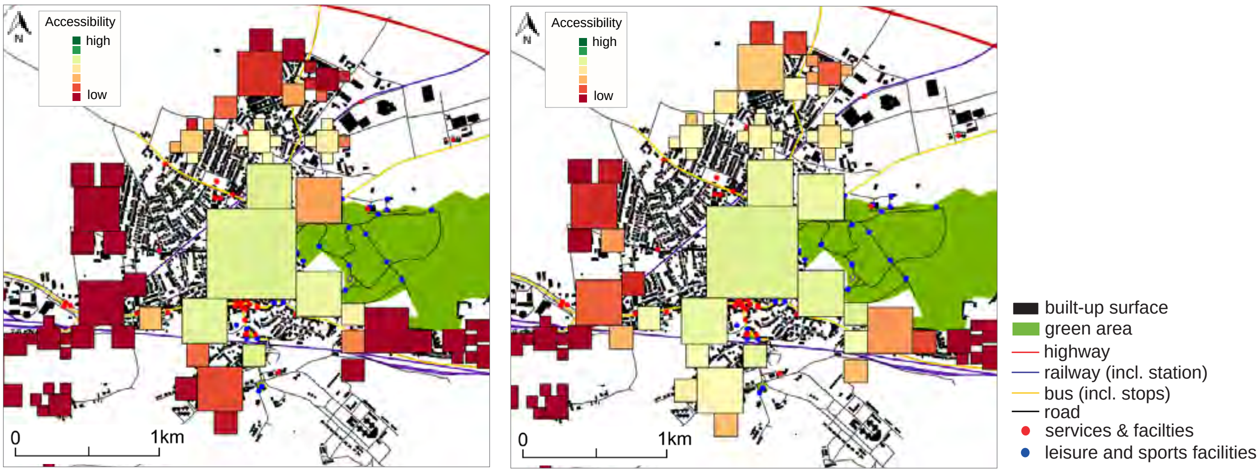
Below we illustrate the above described possibilities in the context of accessibility for two types of option testing, the *relocation of cells and meshes* and the *change of distance functions*:



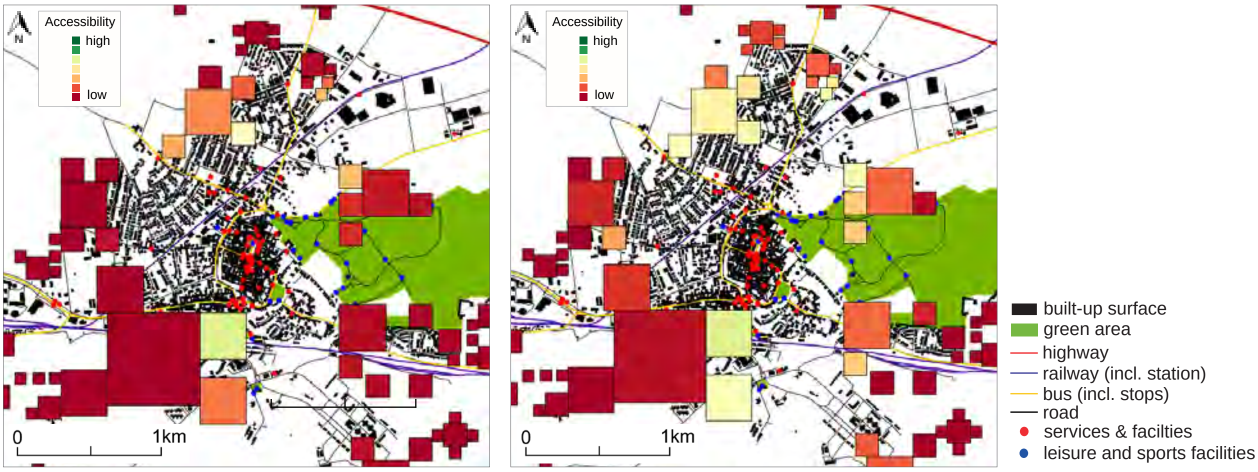
scenario 1 scenario 2

Figure 100

Scenario 1 addresses several planning approaches: revitalisation of the historic centre; grid intensification, extension of residential areas, and new developments. In contrast, *scenario 2* focuses mainly on new developments (and grid intensification) with a mix of residential areas, trade and light industry as well as the existing military base.



scenario 1a　　scenario 1b　　Figure 101



scenario 2a　　scenario 2b　　Figure 102

Accessibility to daily services and facilities, no morphological rule, computed on the road network.

distance functions for scenarios ***1a*** *and* ***2a*** *(daily level)*:

services 0-600m; $\mu(d) = 1$; 600-1,200m, $\mu(d) = 1\text{-}0$;

leisure 0-400m; $\mu(d) = 1$; 400-800m; $\mu(d) = 1\text{-}0$.

distance functions for scenarios ***1b*** *and* ***2b*** *(daily level)*:

services 0-800m; $\mu(d) = 1$; 800-1,600m, $\mu(d) = 1\text{-}0$;

leisure 0-600m; $\mu(d) = 1$; 600-800m; $\mu(d) = 1\text{-}0$.

The scenarios prove that the decision support is flexible enough to be adapted to any urban and metropolitan system. In chapter 9.3. (strategic masterplanning) we will show how Fractalopolis can be combined with other analyses in the context of strategic planning.

3D Visualisation for Accessibility and Morphology

(scenario 1, geo-referenced)

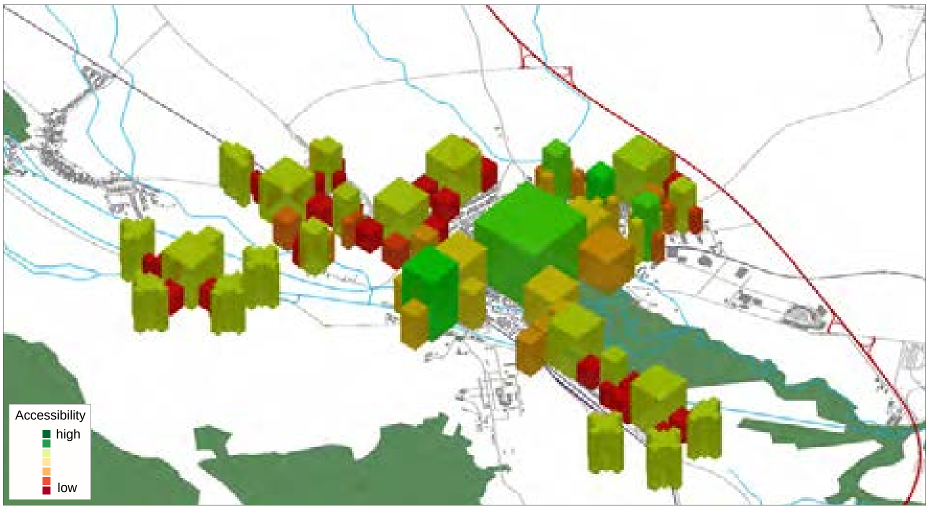


Figure 103

Global accessibility incl. morphological rule (SE-NW view)

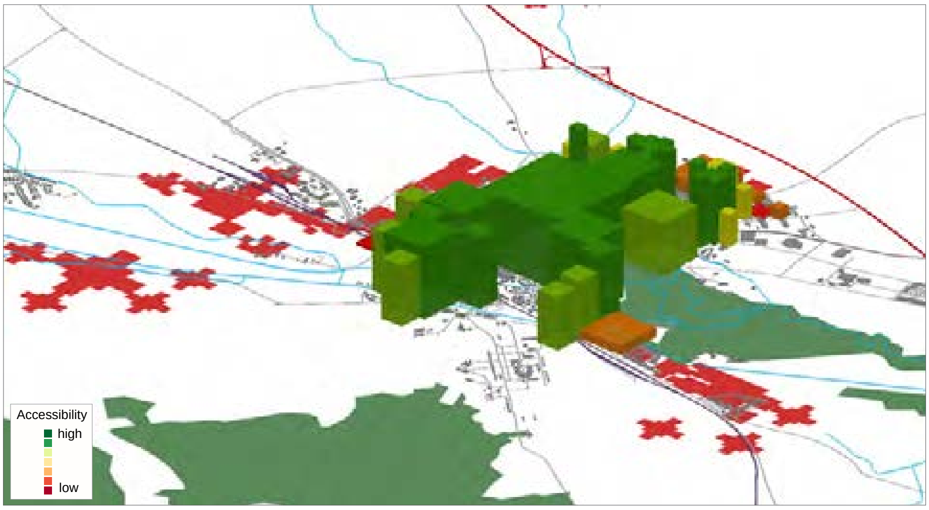


Figure 104a

Accessibility to daily services (SE-NW view)

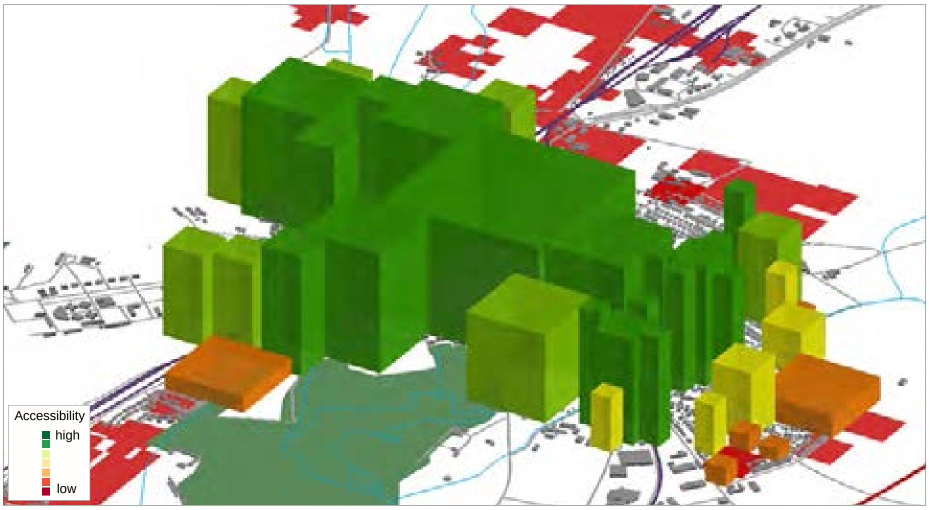


Figure 104b

Accessibility to daily services (NE-W view)

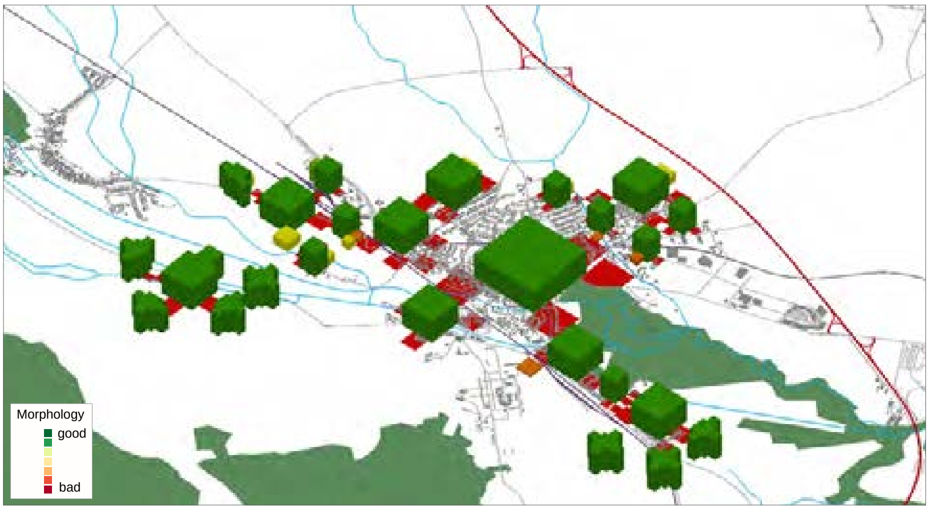


Figure 105a

Morphology rule (SE-NW view)

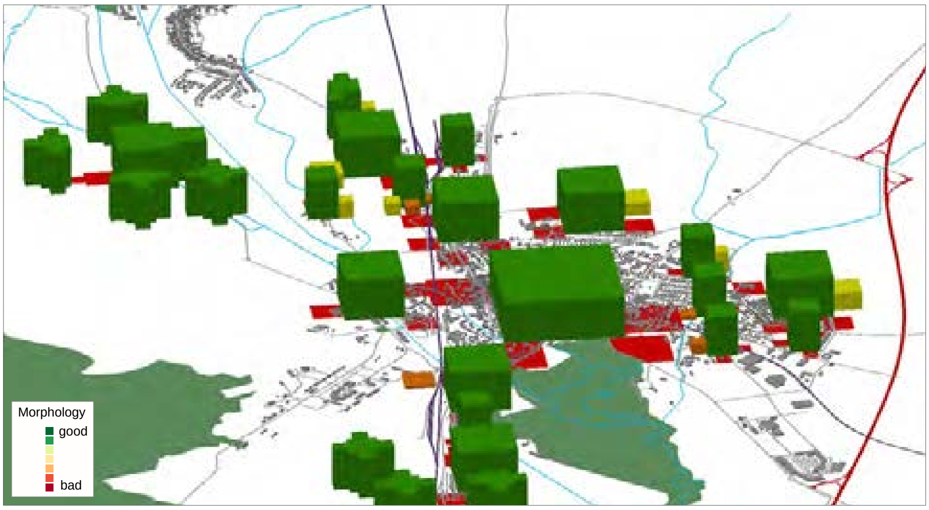
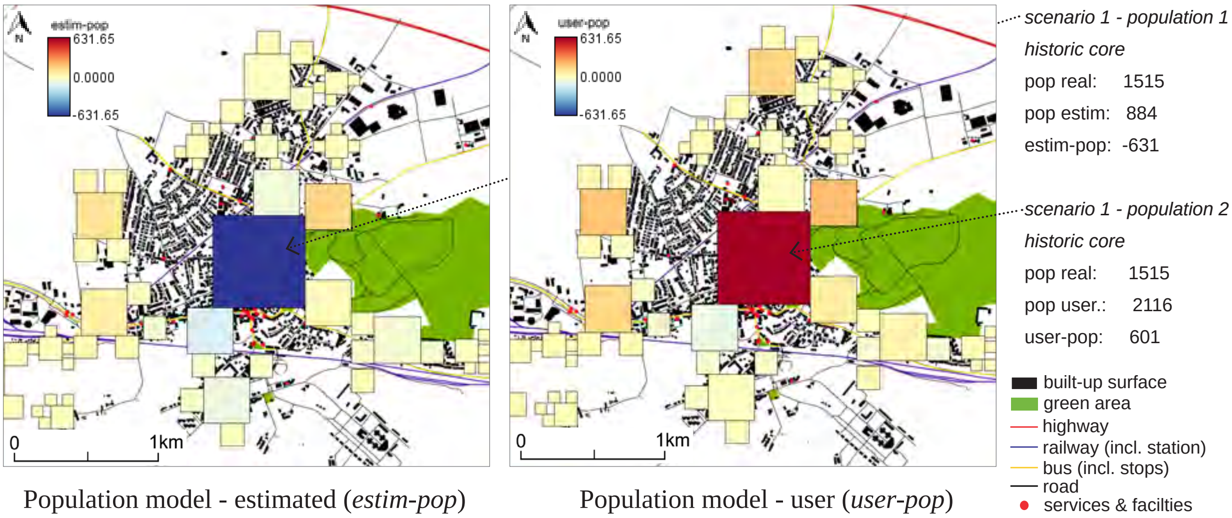


Figure 105b

Morphology rule (E-W view)

Population



Population model - estimated (*estim-pop*)

scenario 1 - population 1

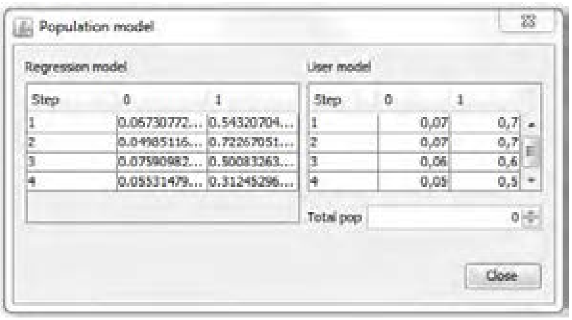
Population model - user (*user-pop*)

scenario 1 - population 2

Figure 106

The empirical population model uses a total population of 14,394 for the Bruck area (wider context; initiator on micro level). By changing the coefficients between the iteration steps the model can be adjusted to a more urban or rural population distribution. The concentrated model is geared to an urban population (above image right).

The population model "estimated" on the left shows the estimated population minus existing population and detects an overpopulation in the historic core (scenario 1- population 1). In contrast, the more concentrated distribution of the population ("user") highlights an underpopulation in the historic core (scenario 1- population 2). It will be recalled that both population scenarios are based on real data for the region (arithmetic mean) and highlight a redistribution by different coefficients (see also population model on macro scale):



3D Visualisation for Population *(geo-referenced)*

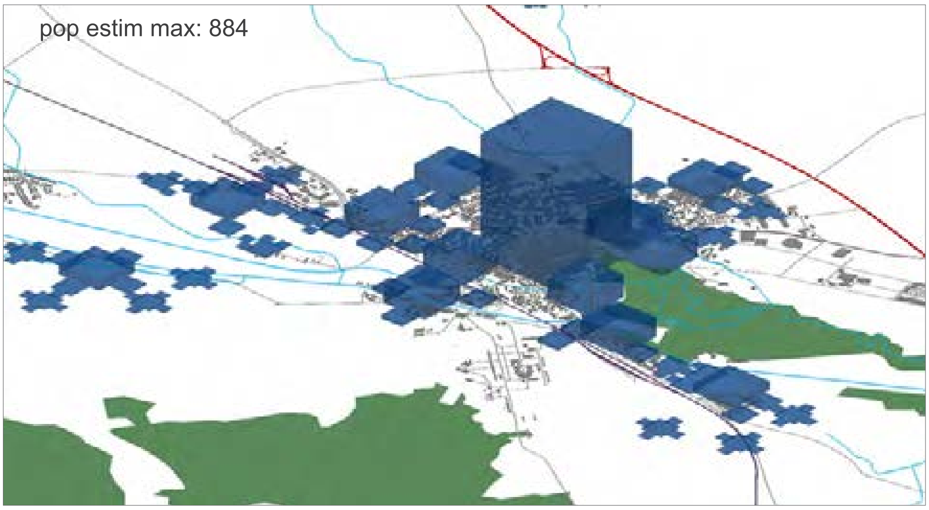


Figure 107a

Population model - *estimated* (scenario 1- population 1)

The visualzation shows the data of the estimated population.

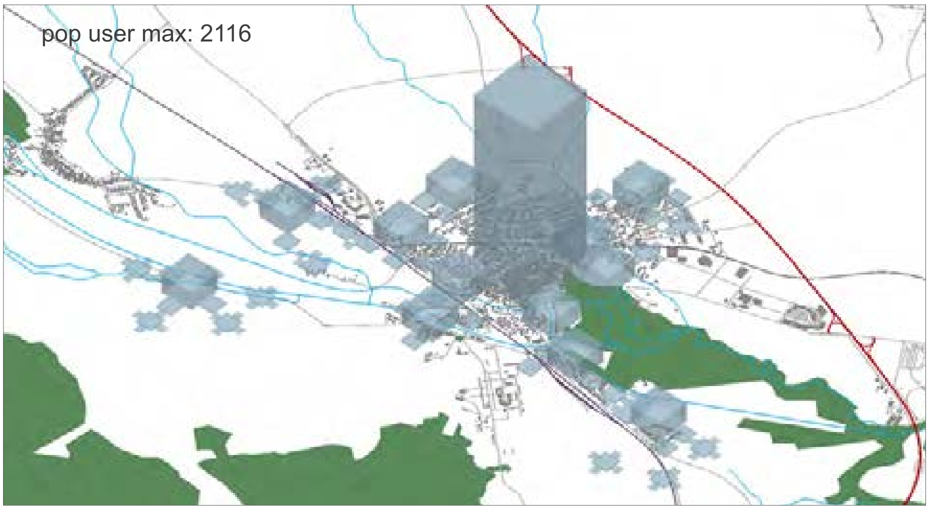


Figure 107b

Population model - *user* (scenario 1- population 2)

The visualzation shows the data of the user population.

8.3. Strategic Masterplanning

In the following we will combine Fractalopolis with strategic masterplanning and 3D visualization for a PSS. We chose two very different scenarios (planning types) in order to test and show the possible use of Fractalopolis software. The two chosen scenarios apply to following planning types:

- Inner development (urban infill) and revitalisation of historic centres
- Grid intensification of residential areas

For developing a local spatial strategy we will use the Space Syntax method combined with VGA (including isovists – serial vision according to Cullen 1961) for wayfinding and orientation, which will further indicate possible permanent or temporary functions and land use such as e.g. shopping, weekly farmer's markets, etc. Finally, 3D visualisations links the core analyses (by way of example).

Masterplanning principles according to Space Syntax[58]

[58] Space Syntax Ltd. London 2008

Spatial Layout – Spatial Layout plays a crucial role in generating sustainable accessible, well-used urban areas – where people want to live, work and spend their leisure time

Through-Movement should be encouraged – The majority of informal space use in urban areas is movement, and that the majority of that movement is through-movement. Therefore, urban areas must be well integrated into the movement network of the surrounding city

Accessibility to the context encourages activity – Improving an urban area thus becomes a process of first understanding its current relationship to the global movement network and then assessing the effects of proposed developments on this relationship. In order to encourage multi-directional through-movement, the primary concern is that the site be accessible to its local and wider urban context. If it is to work well, a site should not turn its back on its context.

Simple and direct visual links make places more accessible – Accessibility is achieved by providing simple and visually direct links with the surrounding urban area. It is essential that proposed developments do not create new obstructions to an area's accessibility, and it is desirable if they can help overcome existing ones.

Too much *permeability* dilutes activity – However, there is a danger of a design, creating too much permeability for an area. Many places fail to work because they have too much permeability. Proposed developments should be fine-tuned to provide a level of permeability appropriate to the level of activity already in the area. The higher the existing levels, the more permeability can be introduced without diluting activities.

Start at the *large scale* then move on to the *local scale* – Once a layout has been achieved that appropriately "stitches" the site into the existing urban fabric, the design focus can then shift to the fine-scale spatial issues of the site. Local design strategies can take advantage of through movement and create locally distinct pieces of the urban fabric through he design of individual routs, spaces, landscaping, signage, street furniture, and individual buildings.

Design *spaces first* and *buildings second* – Trying to work the other way around – designing the individual buildings and expecting them to act as attractors – will not work nearly as well as establishing the large-scale accessibility of the site first and letting it help to shape and form the individual buildings.
Aim for a mixed community of users – Designing a layout that is both globally integrated and locally distinct will bring to the area a mixture of space users – residents, workers, and occasional visitors – and with them an essential ingredient for urban vitality, social cohesion and investment surety.

Design for *movement first* and *stationary activity second* – People construct mental maps of an area by using both perceptual information (what they can see, hear, etc.), and inferences about things they cannot directly perceive. These mental maps then inform route choice plans across the area. They thus also form part of a "way-constructing" and "way-finding" process.

Most of the time people will use spaces that lie on the shortest path towards their seen or unseen destination; minimise directional changes along a journey and avoiding back-tracking; select spaces that offer natural surveillance, such as those with active frontages, and clear indication of use and ownership; select routes which allow them to link into "chain" destinations, and so facilitate multi-purpose journeys. Beside all these factors, the presence or absence of others along the routes or spaces will also affect an individuals' route choice preferences.

In the following we will focus on two scenarios (areas A and C).

8.3.1. Area A: Revitalisation and Consolidation of Bruck's Historic Centre

Aerial satellite image [59]

Fractalopolis - global accessibility excl. morphological rule

Town-wide accessibility - *Centrality* Int N

Town-wide accessibility - *Potential Through Movement* Choice N log [+2]

Figure 108

[59] GeoEye; Google Earth, accessed 14.09.2012; no scale.

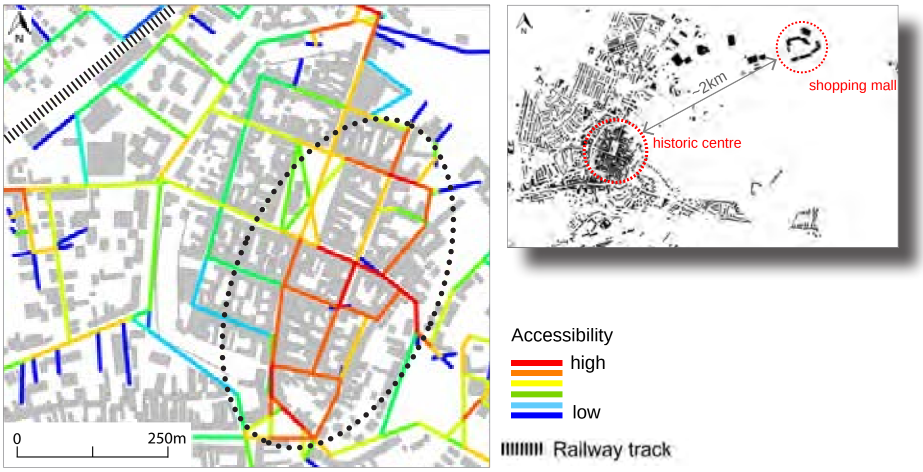
The global accessibility analysis (services and facilties) shows that the historic core has a high potential for revitalisation and consolidation.

The morphological and street network layout will not change as revitalisation and consolidation of the historic centre focuses on the architectural object and not on the urban layout. Centrality and potential through-movement analyses give good results for the shopping street in the historic core –both globally and locally.

We can note, that the urban fabric on a local scale has a higher accessibility evaluation in the eastern quarter of the core. The reason for this can be found in the reason of green amenities like the popular English-style landscaped gardens in close proximity (Harrach Park[60]; access via Prugg Castle) and the

[60] Harrach Park was designed as a Baroque garden at the beginning of th 18th century by Johann Lukas von Hildebrandt. At the end of the 18th century the garden was transformed by Christoph Lübeck (from Anhalt-Dessau, Germany) into an English-style landscaped park which it remains until today.

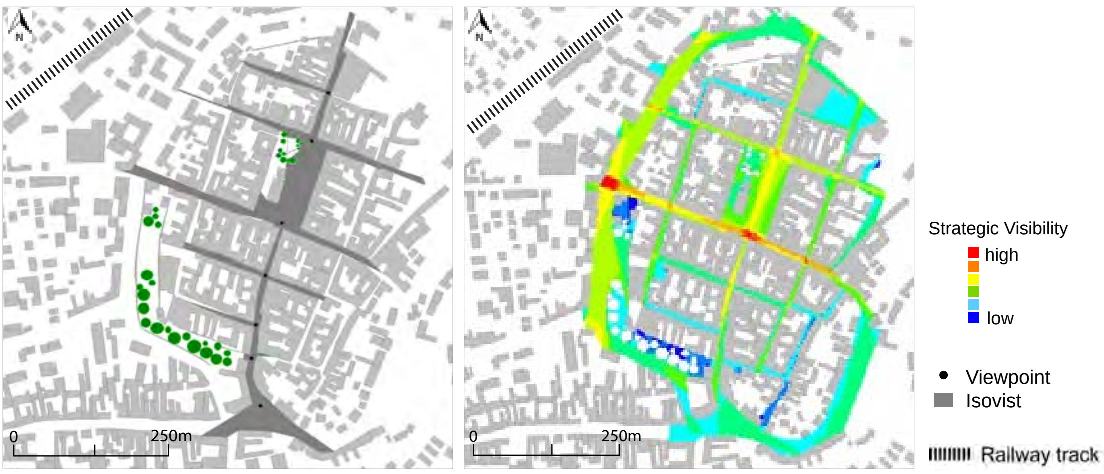
connectivity to the shopping street; both main and sub-centre are connected by a global route. This route acts as the entrance to the shopping street. Town-wide potential through-movement shows the underlying evolved morphological logic from medieval times acting as the main arteries for pedestrian (shopping street) and vehicular movement (area of the former city wall and the former moat).



Local accessibility – Choice 800m [log+2]

Figure 109

The reason for the dysfunctionality of the shopping street is the shopping mall at the periphery of the small town, which detracts from the economic attractiveness of the shopping street. By creating a higher density the attractiveness of the shopping street can be enhanced (e.g. more flats) which will attract more shops.

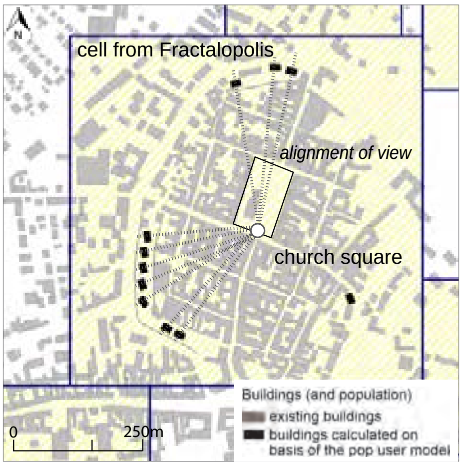


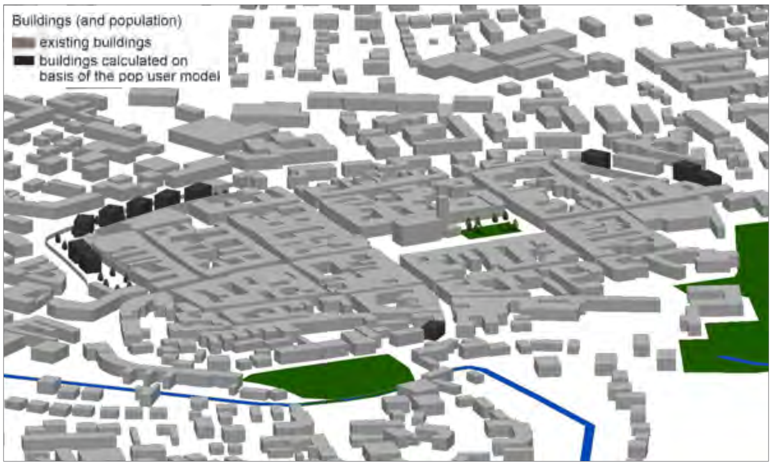
Serial vision (after Cullen)

Visibility graph analysis (VGA) incl. vegetation

Figure 110

The visual links (serial vision, cf. Cullen 1961) provides long, direct links into the subordinated streets from strategic points of the shopping street. This reveals the shopping street as spatial spine. Further, the serial visions detect a strategic cross as also highlichted in the centrality and potential through-movement analyses. This proves the link between orientation, wayfinding, mental mapping and movement (cf. Lynch 1960). The *visual graph analysis* (VGA) model analyses all visible space in the urban street network, taking account of existing vegetation. Generally speaking, vegetation reduces inter-visibility. The effect in our case is detrimental to the overall strategic visibility. High levels of strategic visibility can be found next to the church (crossing point of Kirchengasse and Wiener Gasse) and in direct visibility of the crossing point Wiener Gasse and Raiffeisengürtel (area of the former city wall). This indicates a good potential for stationary activity and social surveillance. Unfortunately, accomodates the crossing point Wiener Gasse/Raiffeisengürtel has no potential for stationary activity as it is a through road for vehicular movement. The historic core has high accessibility to bus stops (200m) and the rail station (400-600m).





Historic core – development scenario (left) and 3D visualization (right)

Figure 111

This development scenario for the historic core is based on the population model (scenario1 - population 2: user-pop = 601 people). The location of additional residential houses (3-4 storeys) provides accomodation for approx. 130-150 households[61] (based on the good access to public transport, daily and weekly services and facilities as well as green open space the developement is ecologically and socially compatible). Focus was to position and align the buildings in such a way that they provide a view to the main church square and its highest strategic point of view (see also strategic visibility analysis) and further to respect the identified potential development area based on the multi-fractal evaluation scenario.

[61] The max. threshold for households is calculated on basis of a family size of 4 people (= 150 households) and 20 m² housing space per person.

The author is aware that the Austrian statistical average is 2.4 persons per household and 30m² (net) per person; for the idea of an inner development (urban infill) the above values/ assumptions were chosen.

The *urban evaluation model* collates the evidence into simple and more complex 3D models/visualization.

Serial vision (after Cullen).

Point isovist

(from high strategic visibility point)

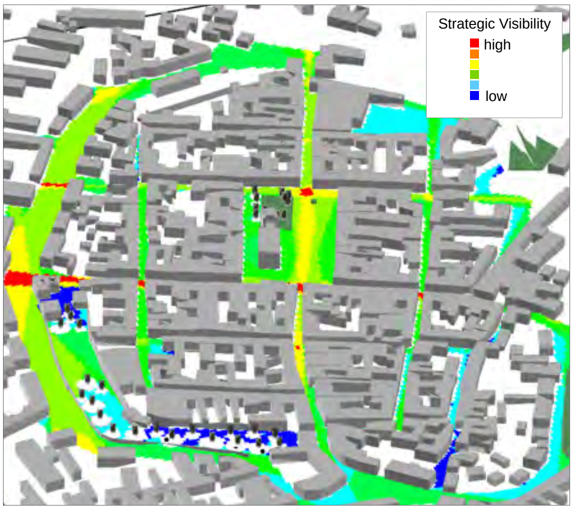


Figure 112

Strategic visibility (VGA)

3D visualizations provide a better understanding of analyses for public and laypersons (support of communication). This can enhance participation processes.

Let us remind that simple and direct visual links will make places more accessible. This is essential in order not to create new obstructions to an area’s accessibility. For the strategic visibility analyses the spots with the highest strategic visibility offer potential for stationary activities and shops. In our case these space are assigned to car transport (through roads). Thus, the possible potential for a pedestrian-friendly environment has not been exhausted.

8.3.2. Area C: Grid Intensification

Aerial satellite image[62]

Fractalopolis - global accessibililty excl. morphological rule

[62]GeoEye; Google Earth, accessed 14.09.2012

Fractalopolis - accessibililty daily facilities

Fractalopolis - accessibililty weekly facilities

Figure 113

The area under scrutiny has good accessibililty to weekly facilities; the access to daily facilties is not evaluated as good in the centre of the mesh; the sub- cell to the north and the neighbouring mesh's sub-cell has a better evaluation. This points to the fact that the main cell including the remainig sub-cells are at the edge of the distance evaluation for daily services (0 - 600m; $\mu(d)$ = 1; 600-1,200m; $\mu(d)$ = 1-0) nor does it fulfil the diversiy criterion (see also Zimmermann-Zysno operator).

The attractiveness of the area can be enhanced with new daily services. For them to be economically viable the area needs a higher density and a pedestrian-friendly well-connected local street network.

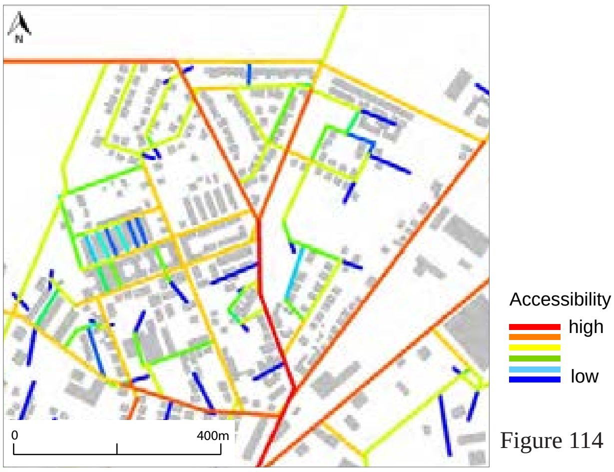


Figure 114

Global accessibility – Choice N [log+2]

The spatial model shows that the area is surrounded with highly accessible roads even while located at the edge of the urban system. Globally it has good accessibility.

Local accessibility -
Choice 800m [log+2] – 10 min. walk

Intermediate accessibility -
Choice 1600m [log+2] – 20 min. walk

Figure 115

In contrast, the local analysis (800m – ten minutes walk) highlights a scattered and inhomogeneous spatial pattern. On an intermediate scale the area starts to “knit back” spatially. The area works well globally, but needs development on a local to intermediate scale – interweaving the local with the global scale to form a sustainable and sustaining well-functioning spatial quarter. The area’s threshold for interventions is equal to or less than 1,600m.

On the basis of the *population model* (scenario 1 - population 2 “user”, p. 265) and in addition an assumed immigration of people for the development structure (respecting the multifractal logic) could be as following (Figure 151).

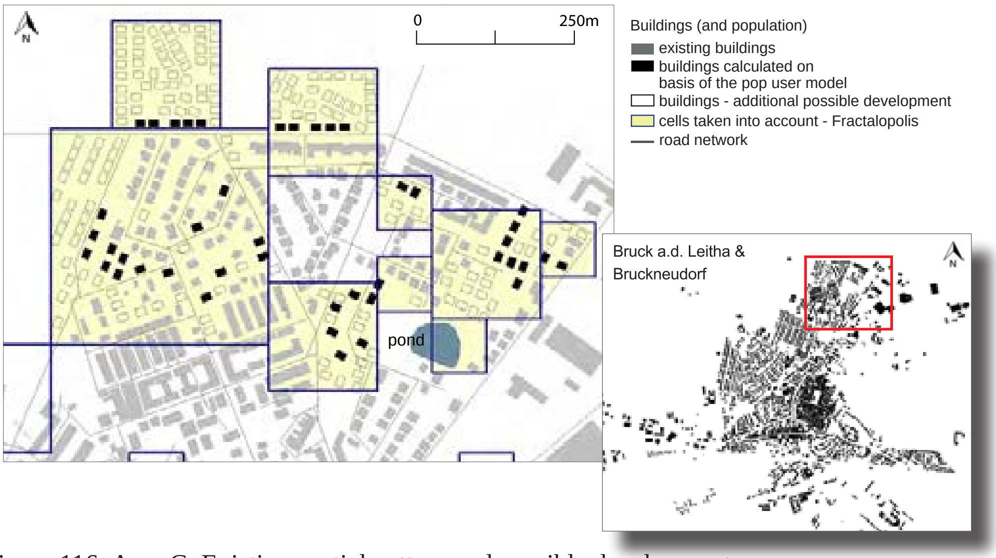


Figure 116: Area C: Existing spatial pattern and possible developments (phasing) by transforming potential cells for urbanisation (with respect to the population model) into buildings . The pond is taken into account as it ensures ecological quality (fauna and flora)

The additional assumption shows that the population model (user pop) in context of the given areas (Fractalopolis cells) remains the possibility for increasing density (concentration of population). The sizes of buildings are based on the exisiting single house typology of this neighbourhood (average family size of 4 persons per household)[63].

[63] Interesting in this context is also the work of Vincent Paillot [A] on transforming proposed cells for urbanisation (using MUP-City software) into realistic buildings according to the local planning agency of Besançon.

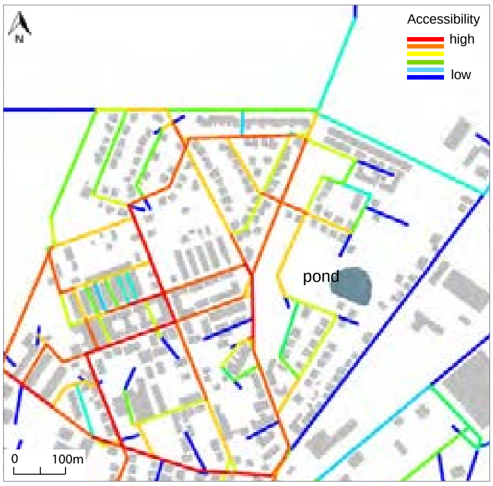
[A] *Étudiant à l‘école d‘architecture de Strasbourg et en stage de 2ème année du cycle conduisant au diplôme d‘état d‘architecte à ThéMA (décembre 2008 – mars 2009).*

The population model and its resulting spatial modifications influences the scenario of *grid intensification* (a) and *additional extension* of the street network (b).

Existing spatial structure

The colour ranges of the analyses are merged in order to allow comparison of the different networks regarding their improvement

Local accessibility – existing
Choice 800m [log+2]

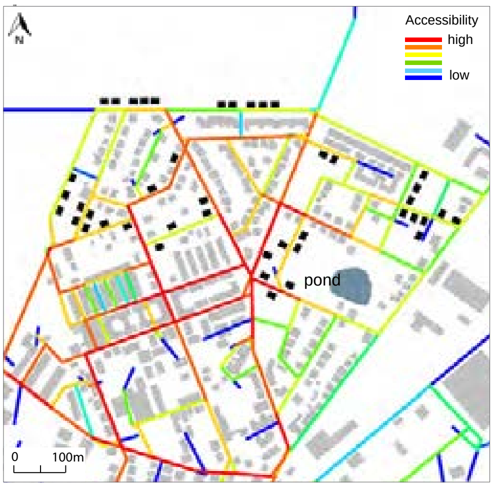


Intermediate accessibility– existing
Choice 1600m [log+2]

Buildings (and population)
existing buildings

Street grid intensification

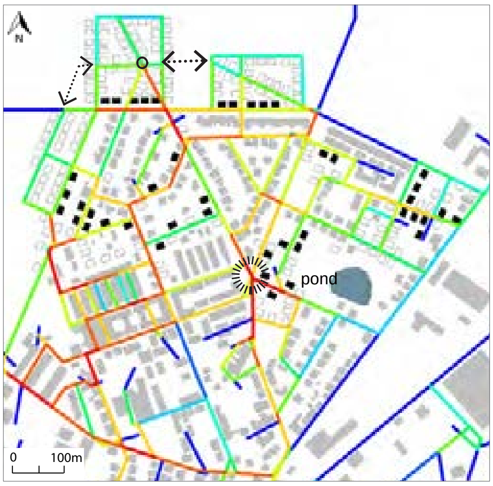
(a) Local accessibility –
Choice 800m [log+2]



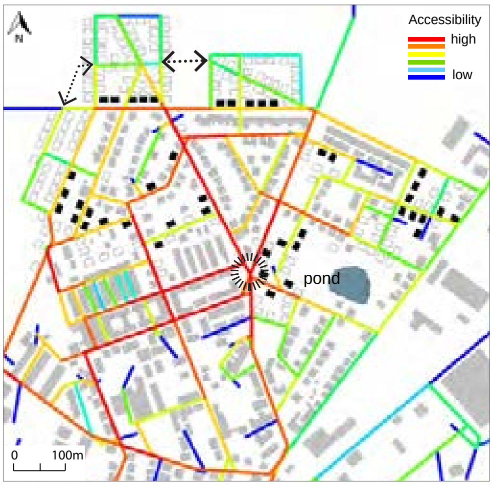
(a) Intermediate accessibility –
Choice 1600m [log+2]

Buildings (and population)
existing buildings
buildings calculated on

Street grid intensification and extension



(b) Local accessibility –
Choice 800m [log+2]



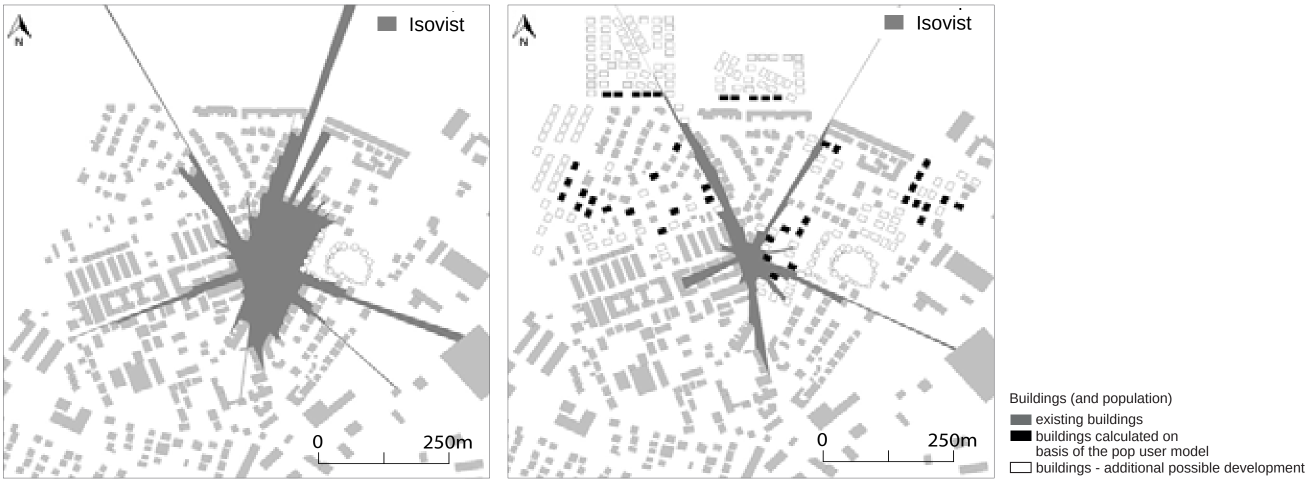
(b) Intermediate accessibility –
Choice 1600m [log+2]

Potential road link
Potential location for shops

Buildings (and population)
existing buildings
buildings calculated on basis of the pop user model
buildings - additional possible development

Figure 117

Grid intensification (even when taking to account landscape areas as the such as the man-made pond) has a major impact on the quality of the network. In our case we used a minimal set of changes.

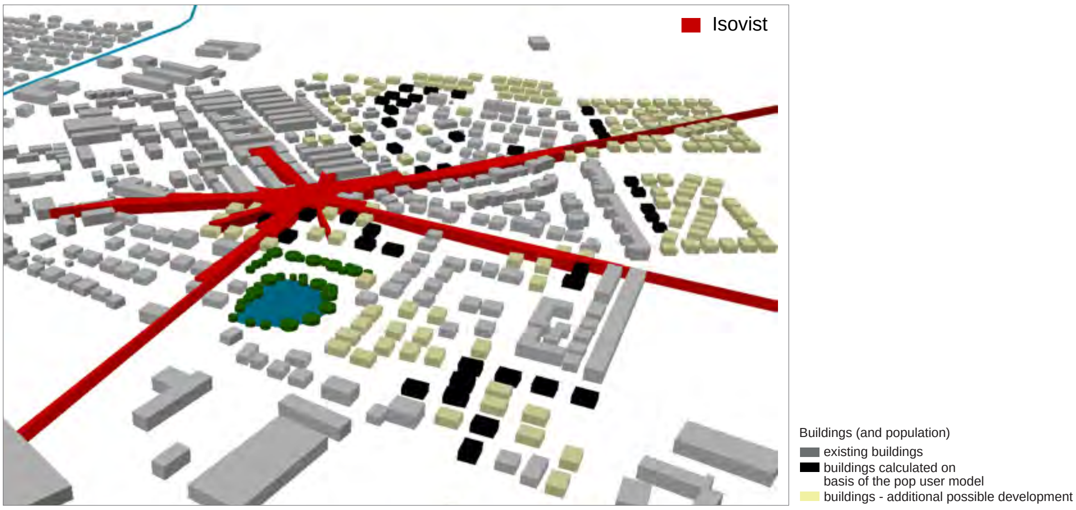


Point isovist (360°) – existing incl. main vegetation

Point isovist (360°) – scenario incl. main vegeration

Figure 118

A higher density in area C provides clear visual links in all directions.



Point isovist – scenario

Figure 119

CHAPTER NINE:

CONCLUSION

9.1. Conclusion and Outlook

In summary, with the multi-scale decision support system Fractalopolis we consider environmental and social compatibility including some social realities (e.g. residential choice criteria such as e.g. living in the countryside, ground rents and individual housing).

Fractalopolis enables to develop scenarios taking into account a sustainable planning approach. It further allowes to validate regional and urban development strategies.
The interactive tool performs consistent through scales (from a regional scale to neighbourhoods). Thus, the development of specific methods such as aggregation and the flexibility (sensitivity) of parameters was important to provide the possibility for the user to adapt the tool any regional and urban system on all scales. It seems that the decision support system can also meet the demand people have in terms of access and frequentation to daily, weekly, monthly, and occassional service and leisure amenities.

The decision support system‘s inherent multi-scale logic works with different sizes of cells within a mesh. On a regional and urban scale it mirrows a stringent hierarchical system of urban systems (cities, towns, villages, hamlets). This is reminiscent to Christaller by introducing an uneven distribution of settlements. On a micro scale it diversify different sized neighbourhoods and on an architectural scale different sizes of buildings.
Continuing, the decision support system offers the possibility to weight and combine different criteria for each level (Oberzentrum, Mittelzentrum, Unterzentrum and Kleinzentrum) on macro and micro scale. From a functional point of view this explicit hierarchical approach allows a a relational link to be made between frequentation of different amenities and the corresponding distances.

In addition, the multi-scale approach incorporates the idea of a radial heterogeneous decreas of density from the centre. This avoids uniformity of areas (intensity of land and plots). Within each mesh, an individuell weight of density can be assigned to each cell (see IFS and population model). For example, cells with a higher density can be placed in close proximity to public transport hubs (e.g. train station).

Further, the introduced population model supports the transformation of potential cells for urbanization to buildings.

The herein developed scenarios and option testing (see further planning support system) have shown that the tool can limit urban sprawl while at the same time avoiding uniform densification. Further, it marries the twin couple of built-up and green open space in a highly efficient manner (morphological rule).
For scenario development Fractalopolis offers both a top-down and bottom-up approach (we start with a top-down approach and can adjust scenarios bottom-up).
The decision support system Fractalopolis can be adjusted to individual spatial and economic situations and thus opens up a spectrum of variants for option testing. This can be done by either:

For option testing only:

- Relocation of cells and meshes
- Change of network (e.g. new network links; this allows to study the topological network properties)
- Implementation of additional facilities and leisure amenities
- Change of population parameters

Further, in combination of system adjustment and option testing:

- Change of accessibility parameters and diversity functions
- Change of weighting and aggregation of services and leisure
- Combination of accessibilities for evaluation
- Consideration or not of morphological rule
- Change of restricted areas

Thus, Fractalopolis allows working on below planning types:

- Inner development (urban infill) and revitalisation
- Peri-urban development
- New developments

Especially, the implementation of new services and facilities close to public transport hubs (e.g. train station) is interesting for inter-urban travels. This is reminiscent to Calthorpe`s Transit Oriented Development model (TOD). In addition, the decision support system takes into cooperation public transport (bus and train lines).
Moreover, the tool allows the assessment of access to green and open space and natural areas (from daily to occasional frequentation). The in addition introduced rule for the “landscape view” (feeding into to the multi-fractal morphological rule) strengthens the idea of an environmental quality assessment. On a local scale it takes into account the idea of different housing types. Introduced restricted zones allow the preservation of non-built up areas.

Following, the herein introduced planning support system (by adding additional GIS based analyses) feeds into a strategic planning approach. The additional Space Syntax analyses support defining the starting point for Fractalopolis on a regional scale and identifying local centres for potential development.
On a local scale Space Syntax`s potential through movement and centrality analyses supports network from a qualitative point of view. Fractalopolis supports a cell based idea of accessibility. It does not take into account the role of the network itself (e.g. new road links can only be evaluated based on the cell but on on the street network segment). Thus, Space Syntax network analyses allows to identify potential locations for new services based on accessibility. This feeds back into an optimisation evaluation which can be carried out by Fractalopolis. In addtion, the strategic visibility, isovists and serial vision analyses support to position possible buildings (retrieved from Fractalopolis‘ population model) in the context of orientation and wayfinding (see cf. simple and direct links) and stationary activties (e.g. outdoor seating for cafés; urban furnitures).

Finally, 3D visualizations work as a communication tool within a planning process between different parties (e.g. lay persons, planners, general public) the communication of different teams.

In general, is Fractalopolis a decision support tool that gives ground to awareness-raising processes in spatial planning by providing the opportunity for option testing. It is meant to support planners and governments in their decision-making processes. In practice, Due to the interactive features of Fractalopolis it can be used for scenario development in team-processes or individually by planners.

Outlook and Ongoing Research

The decision support system Fractalopolis can be enhanced by incorporating economic aspects of ticket prices for bus and train. When developing scenarios, information on land prices can be an useful information.
The rule for the landscape view can be enhanced by introducing the identification of specific housing types blocking the view.
The potential through movement analyis (hierarchy of the street network) can be extended by information on the street network‘s surface as well as traffic census data. It will support information on the usage and importance of specific routes.
A possibility for interactive entries of services and leisure amenities will enhance scenario development on demand within team processes.

Bibliography

ABERCROMBIE P (1944) *Greater London Plan.* HMSO.

AGUILERA A (2005) Growth in commuting distances in French polycentric metropolitan areas: Paris, Lyon, Marseille. In: *Urban Studies* 42(9): 1537-1547.

ALBRECHTS L (2006) Shifts in strategic spatial planning? Some evidence from Europe and Australia. *Environment and Planning A* 38: 1149-1170.

ALBRECHTS L, HEALY P, KUNZMANN K (2003) Strategic spatial planning and regional governance in Europe. *Journal of the American Planning Association* 69: 113-129.

AL-DOURI F A (2010) The impact of 3D modeling function usage on the design content of urban design plans in US cities. *Environment and Planning B: Planning and Design* 37: 75-98.

ALEXANDER C, ISHIKAWA S, et al. (1977) *A Pattern Language*. New York: Oxford University Press.

ALLEN P M (1997) Cities and Regions as Self-Organizing Systems. Models of Complexity. Amsterdam: Gordon and Breach Science Publishers.

ALLEN W, LIU D, SINGER S (1993) *Accessibility measures of U.S. metropolitan areas*, Transport Research B 27B: 439-449.

ALBERTI M (2005) The Effects of Urban Patterns on Ecosystems Function. In: *International Regional Science Review* 28(2): 168-192.

ALONSO W (1964) *Location and Land Use: Towards a General Theory of Land Rent*. Cambridge: Harvard University Press.

ANDRIANI P, Mc KELVEY B (2011), Managing in a Pareto World Calls for New Thinking. *Management* 14(2): 89-117.

APPARICIO P, SEGUIN A (2006) Measuring the accessibility of services and facilties for residents of public housing in Montréal. In: *Urban Studies* 43(1): 187-211.

ARLINGHAUS S (1985) Fractals take a Central Place, *Geografiska Annaler. Series B, Human Geography* 67(2): 83-88.

ARLINGHAUS S, NYSTUEN J (1990) Geometry of Boundary Exchanges. In: *Geographical Review* 80(1): 21-31.

AUERBACH F (1913) Das Gesetz der Bevölkerungskonzentration. *Petermans Mitteilungen* 59(1): 74-76.

BACON E (1967) *Design of Cities*. New York: Viking Penguin Inc.

BÄCKER D (2005) *Schlüsselwerke der Systemtheorie*. Wiesbaden: VS Verlag für Sozialwissenschaften.

BARABÁSI A-L (2001) The physics of the Web. *Physics World* 14: 33-38.

BARABÁSI A-L (2003) *Linked. How Everything is Connected to Everything Else and What It Means for Business, Science, and Everyday Life*. New York: Plume Penguin Group.

BARAN P (1964) On Distributed Communications: I. Introduction to Distributed Communications Networks, RAND Memorandum RM-3420-PR.

BARBOSA O, TRATALOS J A, ARMSWORTH P R et al. (2007) Who benefits from access to green space? A case study from Sheffield, UK. *Landscape and Urban Planning* 83:187-195.

BARNSLEY M (1988) *Fractals Everywhere*. New York: Aacademic Press.

BARTON H (ed) (2000) *Sustainable Communities. The Potential for Eco-Neighbourhoods*. London: Earthscan Publications Ltd.

BARTON H (2005) A health map for urban planners. Towards a conceptual model for healthy sustainable settlements. *Built Environment* 31(4): 339-355.

BATTY M (1998) Urban evolution on the desktop: simulation with the use of extended cellular automata. *Environment and Planning A* 30: 1943-1967.

BATTY M (2001) Exploring isovists fields: space and shape in architectural urban morphology. In: *Environment and Planning B* 28: 123-150.

BATTY M (2005) Agents, cells, and cities: new representational models for simulating multiscale urban dynamics. *Environment and Planning A* 37: 1357-1394.

BATTY M (2003) Planning Support Systems: Technologies that are Driving Planning. In: Geertman S, Stillwell J (eds) *Planning Support Systems in Practice*. Berlin: Springer, v-vii.

BATTY M (2002) Thinking about cities as spatial events. *Environment and Planning B: Planning and Design* 29:1-2.

BATTY M (2005) *Cities and Complexity: Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals*. Cambridge: MIT Press.

BATTY M (2006) Hierarchy in Cities and City Systems. In: PUMAIN D (ed) *Hierarchy in Natural and Social Sciences*. Dordrecht: Springer, 143-168.

BATTY M, LONGLEY P (1994) *Fractal Cities. A Geometry of Form and Function*. London: Academic Press.

BATTY M, LONGLEY P (1986) The fractal simulation of urban structure. In: *Environment and Planning A* 18: 1143-1179.

BATTY M, XIE Y (1996) Preleminary evidence for a theory of the fractal city. In: *Environment and Planning A*: 1745-1762.

BATTY M, XIE Y (1999) Self-organized Criticality and Urban Development. In: *Descrete Dynamics in Nature and Society* 3: 109-124.

BENEDIKT M (1979) To take hold of space: isovists and isovist fields. *Environment and Planning B: Planning and Design* 6: 47-65.

BENGUIGUI L (1995) A fractal analysis of the public transport system of Paris. *Environment and Planning A* 27(7):1147-1161.

BENGUIGUI L, BLUMENFELD E, CZAMANSKI D (2006). The dynamics of the Tel Aviv morphology. *Environment and Planning B* 33: 269-284.

BENGUIGUI L, CZAMANSKI D (2004) Simulation Analysis of the Fractality of Cities. In: *Geographical Analysis* 36(1): 69-84.

BENGUIGUI L, CZAMANSKI D, MARINOV M, PORTUGALI Y (2000) When and where is a city fractal? In: *Environment and Planning B* 27(4): 507-519.

BENGUIGUI L, DAOUD M (1991) Is the suburban railway system a fractal? *Geographical Analysis* 23: 362-368.

BENJAMIN W (1983) *Das Passagen-Werk.* Frankfurt am Main: Suhrkamp.

BERTAUD A (2002) Clearing the Air in Atlanta: Transit and Smarth Growth, or Conventional Economics? *Journal of Urban Economics* 54(3): 379-400.

BIANCONI G, BARABÁSI A-L (2001) Competition and multiscaling in evolving networks. *Europhysics Letters* 54(4), 436-442.

BLEISCH A (2005) Die Erreichbarkeit von Regionen. Ein Benchmarking-Modell, PhD thesis, University of Basel, Switzerland.

BLOTEVOGEL H (1996) Zentrale Orte: Zur Karriere und Krise eines Konzepts in Geographie und Raumplanung. *Erdkunde, Band* 50(1): 9-25.

BLUM H (1967) A Transformation for Extracting New Descriptors of Shape. In: Wathen-Dunn (ed) *Models for the Perception of Speech and Visual Form*. Cambridge: MIT Press, 362-380.

BOBEK H (1969) Die Theorie der zentralen Ort im Industriezeitalter. In: Schöller (ed) (1972) *Wege der Forschung CCCI. Zentralitätsforschung*. Darmstadt: Wissenschaftliche Buchgesellschaft, 165-192.

BOBEK H, FESL M (1978) *Das System der zentralen Orte Österreichs. Eine empirische Untersuchung*. Akademie der Wissenschaften, Wien-Köln: Hermann Böhlhaus Nachf. Verlag.

BOLITZER B, NETUSIL N R (2000) The impact of open spaces on property values in Portland, Oregon. *Journal of Environmental Management* 59: 185-193.

BONAIUTO M, FORNARA F, BONNES M (2003) Index of perceived residential environmental quality and neighbourhood attachement in the urban environment; a confirmatory study on the city of Rome. *Landscape and Urban Planning* 65: 41-52.

BORSDORF A (2004) On the way to post-suburbia? Changing structures in the outskirts of European cities. In: Borsdorf A, Zembri P (eds) (2004) *Cost Action C10. European Cities. Insight on Outskirts - Structures*. Brussels: Blanchard Printing, 7-30.

BORSDORF A (2004) Commercial Areas in the Outskirts of European Cities. In: Borsdorf A, Zembri P (eds) (2004) *Cost Action C10. European Cities. Insight on Outskirts - Structures*, Brussels: Blanchard Printing, 131-148.

BOVILL C (1996) *Fractal Geometry in Architecture and Design.* Boston/Basel/Berlin: Birkhäuser.

BRAMLEY G (2009) Urban form and social sustainability: the role of density and housing type. *Environment and Planning B: Planning and Design* 36: 30-48.

BRAAKSMA JP, COOK WJ (1980) Human orientation in transportation terminals. *Transportation Engineering Journal* 106(TE2): 189-203. Engineering Journal 106(TE2) 189-203

BRAUBACH M (2007) Residential conditions and their impact on residential environment satisfaction and health: results of the WHO large analysis and review of European housing and health status (LARES) study. *International Journal of Environment and Pollution* 30(3/4): 384-403.

BREHENY M (1992) Contradictions of the compact city: a review. In: Breheny M (ed) *Sustainable Development and Urban Form, European Research in Rgional Science 2*, London: Pion, 138-159

BREHENY M (1996) Centrists, ecentrists and Compromisers: Views on the Future of Urban Form. In: JENKS M, BURTON E, WILLLIAMS K (eds) *The Compact City: A Sustainable Urban Form?* London: E & FN Spon, 13-35.

BREHENY M (1997) Urban compaction: feasible and acceptable? *Cities* 14: 209-217.

BRUECKNER J (2000) Urban sprawl: diagnosis and remedies. *International Regional Science Review* 23: 160-171.

BRUN J, FAGNANI J (1994) Lifestyles and locational choices: trade-offs and comprises: a case-study of middle-class couples living in the Ile-de-France region. *Urban Studies* 31: 921-934.

BURTON E (2000) The compact city: just or just compact? In: *Urban Studies* 37(11): 1969-2001.

BRYSON J M (1988) A Strategic Planning Process for Public and Non-profit Organizations. *Long Range Planning* 21(1): 73-81.

BRYSON J M, ROERING W D (1988) Initiation of strategic planning by governments. *Public Administration Review* 48: 995-1004.

CALTHORPE P (1993) *The Next American Metropolis. Ecology, Community and the American Dream*. New York: Princenton Architectural Press.

CALTHORPE P, FULTON W (2001) *The Regional City: planning for the end of sprawl*, Washington DC: Island Press.

CAMAGNI R, GIBELLI M, RIGAMONTI P (2002) Urban mobility and urban form: the social and environmental costs of different patterns of urban expansion. *Ecological Economic* 40: 199-216.

CARLSON R (1962) *Silent Spring*. Boston: Houghton Mifflin Co.

CASPERSEN O, KONIJNENDIJK C et al. (2006) Green space planning and land use: An assessment of urban regional and green structure planning in Greater Copenhagen. *Geografisk Tidsskrift, Danish Journal of Geography* 106(2): 7-20.

CARUSO G, VUIDEL G, CAVAILHÉS J, FRANKHAUSER P, PEETERS D, THOMAS I (2011) Morphological similarities between DBM and a microeconomic model of sprawl. *Journal of Geographical Systems* 13(1): 31-48.

CAVAILHÈS J, FRANKHAUSER P, PEETERS D, THOMAS I (2004) Where Alonso meets Sierpinski: an urban economic model of fractal metropolitan area. *Environment and Planning A* 36: 1471-1498.

CAVAILHÈS J, FRANKHAUSER P, PEETERS D, THOMAS I (2009) Residential equilibrium in a multifractal metropolitan area. Annals of Regional Science 45(3):681-704.

CERVERO R, MURAKAMI J (2010) Effects of built environment on vehicle miles traveled: evidence from 370 US urbanized areas. *Environment and Planning A* 42: 400-418.

CERWENKA P, HAUGER G, HÖRL B, KLAMER M (2007) *Handbuch der Verkehrssystemplanung*. Wien: Österreichischer Kunst- und Kulturverlag.

CHEN Y, ZHOU Y (2003) The rank-size rule and fractal hierarchies of cities: mathematical models and empirical analyses. In: *Environment and Planning B* 30:799-818.

CHEN Y, ZHOU Y (2006) Reinterpreting central place networks using ideas from fractals and self-organized criticality. In: *Environment and Planning B* 33:345-364.

CHEN Y, FENG J (2010) Spatiotemporal evolution of urban form and land-use structure in Hangzhou, China: evidence from fractals. In: *Environment and Planning B* 37:838-856.

CHRISTALLER W (1933) *Die zentralen Orte in Süddeutschland. Eine ökonomisch-geographische Untersuchung über die Gesetzmäßigkeit der Verbreitung und Entwicklung der Siedlungen mit städtischer Funktion*. Jena: Fischer.

CONROY DALTON R (2001) The secret is to follow your nose: route path selection and angular analysis. Proceedings, 3rd International Space Syntax Symposium, Atlanta.7-11 May 2001, 47.1-47.14.

CONWAY T (2009) Local environment impacts of alternative forms of residential development. *Environment and Planning B* 36(5): 927-943.

COOPER J, OSKROCHI R (2008) Fractal analysis of street vistas: a potential tool for assessing levels of visual variety in everyday street scenes. *Environment and Planning B: Planning and Design* 35: 349-363.

CULLEN G (1961) *The Concise Townscape*. New York: Architectural Press.

CZERKAUER C (2006) Space Syntax. Raumkonfigurationen, *Architektur und Bauforum. Zeitschrift für Baukultur* 13: 9-11.

CZERKAUER C (2007) Organizing the City: Morphology and Dynamics. Phenomenology of a Spatial Hierarchy, PhD thesis, Vienna University of Technology.

CZERKAUER C, MERL A D (2006) Sustainable Development, *Architektur und Bauforum. Zeitschrift für Baukultur* 22: 1-2.

CZERKAUER-YAMU C, FRANKHAUSER P (2010) A Multi-scale (Multi-Fractal) Approach for a Systemic Planning Strategy from a Regional to an Architectural Scale, proceedings, International Conference on Urban Planning and Regional Development in the Information Society (Real Corp).Vienna 18-20 May, 17-26.

CZERKAUER-YAMU C, FRANKHAUSER P (2011) A Planning Concept for a Sustainable Development of Metropolitan Areas based on a Multifractal Approach, proceedings, 17th European Colloquium on Quantitative and Theoretical Geography (ECQTG). Athens 2-5 Sept , 107-114.

CZERKAUER-YAMU C, FRANKHAUER P, VUIDEL G, TANNIER C (2011) MUP-City. Multi-Skalare Planung als nachhaltiges Verflechtungsprinzip von bebauten Zonen und Freiraum, *ArchPlus. Zeitschrift für Architektur und Städtebau* 201/202: 28-31.

CZERKAUER-YAMU C, VOIGT A (2011) Strategic Planning and Design with Space Syntax, proceedings, Education and Research in Computer Aided Architectural Design in Europe (eCAADe). Ljubljana 21-24 Sept, 125-133.

CZERKAUER-YAMU C, VOIGT A, FRANKHAUSER P (2012) Spatial Simulation and the Real World. Digital Methods and Techniques in the Context of Strategic Planning. Submitted. University of Cambridge.

DANTZIG G, SAATY T (1973) *Compact city: A plan for a livable urban environment*. San Francisco: W.H. Freeman.

DAVOUDI S (2003) Polycentricity in European spatial planning: from an analytical tool to a normative agenda. *European Planning Studies* 11(8): 979-999.

DE CLERQ E M, DE WULF R, VAN HERZELE A (2006) Relating spatial pattern of forest cover to accessibility. *Landscape and Urban Planning* 80: 14-22.

DE FLORIANI L, MAGILLO P (1994) Visibility Algorithms on Triangulated Digital Terrain Models. *International Journal of Geographic Information Systems* 8(1): 13-41.

DE FLORIANI L, MAGILLO P (2003) Algorithms for visibility computation on terrains: a survey. *Environment and Planning B: Planning and Design* 30: 709-728.

DE KEERSMAECKER M, FRANKHAUSER P, THOMAS I (2003) Using fractal dimensions for characterizing intra-urban diversity. The example of Brussels. *Geographical Analysis* 35(4): 310-328.

DERIX C, GAMLESÆTER Å, CARRANZA P (2008) 3d isovists and spatial sensations: two methods and a case study. In: Report Series of the Transregional Collaborative Research Center SFB/TR 8 Spatial Cognition.
Online: http://aedasresearch.com

DE ROO G, SILVA E A (eds) (2010) *A Planner's Encounter with Complexity*. Farnham (UK)/Burlington (USA): Ashgate.

DESYLLAS J, DUXBURY E (2001) Axial Maps and Visibility Graph Analysis: A Comparison of Their Methodology and Use in Models of Urban Pedestrian Movement, proccedings, 3rd International Space Syntax Symposium, Atlanta 7-21 May, 27.

DUBOIS TAINE G (ed) (2004) *Synthesis. European Cities Insights on Outskirt*s. Cost Action C10. Urban civil engineering.

DUBOIS-TAINE G, CHALAS Y (1998) *La Ville Émergente*.
Chalas, Y. and Dubois-Taine, G. 1998. La ville émergente, La Tour-d'Aigues: Éditions de l'Aube.

DUPUY G (1991) *L'urbanisme des réseaux, théories et méthodes*. Paris: Armand Colin.

DUPUY G (2000) A revised history of network urbanism, *Oase* 53: 3-29.

DUPUY G (1995) *Les Territoires de l'Automobile*. Paris: Anthropos.

EL-GENEIDY A, LEVINSON D M (2006) Access to Destinations: Development of Accessibility Measures. Report 1, Report No. MN/RC-2006-16, National Technical Information Services, Springfield, Virginia 22161.

FASSMANN H (2004) *Stadtgeographie I. Allgemeine Stadtgeographie*. Braunschweig: Westermann.

FASSMANN H, GÖRGL P et al. (2009) *Atlas der wachsenden Stadtregionen*. Materialbandzum Modul 1 des Projekts Strategien zur räumlichen Entwicklung der Ostregion (SRO), Wien: Planungsgemeinschaft Ost (PGO).
www.pgo.wien.at, accessed February 2010.

FEDER J (1988) *Fractals*. New York: Plenum Press.

FELDMAN R M (1990) Settlement-Identity: Psychological Bonds with Home Places in a Mobile Society. *Environment and Behaviour* 22(2): 183-229.

FISHMAN R (1987) *Burgeois Utopias. The Rise and Fall of Suburbia*. New York: Basic Books.

FOUCHIER V (1995) La densification: une comparaison internationale entre politiques contrastées. *Les Annales de la Recherche Urbaine* 67: 95-108.

FRANKHAUSER P (1991) Fraktales Stadtwachstum, *ArchPlus. Zeitschrift für Architektur und Städtebau* 109/110: 85-89.

FRANKHAUSER P (1992) Verzweigungen. Methode und Bedeutung der fraktalen Analyse bei verzweigten Strukturen. In: Sonderforschungsbereich 230, Natürliche Konstruktionen, Heft 4, Universität Stuttgart und Universität Tübingen. Stuttgart: Sprint Druck, 83-99.

FRANKHAUSER P (1994) La Fractalité des Structures Urbaines. Paris: Anthropos.

FRANKHAUSER P (2012) Population model for Fractalopolis, working paper, hal-00758864.

FRANKHAUSER P (1998) The Fractal Approach. A New Tool For The Spatial Analysis Of Urban Agglomerations. Population (Special Issue: New Methodological Approaches in the Social Sciences): 205-240.

FRANKHAUSER P (2004) Comparing in the morphology of urban patterns in Europe – a fractal approach. In: Borsdorf A, Zembri P (eds) (2004) *Cost Action C10. European Cities. Insight on Outskirts - Structures*. Brussels: Blanchard Printing, 79-105.

FRANKHAUSER (2008) Fractal geometry for measuring and modelling urban patterns. In: Albeverio S, Andrey D, Giordano P, Vancheria A (eds) *The Dynamics of Complex Uban Systems - an interdisciplinary approach*. Heidelberg: Springer, 241-243.

FRANKHAUSER P, HOUOT H, TANNIER C et al. (2005) Vers des déplacements péri-urbains plus durables: propositions de modèles fractals opérationnels d'urbanisation. Research program PREDIT, intermediate report, Besancon.

FRANKHAUSER P, HOUOT H, TANNIER C et al. (2007) Vers des déplacements péri-urbains plus durables: propositions de modèles fractals opérationnels d'urbanisation. Research program PREDIT, intermediate report, Besancon.

FRANKHAUSER P, PUMAIN D (2007) Fractals and Geography. In: SANDERS L (ed) M*odels in Spatial Analysis*. London, UK/Newport Beach, USA: Iste Publishing, 281-300.

FRANKHAUSER P, TANNIER C, VUIDEL G et al. (2007) Approche fractale de lúrbanisation. Méthodes d'analyse d'accessibilité et simulations multi-échelles, proceedings, 11th World Conference on Transportation Research, Berkeley, USA.

FRANKHAUSER P, TANNIER C, VUIDEL G, HOUOT H (2010) Une approche multi-échelle pour le développement résidentiel des nouveaux espaces urbain. In: Antonin J-P (ed) *Modéliser la ville. Forme urbaine et politiques de transport*, Economica, Coll. Méthodes et approche, 306-332

FRICK D (2008) *Theorie des Städtebaus. Zur baulich-räumlichen Organisation von Stadt*, 2nd edn. Berlin: Ernst Wasmuth Verlag.

FRIEDMANN J (2004) Strategic planning and the longer range. *Planning Theory and Practice* 5(1): 49-67.

FULTON SURI J (2005) *Thoughtless acts? Observations on Intuitive Design*. San Francisco: Chronicle Books.

GAFFRON P, HUISMANS G, SKALA F (eds) (2005) Ecocity. A better place to live. Research report, European Comission, Key Action 4: City of Tomorrow and Cultural Heritage, 5th Framework Programme RTD Priority 4.4.1.

GAIBAX X (1999) Zipf 's Law for Cities: An Explanation. *The Quartely Journal of Economics* 114(3): 739-767.

GANGLER A, ESEFELD J (2007). *Klaus Humpert. Laufspuren*. Stuttgart: Edition Esefeld & Traub.

GARCIA D, RIERA P (2003) Expansion versus density in Barcelona: a valuation exercise. In: *Urban Studies* 40(10): 1925-1936.

GARREAU J (1991) *Edge City. Life in the new frontier*. New York: Anchor Books.

GAULT B (2007) Les Français et leur habitat - Perception de la densité et des formes d'habitat. Principaux enseignements du sondage réalisé pour l'Observatoire de la Ville. 10-12 January 2007. http://www.observatoiredelaville.com/pdf/Synthesesondage.pdf

GEERTMAN S, STILLWELL J (2004) Planning support systems: an inventory of current practice. *Computers, Environment and Urban Systems* 28: 291-310.

GILL S E, HANDLEY J F, ENNOS A R, PAULEIT S et al. (2008) Characterising the urban environment of UK cities and towns: A template for landscape planning. *Landscape and Urban Planning* 87:210-222.

GIFFINGER R (2007) Smart Cities. Ranking of European medium-sized cities. Research report. Vienna University of Technology/University of Ljubljana/Delft University of Technology. http://www.smart-cities.eu/download/smart_cities_final_report.pdf

GIRARDET H (1992, 1996) *The Gaia Atlas of Cities. New directions for sustainable urban living*. London: Gaia Books Ltd.

GIRARDET H (1999) *Creating Sustainable Cities*. Schumacher Briefings 2. Devon: Green Books Ltd.

GOULD P, WHITE R (1974) *Mental Maps*. London: Routledge.

GORDON P, RICHARDSON H (1997) Are Compact Cities a Desirable Planning Goal? *Journal of the American Planning Association* 63(1): 95-106.

GRANOVETTER M (1973) The Strength of Weak Ties. *American Journal of Sociology* 78:1360-1380.

GREENE M, MORA R, KIRSTEN H, WURMAN D (2007) Finding the Way Back: spatial variables in asymmetric route choice, proceedings, 6th International Space Syntax Symposium. Istanbul 12-15 June, 047-01 – 047-12.

GUO J, BHAT C (2002) Residential Location Modeling: Accommodating Sociodemographic, School Quality and Accessibility Effects. Department of Civil Engineering, University of Texas. Austin.

GÜNEY Y (2007) Analyzing Visibility Structures in Turkish Domestic Spaces, proceedings, 6th International Space Syntax Symposium. Istanbul 12-15 June, 038-01–038-12.

GUSKI R (2000) *Wahrnehmung: Eine Einführung in die Psychologie der menschlichen Informationsaufnahme*. Stuttgart: Kohlhammer

HÄGERSTRAND T (1967) *Innovation diffusion as a spatial process*. Chicago: University of Chicago Press.

HAKEN H (1982) *Synergetik*. Berlin/Heidelberg/New York: Springer.

HAKEN H (1986) The maximum entropy principle for non-equilibrium phase transitions: Determination of order parameters, slaved modes, and emerging patterns. *The European Physical Journal* 63(4): 487-491.

HALL P (1980) *Great Planning Disasters*. Berkley: University of California Press.

HALL P, WARD C (1998) *Sociable cities. The legacy of Ebenezer Howard*. Chichester: John Wiley & Sons.

HANSEN W (1959) How accessibility shapes land use. In: *Journal of the American Institute of Planners* 25: 73-76.

HEALEY P (1997) An institutionalist approach to spatial planning. In: Healey P, Khakee A, Motte A, Needham B (eds) *Making Strategic Spatial Plans: Innovation in Europe*. London: UCL Press, 21-36.

HEALEY P (2004) The treatment of space and place in new strategic spatial planning in Europe. International Journal of Urban and Regional Research 28: 45-67.

HILLIER B (1994) Space as a Material, Paper to the conference of the Association Internationale de Semiotique de l'Espace at Berkeley, 12-18 June.

HILLIER B (1996) Space is the machine. A configurational theory of architecture. Cambridge: Cambridge University Press.

HILLIER B (1999) Centrality As A Process – accounting for attraction inequalities in deformed grids, proccedings, 2nd Space Syntax International Symposia Brasilia: March/April.

HILLIER B (2003) The knowledge that shapes the city: the human city beneath the social city, proceedings, 4th International Space Syntax Symposium. London 17-19 June, 01.1-01.20.

HILLIER B (2005) The art and the science of space In: *World Architecture* 1 (Special issue on Space Syntax): 24-34 (in Chinese); 96-102 (in English).

HILLIER B (accessed 2006) The lesson of the unexpected: basic research in architecture and urban design and why it matter. Intranet: Space Syntax Ltd.

HILLIER B (2009) Spatial Sustainability in Cities. Organic Patterns and Sustainable Forms, keynote paper-proceedings, 7th International Space Syntax Symposium, Stockholm: 8-11 June, K01:1-K01:20.

HILLIER B (2012) Studying cities to learn about minds: some possible implications of space syntax for spatial cognition. *Environment and Planning B: Planning and Design* 39: 12-32.

HILLIER B, GREENE, M et al. (2000) Self-generated Neighbourhoods: the role of urban form in consolidation of infomal setlements. *Urban Design International* 5: 61-96.

HILLIER B (1984) Übersetzung: Haferkorn C. Die Stadt neu gesehen. Syntax des Raums. Abschrift ILPÖ, *Baumeister* 12: 28-35.

HILLIER B, HANSON J (1984) *The social logic of space*. Cambridge: Cambridge University Press.

HILLIER B, IIDA S (2004) The human's shortes path is angular not metric. Space Syntax Ltd., Bartlett School of Graduates, University of London, UK. Working paper, London.

HILLIER B, PENN A et al. (1993) Natural Movement: Or Configuration and Attraction in Urban Pedestrian Movement. *Environment and Planning B: Planning and Design* 20: 29-66.

HILLIER B, PENN A (2004) Rejoinder to Carlo Ratti. *Environment and Planning B: Planning and Design* 31:501-511.

HILLIER B, STONOR T (2010) Space Syntax - Strategic Urban Design. *Future of Urban Space and Humanity* (Special Issue), City Planning Institute of Japan, 25 June 2010; http://www.cpij.or.jp (accessed June 2012).

HUMPERT K (1997) *Einführung in den Städtebau*. Stuttgart/Berlin/Köln: Kohlhammer Verlag.

HOWARD E (1902) *Garden Cities of To-Morrow.* London. Reprinted (1946). London: Faber and Faber.

HUANG B, JIANG B, HUI L (2001) An integration of GIS, virtual reality, and the Internet for visualization, analysis and exploration of spatial data. *International Journal of Geographical Information Science* 15: 439-459.

JACOBS J (1961) *The Death and Life of Great American Cities*. London: Penguin Books.
THOMAS I, FRANKAHAUSER P, BADARIOTTI (2012) Comparing the fractality of European urban neighbourhoods: do national context matter? In: *Journal of Geographical Systems* 14:189-208.
THOMAS I, FRANKAHAUSER P, BIERNACKI C (2008a) The morphology of built-up landscapes in Wallonia (Belgium): A classification using fractal indices. In: *Landscape and Urban Planning* 84: 99–115.
THOMAS I, FRANKHAUSER P, De KEERSMAECKER M (2007) Fractal dimension versus density of the built-up surfaces in the periphery of Brussels.In: *Papers in Regional Science*, 86(2): 287-307.
THOMAS I, TANNIER C, FRANKHAUSER P (2008b) Is there a link between fractal dimension and residential environment at a regional level? In: *Cybergeo: European Journal of Geography*, 413: Online.
JAN O, HOROWITZ A, PENG Z (2000) Using Global Positioning System Data to Understand Variations in Path Choice. *Transportation Research Record 1725* (TRB). Washington D.C.: National Research Council, 37-44.
JENKS M, BURTON E, WILLLIAMS K (1996) *The Compact City: A Sustainable Urban Form?* London: E & FN Spon.
JOHNSON N F (2007) *Simply Complexity. A clear guide to complexity theory*. Oxford: Oneworld Publications.
JOHNSEN S (2001) *Emergence*. London: Penguin Press.
JORDAN D P (1995) *Transforming Paris. The Life and Labors of Baron Haussmann*. New York/London/Sydney/Tokyo/Singapore: The Free Press.
JORGENSEN J (2004) Copenhagen – Evolution of the finger structure. In: Dubois-Taine, G. (Hg.) 2004: *From Helsinki to Nicosia. Eleven Case Studies & Synthesis – Insights on Outskirts*. Paris, 187-198.
KARIMI K (1997) Continuity and Change in Old Cities. An Analytical Investigation of the Spatial Structure in Iranian and English Historic Cities before and after Modernisation, PhD thesis, University College London.
KAUFFMAN S (1995) *At Home In The Universe. The Search for Laws of Self-Organization and Complexity.* Oxford: Oxford University Press.
KAUFMAN J, HARVEY JACOBS (1996) A Public Planning Perspective on Strategic Planning. In: Campell S, Fainstein S (eds) *Readings in Planning Theory*. Cambridge (MA): Blackwell (reprint of 1987 article).
KIM, BENGUIGUI, MARINOV (2003) The fractal structure of Seoul‘s public transportation system. *Cities* 20(1):31-39.

KLOSTERMAN R E (2008) A New Tool for a New Planning: The What if? Planning Support System. In: Brail R K (ed) *Planning Support Systems for Cities and Regions*. New Hampshire: Puritan Press, 85-99.

KNAUFF M, RAU R, SCHLIEDER C, STRUBE G (1997) Analogizität und Perspektive in räumlichen mentalen Modellen. In: Grabski M, Hörnig R (eds) Perspektive in Sprache und Raum. Wiesbaden: Deutscher Universitätsverlag, 35-60.

KOSTOF S (1991) *The City Shaped. Urban Patterns and Meanings Through History*. London: Thames & Hudson.

KREUKELS A (2000) An institutional analysis of strategic spatial planning: the case of federal urban policies in Germany. In: Salet W, Faludi A (eds) *The Revival of Strategic Spatial Planning*. Amsterdam: Royal Netherlands Academy of Arts and Sciences, 53-56.

KRÜGER M J T (1979) An approach to built-form connectivity at an urban scale: system description and its representation. *Environment and Planning B 6*: 67-88.

KRUGMAN P (1996) *The Self-Organizing Economy*. Malden/Oxford:Blackwell Publishers Ltd.

LAHTI P (2004) Traditional and New Models Explaining Urban and Regional Form Change. Case Helsinki. In: Borsdorf A, Zembri P (eds): Structures: European Cities Insights on Outskirts. COST Action 10. Paris, 31-48.

LAMBOOY J (1969) City and city region in the perspective of hierarchy and complementarity. *Tijdschrift voor Economische en Sociale Geografie* (TESG), May/June: 141-154.

LANE D (2006) Hierarchy, Complexity, Society. In: PUMAIN D (ed) *Hierarchy in Natural and Social Sciences*. Dordrecht: Springer, 81-119.

LANG R (2003) *Edgless cities: exploring the elusive metropolis*. Washington DC: Brookings Institution Press.

LANG R E, LE FURGY J (2007) Boomburbs. The Rise of America’s Accidental Cities. Washington D.C.: Brookings Institution Press.

LEVINSON D M, KUMAR A (1994) The rational locator: Why travel times have remained stable. *Journal of the American Planning Association* 60: 319-332.

LICHTENBERGER E (1991) *Stadtgeographie. Begriffe, Konzepte, Modelle, Prozesse*. Stuttgart: Teubner.

LÖSCH A (1940) *Die Räumliche Ordnung der Wirtschaft*. Jena: Fischer.

LOHRBERG F (2001) Stadtnahe Landwirtschaft in der Stadt- und Freiraumplanung. In: *WechselWirkungen*. Jahrbuch der Universität Stuttgart.

LUHMANN N (2004) *Einführung in die Systemtheorie*. Heidelber: Carl-Auer.

LYNCH K (1960) *The Image of the City*. Cambridge: MIT Press.

LYNCH K (1981, 1984) *Good City Form*. Cambridge: MIT Press.

MACH I (2010) Vom Teehaus zum Themenpark. Rauminszenierung in der Japanischen Architektur, PhD thesis, Vienna University of Technology.

MANDELBROT B (1977,1982) *The Fractal Geometry of Nature*. New York: W.H. Freeman and Company.

MARCUS L (2007) Spatial Capital and How to Measure it: An Outline of an Analytical Theory of the Social Performativity of Urban Form, proceedings, 6th International Space Syntax Symposium, Istanbul: 12-15 June, 005.1-005.12.

MARKELIN A, FAHLE B (1979) *Umweltsituation. Sensorische Simulation im Städtebau*. Schriftenreihe des Städtebaulichen Instituts der Universität Stuttgart 11. Stuttgart: Karl Krämer Verlag.

MARSHALL S (2005) *Streets and Patterns: The Structure of Urban Geometry*. London/New York: Spon Press.

MASTOP H, FALUDI A (1997) Evaluation of strategic plan: the performance principle. *Environment and Planning B: Planning and Design* 24: 815-822.

HILLMAN M (1996) In Favour of the Compact City. In: Jenks M, Burton E, Williams K (eds) *Compact City. A sustainable Form?* London: E & FN Spon, 36-65.

MAYERHOFER R, WALCHHOFER HP, VOIGT A, LINZER H (2009) Resourceneffiziente Bebauungsstrukturen und Stadtgestalt. In: Voigt A, Walchhofer H P (eds) *IFOER Schriftenreihe Nr. 7*. Fachbereich für Örtliche Raumplanung. Technische Universität Wien. Wien: Österreichischer Kunst- und Kulturverlag.

MEADOWS D H, MEADOWS D L, RANDERS J, BEHRENS W (1972). *The Limits to Growth*. Translation: (2009) Die Grenzen des Wachstum (3. edition). Stuttgart: Hirzel.

MERL A D (2005) Bau-Ressourcenmanagement in urbanen Räumen. Fallstudie Wien. PhD thesis. Vienna University of Technology.

MINTZBERG H (1994) *The Rise and Fall of Strategic Planning*. New York: The Free Press.

MINTZBERG H (2002) Five Ps for strategy. In: Mintzberg H, Lampel J, Quinn J B et al. (eds) *The Strategy Process: Concepts, Contexts, Cases*. Englewood Cliffs (New Jersey): Prentice-Hall, 3-9.

MONTELLO D R (1991) Spatial Orientation and the Angularity of Urban Routes: A Field Study. *Environment and Behaviour* 23(1): 47-69.

MORELLO E, RATTI C (2009) A digital image of the city: 3D isovists in Lynch's urban analysis. *Environment and Planning B: Planning and Design* 36: 837-853.

MORENO SIERRA D L (2009) Une approche réseau pour l'intégration de la morphologie urbaine dans la modélisation spatiale individu-centrée, Unpublished doctoral dissertation, Université de Pau et des Pays de l'Adour.

MORRIS J M, DUMBLE P L, WIGAN M R (1979) Accessibility indicators for transport planning. *Transportation Research A* 13: 91-109.

NEWMAN P, KENWORTHY J (1989) *Cities and Automobile Dependence: An International Sourcebook*. Brookfiel: Gower Publishing.

NEWMAN P, KENWORTHY J (1999) *Sustainability and Cities. Overcoming Automobile Dependence*. Washington D.C.: Island Press.

PEITGEN H-O, JÜRGENS H, SAUPE D (2004, 1992) *Chaos and Fractals. New Frontiers of Science*. New York: Springer.

PENN A, HILLIER B, BANISTER D, XU J (1998) Configurational modelling of urban movement networks. *Environment and Planning B: Planning and Design* 25(1): 59-84.

PERSSON B (2005) Sustainable City of Tomorrow. Bo01 - Experiences of a Swedish Housing Exposition. *Formas*, Stockholm, 7-18.

PICHLER G, PUCHINGER K (2006) *Zentralität und Standortplanung der öffentlichen Hand.* ÖROK Schriftenreihe 172. Wien: Eigenverlag.

PIETSCH S M (2000) Computer visualization in the design control of urban environments: a literature review. *Environment and Planning B: Planning and Design* 27: 521-536.

PORTUGALI J, BENENSON I (1995) Artificial planning experience by means of a heuristic cell-space model: simulating international migration in the urban process. *Environment and Planning A* 27: 1647-1665.

POISTER T H, STREIB G (1999) Elements of Strategic Planning and Management in Municipal Government: Status after Two Decades. *Public Administration Review* 65(1): 45-56.

PRIGOGINE I (1980) Zeit, Entropie und der Evolutionsbegriff in der Physik. In: *Mannheimer Forum. Ein Panorama der Naturwissenschaften* 80/81. Mannheim: Boehringer Mannheim & Hofmann und Campe Verlag, 9-44.

PUMAIN D (1997) Pour une théorie évolutive des villes. *Espace géographique* 26(2): 119-134.

PUMAIN D (1997) City size distribution and metropolisation. *GeoJournal* 43(4): 307-314.

PUMAIN D (ed) (2006) *Hierarchy in Natural and Social Sciences*. Dordrecht: Springer.

PUMAIN D (2006) Alternative Explanations of Hierarchical Differentiation in Urban Systems. In: PUMAIN D (ed) *Hierarchy in Natural and Social Sciences. Dordrecht*: Springer, 169-222.

PUMAIN D (2011) Scalability and the future of cities: a multi-level approach. lecture, University College London, 4 October. http://www.ucl.ac.uk/gis/files/London11_dp.pdf

PUMAIN D, TANNIER C (2005) Fractals in urban Geography: a theoretical outline and empirical example. *Cybergeo* 307: pp. 22.

RATTI C (2005) The lineage of the line: space syntax parameters from the analysis of urban DEMs. *Environment and Planning B: Planning and Design* 32: 547-566.

RAFORD N (2010) Social and Technical Challenges to the Adoption of Space Syntax Methodologoes as a Planning Support Syste (PSS) in American Urban Design. *The Journal of Space Syntax* 1(1): 230-245.

READ S (2000) The grain of space in time: the spatial/functional inheritance of Amsterdam‘s centre. *Urban Design International* 5: 209-220.

READ S (1999) Space Syntax and the Dutch City. *Environment and Planning B: Planning and Design* 26(2): 251-264.

READ S (2000) Space, Movement and Scale in the Dutch City. Space Lab TU Delft, accessed: 24/11/2012 www.spacelab.tudelft.nl/papers.html.

READ S (2006) The Form of the City. SpaceLab TU Delft, accessed: 24/11/2012 www.spacelab.tudelft.nl/papers.html.

REINER R, MUNZ M, HAAG G, WEIDLICH W (1986) Chaotic evolution of migratory systems. *Sistemi Urbani* 2/3: 285-308.

RÖMMLING U (2001) Ökologische Bausteine bei Städtebau-/ Hochbauwettbewerben - Der Baustein Energie. Institut für Erhaltung und Modernisierung von Bauwerken, Vortrag: Oktober 2001, TU Berlin.

ROSE A, SCHWANDER C, CZERKAUER C et al. (2008) Space Matters. *ArchPlus. Zeitschrift für Architektur und Städtebau* 189: 32-37.

ROSE A, STONOR T (2009) Syntax - Urbane Erreichbarkeitsplanung. In: Christ W (ed) *Access for All. Zugänge zur gebauten Umwelt.* Basel/Boston/ Berlin: Birkhäuser, 78-93.

ROGER R (1997) *Cities for a small planet*. London: Faber and Faber.

ROGERS R (1999) *Towards an Urban Renaissance. Final Report of the Urban Task Force*. London: Spon Press.

ROGERS R, POWER A (2000) *Cities for a small country*. London: Faber and Faber.

ROUPÉ M, JOHFANSSON M (2010) Supporting 3D City Modelling, Collaboration and Maintenance Through An Open-Source Revision Control System. In Dave B, Li A I, Park H-J (eds) *New Frontiers. Proceedings of the 15th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2010*, 347-356.

SADALLA E K, MAGEL S G (1980) The perception of traversed distance. *Environment and Behavior* 12: 65–79.

SALINGAROS N (1998) Theory of the urban web. *Journal of Urban Design* 4, 53-71.

SALINGAROS N (2000) The structure of the pattern languages. *Architectural Research Quarterly* 4, 149-161.

SALINGAROS N (2001) Remarks on a City's Composition. *Yhteiskuntasuunnittelu – The Finnish Journal of Urban Studies* 39: 68-76.

SALINGAROS N (2003) Connecting the Fractal City, Keynote Speech, 5th Biennial of towns and town planners in Europe, Barcelona, April 2003.

SALINGAROS (2005) *Principles of Urban Structure*. Delft: Techne Press.

SALINGAROS (2010) *Twelve Lectures on Architecture – Algorithmic Sustainable Design*. Solingen: Umbau Verlag.

SCHEDIWY R (2005) *Städtebilder. Reflexionen zum Wandel in Architektur und Urbanistik*. 2.Auflage. Wien: LIT Verlag.

SCHÖLLER P (ed) (1972) *Wege der Forschung CCCI. Zentralitätsforschung*. Darmstadt: Wissenschaftliche Buchgesellschaft.

SCHOLL B (1995) *Aktionsplanung. Zur Behandlung komplexer Schwerpunktsaufgaben in der Raumplanung*. Zürich: VDF-Verlag.

SCHOLL B (2005) Strategische Planung. In: Akademie für Raumforschung und Landesplanung (ed) *Handwörterbuch der Raumordnung*. Hannover: Verlag der ARL, 1122-11229.

SCHÖNWANDT W (1999) Grundriss einer Planungstheorie der "dritten Generation". *DISP - The Planning Review* (ETH Zürich) 136/137: 25-34.

SCHÖNWANDT W (2008) *Planning in Crises?Theoretical Orientations for Architecture and Planning*. Hampshire, UK/Burlington, USA: Ashgate Publishing Limited.

SCHÖNWANDT W, VOIGT A (2005) Planungsansätze. In: Akademie für Raumforschung und Landesplanung (ed) Handwörterbuch der Raumordnung. Hannover: Verlag der ARL, 769-776

SCHWANEN T, DIJST M, DIELEMAN F M (2004) Policies for Urban Form and their Impact on Travel: The Netherlands Experience. *Urban Studies* 41(3): 579-603.

SHEN G (2002) Fractal dimension and fractal growth of urbanized areas. *International Journal of Geographical Information Science* 16(5): 437–519.

SHEPPARD S R J (1989) *Visual Simulation. A User's Guide for Architects, Engineers and Planners*. New York: Van Nostrand Reinhold.

SHIFFER M J (1995) Interactive multimedia planning support: moving from stand-alone systems to the World Wide Web. *Environment and Planning B: Planning and Design* 22(6): 649-664.

SIEVERTS T (1997) *Zwischenstadt. Zwischen Ort und Welt, Raum und Zeit, Stadt und Land.* Basel/Boston/Berlin: Birkhäuser.

SPACE SYNTAX Ltd. (2008)

STEAD D (2001) Transport Intensity in Europe - Indicators and Trends. *Transport Policy* 8(1): 29-46.

STEAD D (2002) Urban-rural relationships in the West of England. *Built Environment* 28(4): 299-310.

STEAD D, MARSHALL S (2001) The relationships between Urban Form and Travel Patterns. An international Review and Evaluation. *European Journal of Transport and Infrastructure Research* 1(2): 113-141.

STROGATZ S (2009) Math and the City. *The New York Times (Opinionator)*, 19 May. http://opinionator.blogs.nytimes.com/category/steven-strogatz/

TANDY C R V (1967) The isovist method of landscape survey. In: Murry H C (ed) *Methods of Landscape Analysis*. London: Landscape Research Group.

TANNIER C, PUMAIN D (2005) Fractals in urban geography. *Cybergeo* 307.

TANNIER C, VUIDEL G, FRANKHAUSER P, HOUOT H (2010) Simulation fractale d'urbanisation - MUP-city, un modèle multi-échelle pour localiser de nouvelles implantations résidentielles. *Revue internationale de géomatique* 20(3):303-329.

TANNIER C, VUIDEL G, HOUOT H, FRANKHAUSER P (2012) Spatial accessibility to amenities in fractal and nonfractal urban patterns. *Environment and Planning B: Planning and Design* 39(5): 801-819.

THOMAS L, COUSINS W (1996) The Compact City: A Sucessful, Desireable and Achievable Urban Form? In: Jenks M, Burton E, Williams K (eds) *Compact City. A sustainable Form?* London: E & FN Spon, 53-73.

THOMAS I (2010) Clustering patterns of urban built-up areas with curves of fractal scaling behaviour. *Environment and Planning B: Planning and Design* 37(5): 942-954.

THOMAS I, FRANKHAUSER P, BADARIOTTI D (2010) Comparing the fractality of European urban neighbourhoods: do national contexts matter? *Journal of Geographical Systems*:1-20. doi:10.1007/s10109-010-0142-4 Key: citeulike:8337387

THOMAS I, FRANKHAUSER P, BIERMACKI C (2008) The morphology of built-up landscapes in Wallonia, Belgium: a classification using fractal indices. *Landscape and Urban Planning* 84:99-115.

THOMAS I, FRANKHAUSER P, DE KEERSMAECKER ML (2007) Fractal dimensions versus density of built-up surfaces in the periphery of Brussels. *Papers in Regional Science* 86(2):287-308.

THOMAS I, TANNIER C, FRANKHAUSER P (2008) Is there a link between fractal dimension and residential choice at a regional level? *Cybergeo* paper 413.

TOFFOLI T, MARGOLUS N (1987) *Cellular Automata Machines: A New Environment for Modeling*. Cambridge (MA): MIT Press.

TURING A M (1952) The Chemical Basis of Morphogenesis. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 237(641): 37-72.

TURNER A (2000) Angular Analysis. A Method for the Quantification of Space. London, Centre for Advanced Spatial Analysis: 17.

TURNER A (2001) Angular Analysis. 3rd International Symposium on Space Syntax, proccedings, Georgia Insitute of Technology, 7-11 May 2001, 1-13.

TURNER A (2007) From axial to road-centre lines: new representation for space syntax and a new model of route choice for transport network analysis. *Environment and Planning B: Planning and Design* 34(3) 539-555.

TURNER A, DOXA M, O´SULLIVAN D, PENN A (2001) From isovists to visibility graphs: a methodology for the analysis of architectural space. *Environment and Planning B: Planning and Design* 28: 103-121.

VAN NES A (2007) Centrality and economic development in the Rijnland region. In: Bruyns G, Van Nes A, Pinilla C, Rocco R, Rosemann H J (eds) *The 5th City*. Delft: Internation Forum on Urbanism. TU Delft.

VON NEUMANN J (1951) The general and logical theory of automata. In: Jeffress L (ed) *Cerebral Mechanisms in Behaviour - The Hixon Symposium*. New York: John Wiley & Sons, 1-31.

VAN TONDER G J (2007) Recovery of visual structure in illustrated Japanese gardens. Pattern Recognition Letters Special Issue: *Pattern Recognition in Cultural Heritage and Medical Applications* 28(6): 728-739.

VAN TONDER G J LYONS M J (2005) Visual perception in Japanese rock garden design. *Axiomathes Special Issue: Design and Cognition* 15(3): 353-371.

VAN TONDER G J, LYONS M J, EJIMA Y (2002) Visual Structure of a Japanese Zen Garden. *Nature* 419: 359-360.

VISWANATHAN G M, BARTUMEUS F, BULDYREV S et al. (2002) Levy flight random searches in biological phenomena. *Physica A* 314:208.213.

VOGT C A, MARANS R W (2003) Natural resources and open space in the residential decision process: a study of recent movers to fringe counties in southeast Michigan. *Landscape and Urban Planning* 69:255-269.

VOIGT A (2005) *Raumbezogene Simulation und Örtliche Raumplanung. Wege zu einem (stadt-)raumbezogenen Qualitätsmanagement*. Wien: Österreichischer Kunst- und Kulturverlag.

VOIGT A (2011) Stadtraum-Simulationslabor TU Wien [SRL:SIM]. In: Fakultät für Architektur und Raumplanung (ed) *Stadt: Gestalten. Festschrift für Klaus Semsroth*. Wien/New York: Springer, 175-180.

VOIGT A (2012) The Planning World Meets the Life World. In: International Doctoral College "Spatial Research Lab" (ed): *Spatial Research Lab. The Logbook*. JOVIS, 120-127.

VOIGT A, WÖSSNER U, KIEFERLE J (2009) Urban-spatial Experiments with Digital City Models in a Multi-dimensional VR-Simulation Environment (Urban Experimental Lab, proceedings, SIGraDI 2009, 13th Congress of the Iberoamerican Society of Digital Graphics, Sao Paulo: 16-18 Nov, 144-146.

VON THÜNEN J H (1826) *Der isolierte Staat in Beziehung auf Landwirtschaft und Nationalökonomie*. Hamburg: Perthes.

WATTS D J (1999) *Small Worlds*. Princeton (NJ): Princeton University Press.

WATTS D J, STROGATZ S H (1998) Collective dynamics of "small-world" networks. *Nature* 393(6684) 440-2.

WEIDLICH W, HAAG G (1987) A Dynamic Phase Transition Model For Spatial Agglomeration Processes. *Journal of Regional Science* 27(4): 529-569

WHITE R, ENGELEN G (1993) Fractal urban land use patterns: a cellular automata approach. *Environment and Planning A* 25:1175-1199.

WIENER M J, FRANZ G (2005) Isovists as a Means to Predict Spatial Experience and Behaviour. In: FREKSA C et al (eds) *Spatial Cognition*. Berlin/Heidelberg: Springer, 42-57.

WIENER N, MANDERLBROJT S (1947) Sur les fonctions indefiniment derivables sur une demi-droite. *C. R. Acad. Sci. Paris* 225: 978- 980. Math. Rev. 9 (1948), 230.

WIENER N (1976) *Collected Works - Vol. 1: Mathematical Philosophy and Foundations: Potential Theory: Brownian Movement, Wiener Integrals, Ergodic and Chaos Theories, Turbulence and Statistical Mechanics.* Masani P (ed). Cambridge (Mass): MIT Press.

YEH A (2008) GIS as a Planning Support System for the Planning of Harmonious Cities Harmonious Cities. *UN Habitat Lecture Award Seri*es 3:1-23.

WRIGHT F L (1940) The new frontier: Broadacre City, *Taliesin* 1, entire issue.

ZEMBRI P, HUHDANMAKI A (2004) Transport Network Structures and Outskirts of European Cities. In: Borsdorf A, Zembri P (eds) (2004) *Cost Action C10. European Cities. Insight on Outskirts - Structures*. Brussels: Blanchard Printing, 107-128.

ZIPF G K (1941) *National unity and disunity*. Bloomington (Indiana): Principa Press.

ZIPF G K (1949) *Human behaviour and the principle of least effort*. Cambridge: Addison-Wesley Press.

List of Figures
List of Tables and Diagrams
List of Maps

List of Figures

All figures, diagrams, tables and maps not providing an author's source are from the author of this research and thus in her ownership and copyright.

List of Tables and Diagrams

List of Maps