MASTERARBEIT

Master Thesis

Multi-Scale Planning Using the MUP-City Software
- The Klosterneuburg Case -

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Univ.Ass. Dipl.-Ing. DDr. Claudia Czerkauer-Yamu
E280, Arbeitsbereich "Räumliche Simulation und Modellbildung"

Prof. DDr. Pierre Frankhauser
Universités de Franche-Comté et de Bourgogne

eingereicht an der Technischen Universität Wien
Fakultät für Architektur und Raumplanung von

submitted at Vienna University of Technology
Faculty of Architecture and Planning by

Iris Flamm

0640882

Sochařská 356/13, 170 00 Praha

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Deutsche Kurzfassung

Im Rahmen der Masterarbeit wurde betrachtet, wie die Software MUP-City in der Stadtentwicklung eingesetzt werden kann. Konkret wurde untersucht, wie bestehende Siedlungsstrukturen und ihre Vernetzungen mit Grünräumen und unterschiedlichen Annehmlichkeiten in Kleinstädten, welche sich in der Peripherie von Großstädten befinden, mittels der Software analysiert werden können. Weiters wurde evaluiert, ob und wie MUP-City Planer sinnvoll bei der Entwicklung von Szenarios und dem Testen unterschiedlicher Optionen hinsichtlich zukünftiger nachhaltiger Entwicklungen untersützen kann um Konzepte, Planungsvorschläge und Entscheidungen zuständiger Behörden beispielsweise gegenüber Laien wissenschaftlich und gleichzeitig verständlich begründen zu können.

Theoretischer Hintergrund

Der erste Teil der Arbeit befasst sich mit den theoretischen Hintergründen, welche zum Verständnis der Funktionsweise der Software und der Prinzipien auf welchen sie basiert beitragen soll. Beginnend beim Thema Nachhaltigkeit wird die Rolle der Stadt zur Erreichung dieser ausgeführt (Newman & Kenworthy 1999, Frick 2008, Anderberg 2012). Besonderes Augenmerk wird hierbei auf die Bedeutung von Grünräumen, urbanen Transportmodi und Erreichbarkeit gelegt (Lichtenberger 1986, Newman & Kenworthy 1999, Cerwenka et al. 2007, Cadenasso & Pickett 2011, Pauleit et al. 2011, Nuissl & Siedentop 2012, Snep & Clergeau 2012). Davon abgeleitet werden Urban Villages als eine mögliche Strategie für nachhaltige Städte vorgestellt (Newman & Kenworthy 1999, Cadenasso & Pickett 2011, Nuissl & Siedentop 2012). Multiskalare Planung greift die Prinzipien dieses Konzeptes auf und überträgt sie auch in mathematische Ausdrücke. Komplexität und Selbstorganisation spielen hierbei ebenso eine Rolle wie das Konzept der Zentralen Orte (Lichtenberger 1986, Batty & Longley 1994, Portugali 2000 & 2009, Batty 2005, Newman 2009). Eine einleitende Übersicht über Fraktale und fraktale Städte (Mandelbrot 1991, Salingaros 2005) bildet schließlich den Übergang zur Erklärung der Funktionsweise von MUP-City. Die Software basiert auf verschiedenen Prinzipien welche zuvor als nachhaltig identifiziert wurden: Vermeidung von Fragmentierung des bebauten und des unbebauten Raumes, Verminderung der Anzahl und Länge der Fahrten mit Autos bei gleichzeitiger Sicherstellung hoher Erreichbarkeit von verschiedenen Annehmlichkeiten, und die Minimierung des Flächenverbrauchs (Tannier et al. 2010, Czerkauer-Yamu & Frankhauser 2011).

Praktische Anwendung

Im zweiten Teil wird die praktische Anwendung der MUP-City Software am Beispiel der Stadt Klosterneuburg getestet. Dieser Teil beginnt mit einer kurzen Vorstellung der Stadt (Fink 1992, Wonka 2011), der Bedeutung ihrer Lage zwischen Wienerwald und Donautal, sowie ihrer historischen und geplanten zukünftigen Entwicklung. Anschließend wird

erläutert, wie die Daten zur Verwendung in MUP-City aufbereitet wurden. Schließlich wurden zwei Szenarios entwickelt. Zunächst wurde der gegenwärtige Zustand der Stadt in Hinblick auf Erreichbarkeit verschiedener Annehmlichkeiten und möglicher künftiger Bebauung analysiert und dabei die Funktionsweise der Software kennengelernt. Nachdem verschiedene Annahmen über Änderungen an den Ausgangsdaten und ihre Auswirkungen auf die Analyse getestet wurden, wurden als zweites phasenweise Szenarios für den Stadtteil Weidling entwickelt wobei während beider Entwicklungsphasen eine zufriedenstellende Erreichbarkeit aller Annehmlichkeiten gegeben sein sollte.

Conclusio

Während für Klosterneuburg, und den Stadtteil Weidling im Speziellen, keine neuen und überraschende Erkenntnisse hinsichtlich der künftigen Siedlungsentwicklung gewonnen wurden, so konnte mit Hilfe von MUP-City grafisch dargestellt werden, wieso das aktuelle lokale und regionale Entwicklungskonzept als nachhaltig (in Bezug auf die oben genannten Nachhaltigkeits-Prinzipien) bezeichnet werden kann und welche Areale daher für die künftige Bebauung zu bevorzugen sind. Konkret bedeutet dies für Weidling das Schließen bestehender Baulücken und Ansiedeln von Einrichtungen des täglichen Bedarfs in bisher unterversorgten Gebieten. Dieses Ergebnis ist größtenteils der Topografie geschuldet, welche die Eignung von Flächen für künftige Bebauung limitiert. Andere Einschränkungen entstehen aus der bereits relativ starken Fragmentierung des Raumes durch Bauten im Grünland sowie durch Schwierigkeiten der Erreichbarkeit mit öffentlichen Verkehrsmitteln bestimmter Gebiete.

Im Rahmen der Arbeit konnte daher ermittelt werden, dass die Software geeignet ist, um in kleinen Städten in der Peripherie von Großstädten zur Unterstützung nachhaltiger Entwicklung eingesetzt zu werden. Besondere Stärken sind hierbei die einfache Verständlichkeit der grafischen Darstellung auch für Laien sowie die starke wissenschaftliche Grundlage.

English Summary

In the course of the master thesis the application of the decision support software MUP-City was evaluated. It has been tested if and how the software can be used to evaluate current settlement structures and their access to open green space as well as amenities in small towns that are in the periphery of big cities. It has also been evaluated if and how the software can support planners in the process of developing scenarios and testing different options for future sustainable development in order to support concepts, proposals and decisions by competent authorities for instance towards lay people.

Theoretical Background

The first part of the thesis covers the theoretical background that leads to a better understanding of the functioning of the software and the principles it is based on. It is started with the subject of sustainability and the importance of cities in achieving it (Newman & Kenworthy 1999, Frick 2008, Anderberg 2012). Focus is on the significance of open green space, urban transport modes and accessibility (Lichtenberger 1986, Newman & Kenworthy 1999, Cerwenka et al. 2007, Cadenasso & Pickett 2011, Pauleit et al. 2011, Nuissl & Siedentop 2012, Snep & Clergeau 2012). Based on this, the concept of urban villages as one strategy for sustainable cities is briefly introduced (Newman & Kenworthy 1999, Cadenasso & Pickett 2011, Nuissl & Siedentop 2012). Multi-scale planning takes up the underlying principles and translates them into mathematical expressions. Hereby the topics of complexity and self-organisation as well as the concept of central places, and possible models and their benefits of and for cities are further explained (Lichtenberger 1986, Batty & Longley 1994, Portugali 2000 & 2009, Batty 2005, Newman 2009). An introduction to fractals and fractal cities (Mandelbrot 1991, Salingaros 2005) then leads to more detailed explanations on how the software MUP-City works and how it is used. The software is based on different principles that have previously been identified as sustainable: avoidance of fragmentation of built-up and open space, minimisation of the number and length of travels by car and ensuring high accessibility of rural and urban amenities as well as limitation of land consumption (Tannier et al. 2010, Czerkauer-Yamu & Frankhauser 2011).

Practical Application

In the second part, the practical application of MUP-City is explained at the example of Klosterneuburg. It is started with a short introduction of the city (Fink 1992, Wonka 2011), its natural setting and significance between Vienna Woods and Danube Valley and its historical as well as planned future development. Afterwards the data preparation is explained, including the use of the open source software QGIS and publicly available data as well as data provided by the municipality of Klosterneuburg. Finally scenarios are developed. The first one analyses the existing state of the town in terms of the accessibility of different amenities and future urbanisation. It serves the purpose to get to know

the software. After verifying assumptions concerning the alteration of the source data and its effect on the analysis, it is then a phasing scenario developed. For this, the part of Klosterneuburg called Weidling is developed in two steps with the goal to provide good accessibility to amenities during the entire process.

Conclusion

While there were no new or surprising findings concerning the future settlement development, the software helped visualising why the current local and regional development concept can be regarded as sustainable in regards of the sustainability principles that were mentioned before and which areas are to be preferred for future development. For Weidling this means closing gaps in the settlement fabric and the introduction of amenities of daily frequency in areas that are currently lacking them. This result is mainly caused by the topography which limits the areas that are suitable for future development. Other limitations occur due to the already rather high fragmentation of built-up and open space due to buildings in open green space as well as due to the difficulty of reaching certain areas by public transport.

In the course of the thesis it was determined that the MUP-City software is suitable to be used for sustainable development in small towns in the periphery of large cities. Particular strengths include the comprehensibility of the visual figures, also for lay people, and the strong scientific basis.

Extended Summary

A main goal of urban planning is to formulate plans and concepts for the development of cities that require few resources and ensure high quality of living for their citizens with the aim of achieving sustainable settlements. One of the main challenges is to decide on land use zoning and building development. To help with these questions, various analysis and evaluation techniques have been developed. In recent years, computer based tools have gained in importance.

Spatial modelling and simulation software can be used in various planning and design processes. They can be used as awareness raising and communication tools as well as to support decisions in terms of developing and sustaining spatial qualities (cf. Voigt 2011). One of these tools is the computer based decision support system *MUP-City*, which is examined in the thesis.

MUP-City is short for “Multi-scale Urban Planning for a Sustainable City” and can be used to simulate and visualise scenarios for development, consolidation and shrinking. It follows the logic of fractal settlement development as counter-proposal to compact settlement structures (cf. Czerkauer-Yamu et al. 2011). Main objectives of the software are to find suitable areas for urbanisation, consolidation or shrinking that allow for a reduction of number and length of car travels and a high accessibility of shops and services, open green areas, and close proximity to existing roads (cf. Tannier et al. 2010a/b).

In the course of the thesis it is examined how MUP-City can be applied to support proposals for sustainable settlement structures and development in small towns in the periphery of large cities. As area under scrutiny the municipality of Klosterneuburg was chosen. This town is suitable for testing the software as it lies just North of Vienna but is clearly distinguishable from this and other surrounding towns. Its size allows the thorough collecting and preparation of data while staying comprehensible.

Two hypotheses were to be verified:

I *MUP-City can be used to evaluate current settlement structures and access to open green space and amenities of small towns in the periphery of big cities.*

II *MUP-City can support planners to develop scenarios and test different options for future sustainable development to support concepts, proposals and decisions by competent authorities for instance towards lay people.*

Scope of Research and Methodology

In the first part of the thesis the theoretical background is covered to allow a better understanding of the functioning of MUP-City. It includes the general goal of sustainability in planning and characteristics of sustainable cities that are greatly influenced by open green

space as well as the choice of transport mode in the city. Developed from this are favourable urban forms and the concept of urban villages as one sustainable strategy. After this, multi-scale planning is recommended as a sustainable planning approach, introducing topics of self-organisation and complexity, fractals and finally how findings in these fields are used in MUP-City.

The second part of the thesis focuses on possible applications of MUP-City for the municipality of Klosterneuburg in Lower Austria. Klosterneuburg is introduced to the reader by describing the municipality's topographic and natural setting as well as its historical and planned future development.

For the scenario development with MUP-City it is necessary to create GIS files that contain all amenities in the area under scrutiny, including public transport stops, buildings, existing street network and undevelopable areas. The data gathering and processing, for which open source applications and publicly available data are used as well as data that was made available by the building and planning department of the municipality of Klosterneuburg, is explained in detail in the beginning of the fifth chapter. With the help of MUP-City the accessibility of amenities on different scales is then examined. It is used to identify suitable areas for sustainable future development and for interactively developing scenarios for a selected area within the town.

A total of two scenarios are being developed for Klosterneuburg:

1. <u>Existing State:</u> The visualisation of the existing state shows the overall supply and accessibility of different amenities and identifies areas that are potentially under-supplied with specific amenities. It is also shown which areas are suitable for further urbanisation without altering existing amenities.

2. <u>Development of Weidling:</u> It is analysed how the introduction of certain amenities in particular areas affects the accessibility of amenities on the different scales and how this in turn alters the suitability for urbanisation of cells. The goal is to develop phasing scenarios in which all parts of Weidling have sufficient access to different kinds of amenities during multiple steps of the development.

Finally, the outcomes of the scenario development and option testing are evaluated in the third part of this thesis. The conclusion involves a discussion on MUP-City and its outcomes for Klosterneuburg, and outlook for this software.

In the following, the discussed subjects are summarised in order to give the reader an overview of the contents.

I Theoretical Background

As mentioned before, this chapter serves the purpose of providing a better understanding of the MUP-City software, the sustainability principles it is based on and its functioning.

1. Sustainability as General Objective in Spatial Planning

Sustainability is a central objective in urban and regional planning. A widely accepted definition of it is the long-term and extensive securing of liveability and productivity in social, economical and ecological terms while using mostly renewable resources (cf. Frick 2008). Cities have been recognised to have an important role in achieving and maintaining sustainability on a global scale due to their size. Reducing waste and pollution, and conserving natural resources while at the same time increasing liveability are main aspects of creating sustainable cities (cf. Newman & Kenworthy 1999).

2. Challenges and Opportunities of the Sustainable City

Amongst others, challenges that have to be tackled in order to achieve sustainability are urban open green space and modes of transport. Planning measures that regulate urban form and structure can influence both.

2.1. Open Green Space

Cities are complex socio-bioecological systems as there is constant interaction between urban and rural areas as well as between the various sub-systems (cf. Cadenasso & Picket 2011). Open green space has many positive effects on the city, some of them being the regulation of the heat-island effect, binding of air pollution, absorption of water and aesthetic appealing to people (cf. Nuissl & Siedentop 2012, Pauleit et al. 2011, Cadenasso & Picket 2011). In order to cater for the increasing number of people living in cities and benefiting from the positive effects of open green space, the appropriate ratio and configuration of built-up and open space has to be found (cf. Snep & Clergeau 2012).

When dealing with the question of what areas to urbanise, it has to be taken into account that cities act as barriers and open green space can only develop the full potential of benefits for the city if it is continuous. The Metapopulation Theory explains that in fragmented landscapes local populations have to be linked together in order to create larger metapopulations which are more likely to persist. But interconnected green space and consistency through different scales does not only allow animal and plant species to migrate, it also increases the degree of accessibility by the citizens who use open green space for various activities. Radial city forms that have so-called green wedges, which can lead as far as to the centre, are therefore favourable as they allow for easier wildlife migration as well as access to the open green space (cf. ibid.).

2.2. Urban Modes of Transport

The way people move within the city largely influences their livelihoods, environmental effects and the image of the city overall. It also has a big influence on the form, structure and accessibility of the city. Public transport supports radial structures and leads to the best accessibility in the centre (cf. Lichtenberger 1986). Accessibility is a central term in spatial planning and means the number of opportunities that can be visited within a certain time span from a certain location. A declared goal of urban planning is to increase those opportunities and therefore increasing sustainability (cf. Cerwenka et al. 2007).

2.3. Approach to the Sustainable City

From the earlier discussed topics, it can be derived that there are urban forms that are more sustainable than others. The radial Copenhagen Finger Plan is an example of a suitable form because it supports public transport which in turn supports development with fractal characteristics, as will be seen in the following chapter. However, the form alone does not make a sustainable city.

The concept of urban villages provides a strategy for increased accessibility within neighbourhoods due to mixed land use and increased density. Other characteristics include the availability of public transport stations, attractive public green space and a mix of different kinds of amenities nearby or easily reachable via public transport (cf. Newman & Kenworthy 1999).

Combining mixed land use, that allows for high accessibility to different kind of amenities and open green space on different scales, with city forms that support public transport as well as pedestrian friendly distances can therefore be regarded as a sustainable strategy for cities.

3. Multi-Scale Planning as a Sustainable Approach

The multi-scale planning approach incorporates the discussed characteristics in a strictly scientific and quantitative way.

3.1. Complexity & Self-Organisation

Recent theories suggest that cities are complex systems that behave non-linearly and self-organisationally (cf. Portugali 2000), as there are many different elements that influence the evolution of the city. Human problems are generally met in an efficient manner by following simple rules of self-interest and self-governance in order to react to influences from the surroundings. These adaptations take place on a small scale and the final result is so complex that it is impossible the design it in a top-down approach (cf. Mehaffy & Salingaros 2011; Alexander 1964 in: Batty 2005). However, this does not mean that cities are chaotic. Henri Bénard (cf. Portugali 2000) showed in an experiment that from seemingly chaotic actions or movements can lead to a notably ordered pattern due to self-organisation. The three main characteristics of self-organisation that can be taken from that experiment are:

- Open systems that interact with their surroundings and therefore can reach and maintain spatio-temporal structures far from equilibrium.
- Spontaneous self-organisation and emergence of new structures and behaviours.
- Impossibility to explain causal relations between the countless elements, and a complex network of feedback loops that interconnects these elements in a non-linear way. Both of which are aspects of complexity (cf. Portugali 2009).

Cities typically develop in bifurcations rather than continuously. This means that their evolution shows a long period of a more or less stable state that is followed by a shorter time span of intense fluctuations or chaos, caused by changing parameters, that eventually leads to a new level of steady state and stable structures. These dynamics also sets in the morphology of the city (cf. Portugali 2009).

Hierarchies provide a framework describing and measuring urban functions on different scales and for relating different scales to each other (cf. Berry 1964 in: Batty & Longley 1994). Central places theories pick this up, such as Christaller's "Theory of Central Places" (1933 in: Portugali 2009). Hierarchy exists on one hand between different towns but also within individual towns.

In order to illustrate and analyse the behaviour of systems models are used. One way to do so is to model cities as two-dimensional cellular automata. Such a model consists of a grid of cells, of which each can be in one specific state such as empty or occupied and have one of multiple possible properties such as "developed", "undeveloped" or others. With those the nature and circumstances of interactions and interrelations between cells can be determined (cf. Portugali 2000). It is not necessary to define complicated rules for this as already simple ones can generate highly complex global structures and behaviours. Urban forms and structures can be relatively easy adapted for cellular automata.

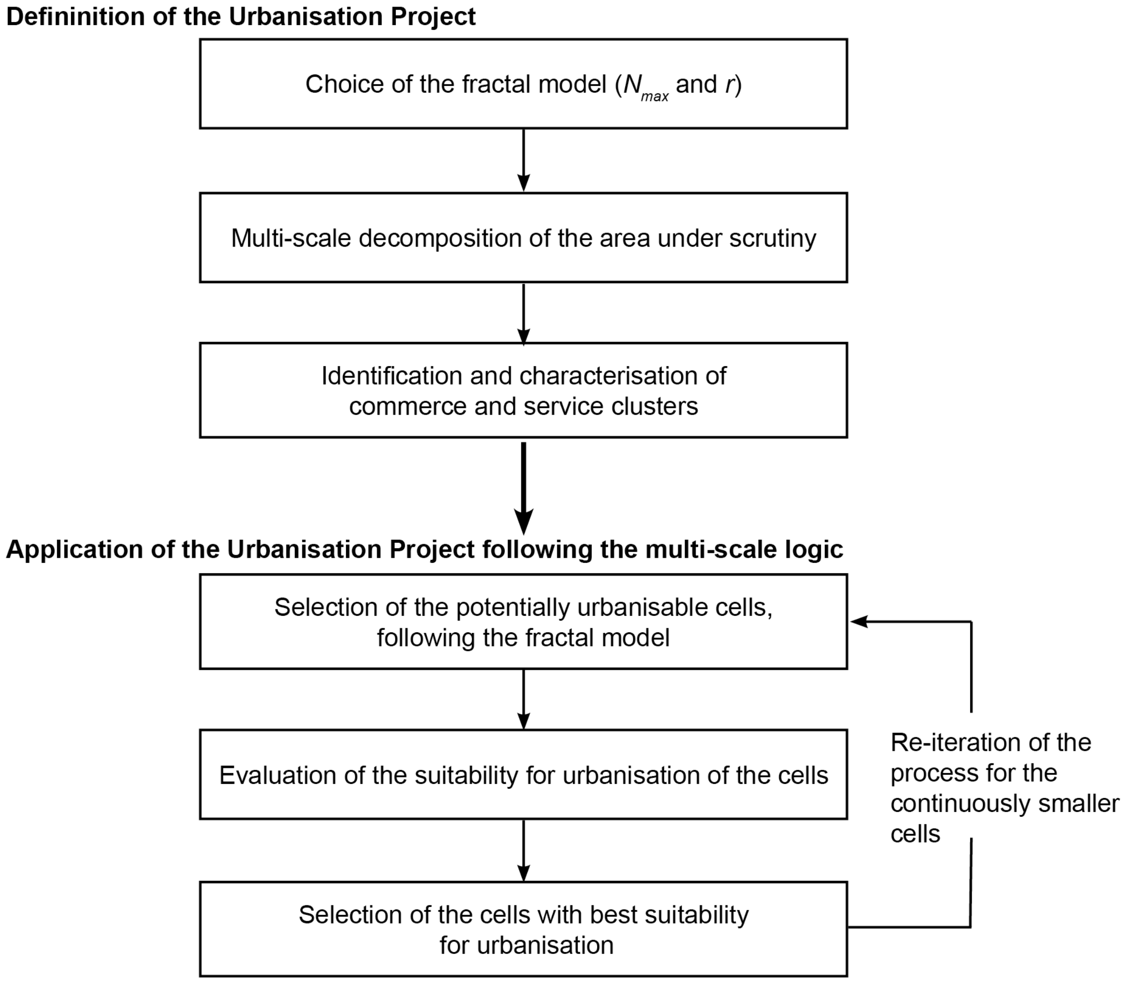
3.2. Fractals and the Fractal City

Mandelbrot is widely known for having developed a mathematical language to describe fractals in order to describe and analyse the geometry of nature in opposition of Euclidean geometry. Characteristic for fractals is that their irregularity and fragmentation is identical at all different scales, they are self-similar (cf. Mandelbrot 1991). Relating to one's surroundings happens on the smallest scales, while people instinctively get a natural feel by the scaling hierarchy of urban elements. In order to create functioning, liveable cities, the different scales therefore have to be linked to each other. Mathematically this means that sustainable/sustaining environments are those that show fractal characteristics. Traditional pedestrian cities are fractal because they work on all scales due to continuous incremental additions (cf. Salingaros 2005). It can therefore be argued that fractal and well-interconnected cities are human cities. This knowledge can further be used to create sustainable cities on a top-down approach, which is what the aim of the MUP-City software is.

3.3. MUP-City

Complexity, self-organisation and fractals are used to explain bottom-up processes in the nature. While MUP-City is used in top-down approaches, it is mathematically based on fractals by maintaining self-similar structures on large to small scales in order to create sustainability.

The Process of the scenario development with MUP-City can be seen in the diagram below:



Process of Scenario Development with MUP-City (Source: adapted from Tannier et al. 2010a:12)

MUP-City has three objectives (cf. Tannier et al. 2010a):

- Avoidance of fragmentation of built-up and open space.

- Minimisation of the number and length of travels by car and ensuring high accessibility of rural and urban amenities.
- Limitation of land consumption.

They are tried to be achieved by following a fractal logic that allows for good accessibility and variety in amenities while minimising the fragmentation of built-up and open space. The main feature of the software is its multi-scale approach by evaluating different scales of cells according to the accessibility of:

- open space by preserving its connectivity
- commercial and service centres of daily frequency
- commercial and service centres of weekly frequency and
- proximity to existing roads

II Practical Application of Multi-Scale Urban Planning

The second part of the thesis consists of the introduction to Klosterneuburg, the area under scrutiny, and the development of two scenarios for this town. The first one being the analyses of the existing state of the whole town and the second being a 2-stage development scenario for the part of town called Weidling.

4. Area under Scrutiny – Klosterneuburg

Klosterneuburg was chosen as it is rather small, close to Vienna, well distinguishable from its neighbour towns and shows suburban characteristics. It lies in the North of the capital, next to the Danube in the federal state of Lower Austria and has approximately 26,000 permanent residents (cf. Stadtgemeinde Klosterneuburg s.a.).

The town's setting between the Vienna Woods and the Danube Valley allows for countless outdoor activities. Anthropologically formed landscapes include the wetlands as well as numerous vineyards and meadows. Similar landscapes are found in the North of Vienna, namely the district (Ober-)Döbling. Equally long travels to the centre of Vienna add to the likewise perception of these areas. Historically the town developed mainly around the monastery and the church St. Martin north of it. On a larger scale the town developed mostly into the valleys, along main roads (cf. Wonka 2011). Typical linear structures evolved as individual villages grew together.

Concerning the future development there exist two major development plans: the Lower Austria Central Place Development Programme and the Klosterneuburg Development Concept. Klosterneuburg is defined as a level III central place in the regional development programme, which means that the town should perform as a regional development centre in economical, social and cultural areas (cf. Zentrale-Orte-Raumordnungsprogramm 1992). It is therefore important that it is easily accessible from surrounding towns.

The concept of central places is also followed on the local scale in the development concept as it suggests the strengthening of local sub-centres in order to cater for an increasing number of people living in the town. These local centres are to supply residents with basic services. The town also aims for a diverse mix of industry sectors, commerce, services and craft as well as of recreational amenities. Public transport is to be preferred over individual motorised transport and therefore accessibility and regional connections are to be improved.

The MUP-City software follows very similar sustainability principles as the development programme and concept, and therefore is expected to complement them in a useful manner.

5. Scenario Development

In order to work with MUP-City, extensive data preparation was necessary. After this, two scenarios were developed: the existing state of the whole town and a 2-stage development scenario for Weidling.

5.1. Data Preparation

MUP-City (version 0.8 beta) uses five different layers with spatial information on undevelopable areas, the road network, buildings, amenities and public transport. These layers were created with the open source software Quantum GIS (QGIS), version 1.7.4 for Mac.

For the layer consisting of undevelopable areas, the SRTM-image for the coordinates 48°N 16°E by NASA was used in order to identify slopes that are too steep to be built-up. As reference the currently steepest built-up slope in Klosterneuburg was used as maximum. The Danube is also part of the “undevelopable” layer. The network-layer consists of OpenStreetMap data that was cleared of not required streets, as well as completed and corrected where needed. It is very important that all lines snap to each other and consist of single segments rather than multi-lines, as MUP-City returns an error if this is not the case. A great amount of time was therefore spent on re-examining the layer in order to avoid errors. The building department of Klosterneuburg provided GIS data on roof top areas, which were used and completed to create the buildings-layer. Based on earlier MUP-City projects, a classification was developed for the amenities in Klosterneuburg. Amenities on two levels were included: level 1 for daily frequency and level 2 for weekly. The spatial information for these amenities was taken from the Austrian business directory Herold as well as from GIS files on green areas from the building department of Klosterneuburg. The public transport layer was created with the help of GIS data provided by the municipality and completed with the Herold map.

Already at this stage it is very visible that the historic centre stands out and that the city seems to be sufficiently supplied with public transport stations.

Scenario 1: Existing State

The decomposition of the GIS data reveals that Klosterneuburg has a lot of fragmented open space and that the settlement structures are often disconnected. Accessibility of level 1 amenities is best in the historic centre, followed by the sub-centres. However, there are some areas where it is quite poor. In order to increase accessibility in these areas it could be useful to introduce level 1 amenities there. This assumption was verified in one area by changing amenities and the street network.

As for future urbanisation, the software identifies cells on the smaller scales and in already built-up areas as being the most suitable. One reason for this is the topography, as settlement development is restricted by the Danube and the numerous hills. The other major reason for this is that the built-up areas and the open green space are rather fragmented, which limits the amount of suitable additional land.

Scenario 2: Weidling Growth Scenario

For the second scenario, a part of the town, Weidling, was chosen to be built-up in two stages in a way that accessibility to different kinds of amenities is always satisfying.

In the first state, level 1 amenities were introduced in under-supplied areas. Additionally, level 1 and level 2 amenities were added to the local centre in order to strengthen it. It was deliberately chosen to introduce amenity classes that were not existent at those specific areas in order to increase the diversity there, which is taken into account by the software and leads to better suitability of the surrounding cells for being built-up. After implementing these changes, the analysis with MUP-City showed that accessibility had increased in general and formerly unsuitable cells were now suitable for being built-up. In the process of the interactive scenario development, free cells in built-up areas were being built-up, and therefore gaps were closed. This step was done first on the 60m scale and then again on the 20m scale as there were no new cells suggested for development on the larger scales. After doing this in MUP-City, the GIS files were altered accordingly by adding buildings to the areas that were built-up in the process.

In the second state, additional level 1 amenities were introduced. While state 1 was focusing on closing gaps, in state 2 new areas were to be made suitable for building up. Therefore, level 1 amenities were introduced in areas, where future building activities could take place. Again, cells were being built-up on the 60m and 20m scales during the interactive scenario development.

The scenario showed that in Weidling there is a very limited amount of land suitable for further urbanisation in the current settlement fabric and with the existing infrastructure and amenities. Therefore it is necessary to introduce additional amenities and to expand the existing network if settlement development is to take place in that area in the future.

III Conclusion and Outlook

While MUP-City does not provide fundamentally new findings, it helps simulating and visualising development strategies and their effects on accessibility of different kinds of amenities. For Klosterneuburg the software could be rather useful as the development concept and regional development programme feature the same principles of reduced urban sprawl, increased use of public transport, access to and protection of open green spaces as well as access to shops and services. MUP-City brings in the aspect of fractals that can help achieving those goals.

The software itself is a work in progress, which sometimes leads to errors. After the bugs are resolved, it could be useful to adapt it in a way so it is less sensitive to data imperfections, mainly of the network layer as this is regarded as the major inconvenience. A great help would also be to improve the interactive scenario development in a way that it allows to change the data base in the software itself, so that switching to other GIS software in between steps could be avoided.

Particular strengths include the comprehensibility of the visual figures, also for lay people, and the strong scientific basis, which make the software very suitable for the use in small towns in the periphery of large cities in order to support sustainable development.

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Introduction

A main goal of urban planning is to formulate plans and concepts for the development of settlements that require few resources and ensure high quality of living for their citizens with the aim of achieving sustainable settlements. One of the main challenges is to decide on land use zoning and building development. To help with these difficult questions, various analysis and evaluation techniques have been developed. In recent years, computer based tools in this field have gained in importance.

Spatial modelling and simulation software can be used in various planning and design processes. They can be used as awareness raising and communication tools as well as to support decisions in terms of developing and sustaining spatial qualities (cf. Voigt 2011). One of these tools is the computer based decision support system *MUP-City*, which is examined in the thesis.

MUP-City is short for “Multi-scale Urban Planning for a Sustainable City” and can be used to simulate and visualise scenarios for development, consolidation and shrinking. It follows the logic of fractal settlement development as counter-proposal to compact settlement structures (cf. Czerkauer-Yamu et al. 2011). Main objectives of the software are to find suitable areas for development, consolidation or shrinking that allow for a reduction of number and length of car travels and a high accessibility of shops and services, open green areas and close proximity to existing roads (cf. Tannier et al. 2010a/b).

In the course of this thesis it is examined how MUP-City can be applied to support proposals for land use and development in small towns in the periphery of large cities. As area under scrutiny the municipality of Klosterneuburg, which lies in the North of Vienna, was chosen.

The following hypotheses are to be verified in the course of this thesis:

I MUP-City can be used to evaluate current settlement structures and access to open green space and amenities of small towns in the periphery of big cities.

II MUP-City can support planners to develop scenarios and test different options for future sustainable development to support concepts, proposals and decisions by competent authorities for instance towards lay people.

Scope of Research and Methodology

In the first part of this thesis the theoretical background is covered to allow a better understanding of the functioning of MUP-City. It includes the general goal of sustainability in planning and characteristics of a sustainable city that are greatly influenced by urban open green space as well as the choice of transport mode in the city. Developed from this are favourable urban forms and the theory of urban villages as one sustainable concept is briefly introduced. After this, multi-scale planning is recommended as a sustainable planning approach, introducing topics of self-organisation and complexity, fractals and finally how findings in these fields are used by MUP-City.

The second part of the thesis focuses on possible applications of MUP-City for the municipality of Klosterneuburg in Lower Austria. Klosterneuburg is introduced to the reader by describing the municipality's topographic and natural setting as well as its historical and planned future development.

For the scenario development with MUP-City it is necessary to create GIS files that contain all amenities in the area under scrutiny, including public transport stops, buildings, the existing street network and undevelopable areas. The data gathering and processing, for which open source applications and publicly available data are used as well as data that was made available by the building and planning department of the municipality of Klosterneuburg, is explained in detail in the beginning of the fifth chapter. With the help of MUP-City the accessibility of different amenities on different scales is examined. It is then used to identify suitable areas for future development and for interactively developing a scenario for a selected area within the town.

A total of two scenarios are being developed for Klosterneuburg:

1. <u>Existing State:</u> The visualisation of the existing state shows the overall supply and accessibility of different amenities and identifies areas that are potentially under-supplied with specific amenities. It also shows which areas are suitable for further urbanisation when existing amenities are not changed.

2. <u>Development of Weidling:</u> It is analysed how the introduction of certain amenities in particular areas affects the accessibility of amenities on the different scales and how this alters the suitability for urbanisation of cells. The goal is to develop a scenario in which all parts of Weidling have sufficient access to different kinds of amenities during all steps of the development.

Finally, the outcomes of the scenario development and option testing are evaluated in the third part of this thesis. The conclusions involve a discussion on MUP-City and its outcomes for Klosterneuburg, as well as outlook for the software.

I Theoretical Background

In the following chapters several main subjects are discussed to facilitate a more comprehensive understanding of the functioning of the MUP-City software and its theoretical background.

Starting with *sustainability*, a goal that is generally pursued in various aspects of urban and regional planning, it is discussed how it can be measured by determining the *ecological footprint* and what role the city plays in reaching the objective of lowering it.

Central challenges of the sustainable city are discussed next. The particular importance of the natural environment, consisting of flora and fauna, and its impacts on the city is examined. Influences on the urban micro-climate are discussed and what benefits *open green space* has, as part of the socio-bioecological system that the city is. Finally, it is discussed why it is important that green areas are coherent, in opposition to being fragmented, based on the *island biogeography* and the *metapopulation theory*. In a next step, *transport* and its different *modes* are discussed in terms of how different transport technologies shape the city and how *accessibility* is affected by it. Particular focus is on the widely existing *automobile dependency* and why it can and should be reduced. Taking those main topics into account, the characteristics of a sustainable city are then derived. It is particularly looked at *favourable urban forms* and the concept of *urban villages* as a sustainability strategy.

Multi-scale planning as a sustainable planning approach is discussed as it incorporates the before as sustainable identified principles in a strictly scientific way. It is started by describing *self-organisation* and *complexity*. Then it is explained how *fractals* are related, why fractal cities are particularly sustainable and how the software *MUP-City* uses the approach of fractal geometry to provide a helpful decision support system for planners.

1. Sustainability as General Objective in Spatial Planning

A central objective, and challenge, in urban and regional planning is to achieve sustainability. A generally accepted definition of sustainability in cities is the long-term and extensive securing of liveability and productivity in social, economical and ecological terms while using mostly renewable resources (cf. Frick 2008). For cities this means improving liveability while at the same time reducing metabolic flows by lowering the use of natural resources (input) and lower production of waste (output). While the latter is quite straightforward, the former needs some clarification: The factors that impact liveability most have been identified as the availability of social amenities as well as health and well-being (cf. Newman & Kenworthy 1999).

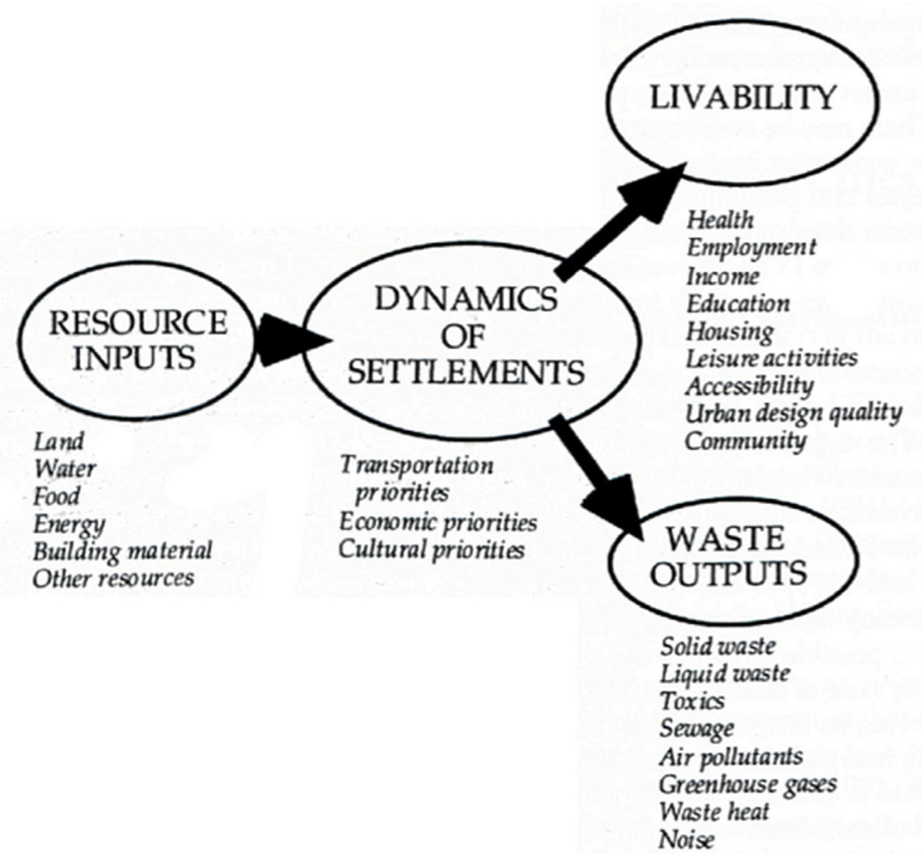

Figure 1: Extended Metabolism Model of Human Settlements (Source: Newman & Kenworthy 1999:8)

While there are many factors that influence the degree of sustainability, cities as a whole have been recognised to have a particularly important role in achieving and maintaining sustainability on a global level (cf. Grimm et al. 2008 in Anderberg 2012). As cities have changed over the course of time, their problems have changed with them. In the past, when industrial cities became overcrowded and polluted, there were two main solutions to deal with them: they were either abandoned all together or environmentally modified to provide clean water and air, more housing space, and to reduce the production of waste while removing the waste that was already there. Where cities were abandoned, suburbs were often established as well as garden cities in green areas outside of town (cf. Cadenasso & Pickett 2011). Today the demand for constantly increasing living space in cities in opposition to the by planners generally accepted objective to minimise additional area for urbanisation makes it difficult to turn away from city-related issues by “starting over” in a different place. It is thus inevitable to find ways and development concepts for and within existing cities to tackle those challenges. In order to assess the success of measures taken towards sustainability, it has to be measured.

A widely known and used indicator to measure the impact of cities on the environment, which correlates with their level of ecological sustainability, is the *ecological footprint*, developed by Waekemagel and Rees in the 1990’s. The impact is calculated based on the metabolic flows of the city, based on the amount of used resources to the quantity of produced waste, in order to estimate the land area that is required to sustain the city’s activities. Included in this area is the land needed for the production of food and fibre, for the mining of resources, the construction of the city itself, but also the area needed for the absorption of the various kinds of waste. By considering the required land to absorb the produced carbon dioxide, the production and use of energy is included as well. The objective is to get the ecological footprint as small as possible (cf. Newman & Kenworthy 1999). This indicator allows taking into account many factors that have ecological effects. Besides being calculated for cities, it can also be used to determine the ecological footprint of individuals, countries or the whole planet. Currently the ecological footprint for developed countries is too big to be regarded as sustainable and the high consumption of land is only partly balanced, on a global scale, by developing countries that have a much smaller ecological footprint.

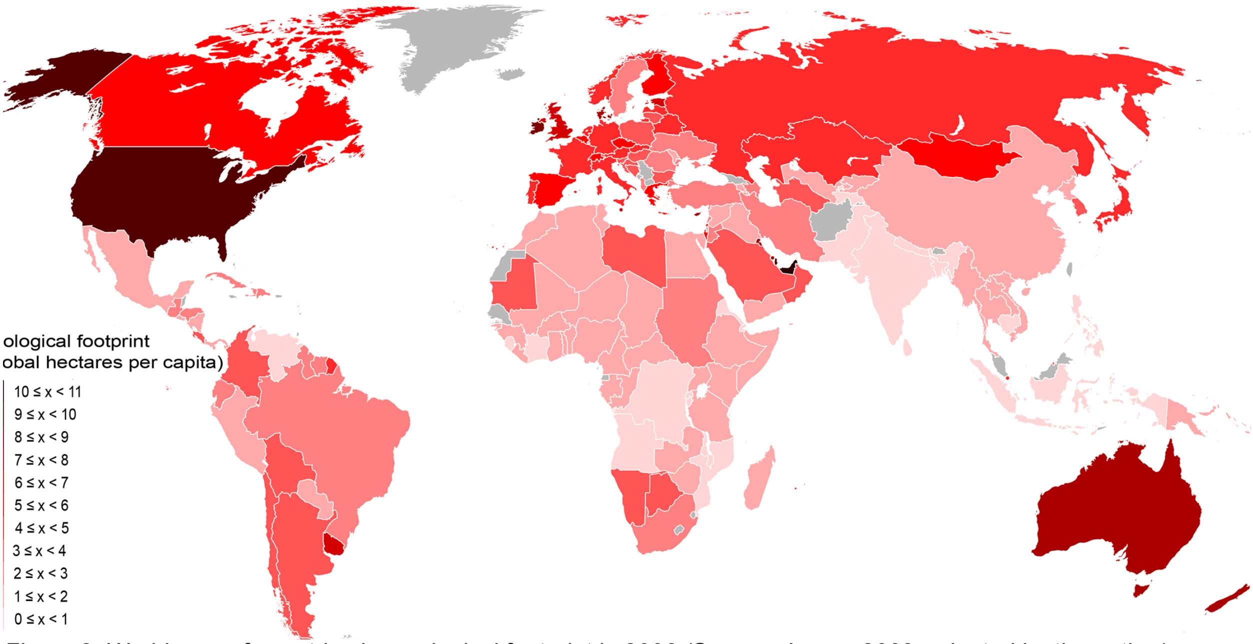

Figure 2: World map of countries by ecological footprint in 2006 (Source: Janner 2009, adapted by the author)

The map above is based on the countries’ ecological footprint in 2006 and shows the global hectares per capita. Six factors were included in the calculation of the ecological footprint: cropland, grazing, forest, fishing, carbon footprint and built-up land (cf. Janner 2009). However, the ecological footprint does not directly include economical and social aspects or the distribution of resources among the population, nor does it take the spatial distribution of land into consideration. Other problems with the ecological footprint include the difficulty to compare different footprints that have been calculated in different countries and in different years they are not necessarily comparable with each other. This is due to the change of biological production and capacity over time and different methods of calculation. However, the ecological footprint provides a useful instrument to communicate sustainability and translates this rather abstract term into something more tangible.

As mentioned before, cities play a particular role in achieving global sustainability. This is mainly owed to their, in general constantly growing, size; concerning both area and population. While cities occupy and alter space there is constant competition between different land uses for the available space. As the modifications of their local environments also influence the environment on a global level they have to be carefully assessed (cf. Batty 2008 in: Anderberg 2012). While the scarcity of land and resources has become crucial in some regions, cities have historically encountered all kinds of different crises. In the nineteenth century, fast-growing industrialising cities in Europe have faced three types of urban sustainable crises:

- *hygienic* crisis due to poor quality drinking water, insufficient sanitation and waste management, resulting in epidemics
- *social* crisis due to poverty and inadequate, poor and unhealthy housing as well as missing access to greenery, clean air and light
- *environmental* crisis due to intense pollution, leading to citizens' health being threatened (cf. Anderberg 2012)

While these crises have mostly been overcome in developed countries, they are still very present and frequently getting worse in fast-growing cities of developing countries. In developed countries and modern societies global change problems such as climate change, scarcity of resources, biodiversity and competition about land use have shifted the focus on the use of energy, spatial structure and infrastructure, particularly in big city regions (cf. ibid.). The urban metabolism flows changed due to industrialisation, increasing wealth and the expansion of the city, changed designs of buildings, city areas and new settlement patterns but also due to change of work, commuting, production, consumption, trade, recreational activities and use of urban landscapes. Urban planning has a strong impact on these metabolism flows but has rarely addressed the management of resources directly until recently (cf. Agudelo-Vero et al. 2001 in: Anderberg 2012). In the 1970s increasing concern about the environment and natural resources started impacting urban planning, leading to the promotion of new urban forms such as the compact city. High-density settlement and mixed used was suggested to fight urban sprawl, car dependency and therefore to reduce fossil fuel consumption. In the 1980s the focus shifted slightly, this time towards sustainable development; visions of ecocities and sustainable cities emerged (cf. Anderberg 2012). With today's global market, it became more important for cities to be competitive on an international level as well. Cities that are being developed with the global sustainability agenda in mind are more likely to succeed in the long run (cf. Ohmae 1990, Jacobs 1984 in: Newman & Kenworthy 1999). So, there is in fact also an economical incentive for sustainability. It has been attempted to identify characteristics that make a sustainable city and to develop concepts, methods and instruments to introduce these characteristics in spatial planning practice. However, since there are so many different factors involved, it is difficult to analyse the systems of the city, let alone find functioning solutions.

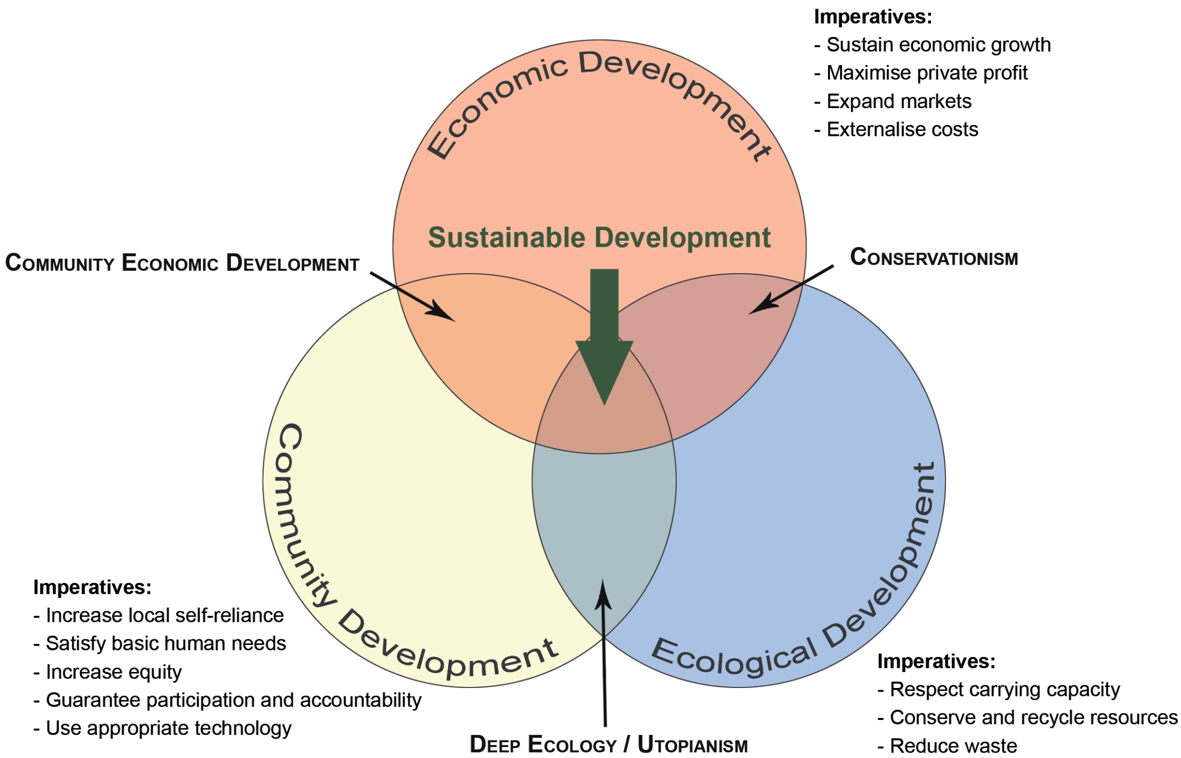

Figure 3: Development Processes on the local level (Source: by author, based on: International council on Local Environmental Initiatives 1996 in: Newman & Kenworthy 1999:4)

The main objectives of sustainable cities are clear: reduction of waste and pollution, conservation of natural resources and respecting the carrying capacity of the ecosystem. Translated to the planning of cities, this means in particular using the available land efficiently as well as reducing automobile transport, which in turn is closely connected to efficient public transport. Social aspects include satisfying housing and living environments, involvement and participation of the community, equity and inclusion of the population. Finally, a sustainable economy is essential to achieve overall sustainability (cf. Roseland 2005 in: Anderberg 2012). Since there are many different aspects involved, sustainable planning has to be approached in a holistic way that takes all three pillars of sustainability, ecological, economical and social, into account (cf. Newman & Jenning 2008 in: Anderberg 2012). Finding efficient ways to use land while at the same time conserving the natural surroundings and reducing negative environmental effects as well as supporting environmental-friendly and sustainable means of transport are a particular challenge that planners face.

As will be seen later in this thesis, multi-scale planning that is based on fractals can offer a solution to this challenge as it aims for a reduced fragmentation of urban and open green space.

Urbanised and natural areas interact with each other and it is important to know how these interactions work and what effects they have on one another to be able to plan in a manner that creates long-lasting benefits for the city and its citizens and does not damage the natural environment.

2. Challenges and Opportunities of the Sustainable City

In the process of creating a sustainable city, various challenges are faced. As indicated before, a variety of factors across diverse disciplines determine the degree of sustainability of a city. While there are many issues that range from difficult to impossible to influence by urban planning such as the existing topography or large scale climate, there are two main subjects that can be tackled by planners by regulating urban form and structure, and are therefore being discussed in the following: *open green space*, in and outside the city, that regulates the local climate and has other positive effects on the liveability in the city, and *modes of transport* that are strongly interlinked with *accessibility*.

2.1 Open Green Space

Green space is generally perceived positively, particularly in cities where the sight of greenery can be rare. Cities are essentially built for people and at times it seems to be forgotten that natural elements within and around cities have more than only aesthetic benefits, and which will be discussed later in this chapter. If the complex interactions between humans, their built environment and their natural surroundings is understood, the introduction or conservation of suitable green space can lead to long-term social, ecological and economical advantages.

2.1.1 Cities as socio-bioecological systems

Since there is constant interaction between urban and rural areas as well as between various sub-systems within urban areas cities have become to be understood as hybrid *socio-bioecological systems*. In this concept, cities are regarded as human ecosystems with biotic and physical elements, social fabric and built components. There is feedback between vegetation and human comfort that can be studied when the complexity of demographics, institutions, behaviour and economy as well as bioecological activities are considered. It is essential to mediate those feedbacks according to values and perception of the local population (cf. Cadenasso & Pickett 2011). This mediation is in so far important as different regions have different ecological and cultural backgrounds and consequently there is not one general interpretation of the systems' interactions that applies everywhere equally.

The native biodiversity in cities is typically reduced. However, some wild animals are feeding from urban garbage, garden plants or are purposefully fed which can lead to growth of certain species populations in cities (cf. Beissinger & Osborne 1982 in: Cadenasso & Pickett 2011). When removing the natural greenery and introducing new one, of the same species or a different one, as it is often the case during urbanisation processes, the loss of some animal and plant species in that area is inevitable. If the original, native green areas want to be preserved, it is more purposeful to not removing them in the first place. Also, while having certain species, such as butterflies, singing birds or certain introduced, non-native plants, close to residential areas is desirable for people, it also can have some undesired side effects. Flocks of pigeons soiling urban buildings or wild boars ploughing through domestic gardens are examples of such less appreciated effects. Introducing species (willingly or unwillingly) that are not native to the particular area in addition involves the risk of them spreading more than wanted and possible driving out native species.

One often-overlooked effect cities have is the regional dispersion of species as wildlife adapts its biogeographical distribution area due to climatic change (cf. Hickling et al. 2006 in: Snep & Clergeau 2012). The continuous built up land of cities creates a barrier to moving species, especially to the ones that struggle with movement. Allowing movement by making the city permeable is therefore another challenge for planners (cf. Snep & Clergeau 2012). This is an aspect that is particularly important for animals, since plants usually stay at the same spot during their lifetime. However, the consideration of movement paths of wild animals is not only beneficial to them but it also helps avoiding unpleasant encounters such as the wild boars destroying gardens mentioned earlier. Since some plants rely on animals for their reproduction, for example fruit trees that need bees for pollination, it is therefore also beneficial to those plants if their required animals can get to them.

Figure 4: Foxes behind a house in London, feeding from garbage (Source: Wilson 2009)

2.1.2 Beneficial Effects of Open Green Space

As mentioned in the beginning of this chapter, open green space in and around the city provides a number of benefits for the city and its inhabitants.

Materials that are widely used in cities, such as concrete and asphalt, absorb solar energy and emit heat plus the high percentage of impervious surface affect the urban micro-climate. Urban temperatures are on average higher than in the periphery (cf. Voogt 2002, Parks 1986, Watkins et al. 2007 in: Nuissl & Siedentop 2012). This phenomenon of higher temperatures in cities compared to their rural surroundings is called the *urban heat-island effect.*

Cities of all sizes show this effect because they have a higher density of population, activity and built-up space and are surrounded by a wider and more rural environment. Hence, they naturally are alien elements in their surroundings. The intensity, geographic expansion and transitory persistence of the urban heat-island effect, however, are regulated by factors such as size, morphology, topography and land-use pattern (cf. Brazel & Quadrocchi 2005). The complex building geometry and thermal characteristics of typical building materials of cities lead to a higher absorption of solar radiation, greater storage of heat during daytime and release of heat during the night. Direct releases of heat from various anthropological activities, such as heating of buildings or using petrol-fuled vehicles, further reinforce the heat effect (cf. Balling 1999). Urban green space can help reducing this effect (cf. Pauleit et al. 2011). By providing shade and through evapo-transpiration processes, vegetation cools down its immediate surroundings.

Especially trees and bushes additionally have the capacity to bind air pollution (cf. Nowak

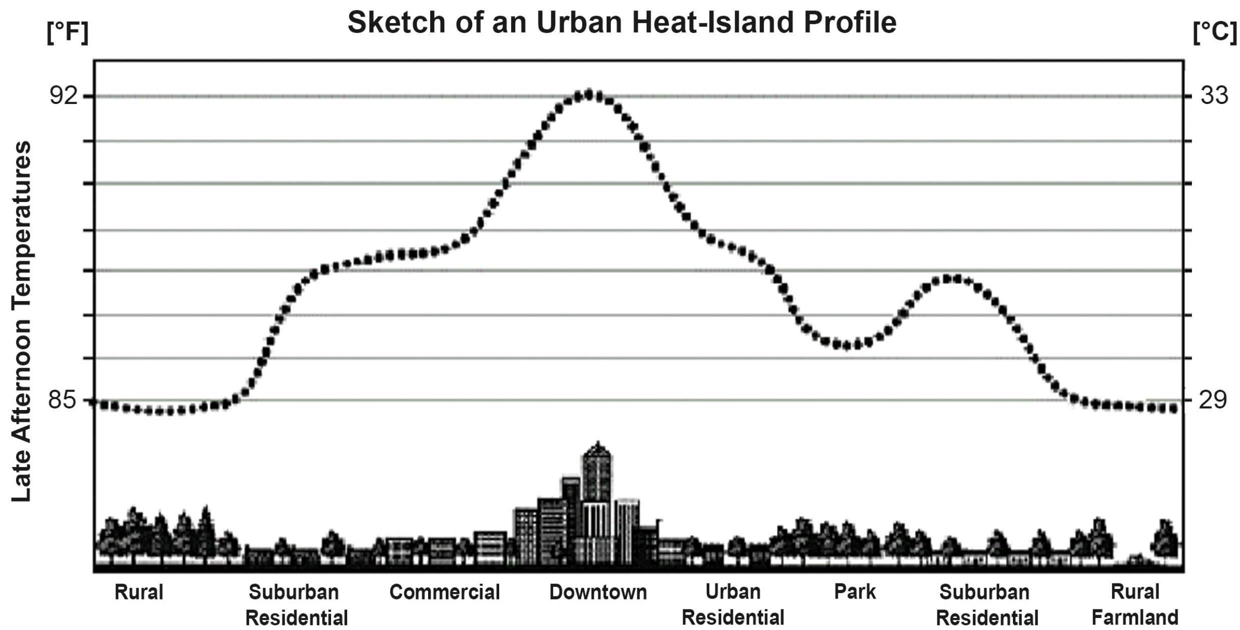

Figure 5: Urban Heat-Island Profile (Source: NASA s.a., modified by author)

2002 in: Pauleit et al. 2011). The benefits of binding carbon dioxide last as long as dead or cut trees and bushes are replaced and their biomass are used in replacement of fossil fuel as simple decay leads to a release of the full amount of stored carbon dioxide into the atmosphere again (cf. Pauleit et al. 2011). Also, it is not relevant if the mentioned services are performed by native species, as neobiota work equally well. Important is that the various components of urban biodiversity contribute different ecosystem services that have to be assessed (cf. Cadenasso & Pickett 2011).

Another main asset of urban vegetation is its ability to absorb water. Storm water management usually consists mainly of collecting the water and passing it off further downstream as quickly as possible. While this approach can solve the problems that water causes locally, it creates new ones further down the stream: The additional amount of water can lead to erosion of the steam bed, scour of aquatic organisms' habitats and fish's spawning grounds. Runoff from heated surfaces can result in increased water temperatures downstream, which hereinafter can disturb sensitive habitats (cf. Cadenasso & Pickett 2011). Alternatively, it is possible to use this water for vegetation that cools down the immediate environment through evapotranspiration processes (cf. Balling 1999). By helping to reduce the urban heat-island effect and storm water management, urban green directly assists as a passive system in reducing energy demand as less energy is needed in housing for heating and cooling (cf. Nowak 2002 in: Pauleit et al. 2011). As it gets clear, managing storm water in a conventional way is neither environmentally friendly nor sustainable. In addition, building and maintaining these water management systems and possibly repairing damages it causes downstream are cost-intensive. Open green space, on the other hand, helps with the drainage and actually uses the water, creating additional positive effects in the process.

Besides providing those ecosystem services, urban green space naturally appeals to humans, providing places for recreation and a sense of place (cf. Cadenasso & Pickett 2011). The ability of citizens to get in touch with nature and interact with it greatly depends on the design of the urban green space. It has to be found an appropriate ratio and configuration of built-up and green area. From an economical point of view this is preferable as well, as people like to live and work in cities with a minimum amount of green space for improved quality of life. Public gardens, parks and green between residential and business zones provide recreational space and also support visual features of those built-up areas (cf. Snep & Clergeau 2012).

2.1.3 The Importance of Continuous Open Green Space

Some species depend on the interaction with populations from other areas to be able to thrive. While this is evidently true for animals, it also applies to a number of plants, particularly the ones that depend on the movement of animals e.g. for pollination. In order to benefit from the positive effects of green space in and around cities in the long run it is therefore important to not only conserve and maintain single patches but to take the interlinkage with each other into consideration.

Two ecological theories that explain the significance of surrounding animal and plant populations for the endurance of local ones are the *island biogeography* and the *metapopulation theory* (cf. Snep & Clergeau 2012).

The island biogeography comes to the conclusion that large islands which are close to the mainland are principally richer in species than islands that are smaller and further away. Since smaller islands offer a smaller habitat and therefore cater for a smaller population, the vulnerability of said population is higher towards disasters and therefore the extinction rate of the entire population is higher as well (cf. ibid.). Islands in this context are not only the patches of land surrounded by water but all habitats that are surrounded by areas that have different characteristics and cannot be populated by the same species.

As landscapes today are largely influenced by anthropological activities such as transport infrastructure and urbanisation, habitats are often fragmented. The remaining habitats are smaller and usually of poorer quality. To study these fragmented landscapes, the metapopulation theory is more suitable. It states that landscapes link local populations together and create a bigger metapopulation. To ensure the metapopulation's long-term persistence, two factors are important: the re-colonisation from neighbouring populations if a local population becomes extinct and a sufficient number of individuals within the entire metapopulation in order to reproduce successfully. The interaction and exchange between different local populations and between local and global populations therefore is of high importance and the pattern of the habitat on the landscape level determines if local populations will successfully work together as a metapopulation (cf. ibid.).

The likelihood of the survival of species is on one hand determined by landscape parameters and on the other hand by species-specific parameters:

Landscape Parameters

- available amount of habitat
- quality of the habitat, which regulates the carrying capacity
- connectivity of habitat patches
- size of individual habitat patches
- permeability of the landscape, particularly size and characteristics of non-habitat areas
- landscape structures that act as barriers

Species-specific Parameters

- capacity of dispersion to determine the extent to which species can migrate
- distance of dispersion to determine the travelable distance for colonisation of new habitats
- home-range size that is travelled during daily activities
- sensitivity to disturbance such as traffic, recreational activities or noise
- size of the local population, as a minimum number of individuals is needed for a population to function
- size of the key population that is needed to be able to act as source for neighbouring populations
- size of the minimum viable population within the metapopulation

(cf. Verbloom et al. 2001, Shaffer 1981 in: Snep & Clergeau 2012:10)

Even though landscapes and species each have their unique characteristics, there are some universal rules that have to be followed for successful biodiversity conservation:

- A sufficient amount of habitat area has to be conserved or restored in order for the target species to form a viable population (cf. Soulé 1986 in: Snep & Clergeau 2012:10).
- Species need to be able to migrate between patches; therefore a sufficient interconnectivity is necessary (cf. Schumaker 1996 in: Snep & Clergeau 2012:10). Ecological corridors for species with difficulties to migrate or stepping-stones for those having less difficulties support dispersal of plants and animal also through urban areas (cf. Snep & Clergeau 2012:10).
- For the habitat networks to be big enough and sufficiently inter-connected for (meta)populations, either a single large patch or multiple small ones have to be conserved (cf. Simberloff & Abele 1982, Abele & Connor 1979 in: Snep & Clergeau 2012:10).

When connecting biotopes this way, it has to be taken into consideration that different species have different habitats and use urban green in different ways. Therefore it is necessary to connect similar types with each other to achieve the conservation goal (cf. Snep & Clergeau 2012). Benefiting from positive effects of open green space does not necessarily depend on the conservation of existing habitats as neobiota work just as well when it comes to positive effects such as evapotranspiration. Some trouble can still be saved if habitats are not being fragmented in the first place. If species become extinct in certain areas it can be very difficult to bring them back to their original place of residency. In addition, specific local flora and fauna can add to the sense of place and provide citizens, and visitors, with unique recreational opportunities.

The city shape does not only determine to which extent wildlife can populate the urban environments but also influences the degree of accessibility of the green space by the citizens. The interaction of citizens with wildlife and its habitat happens at the urban fringe, where urban and rural environment come together. In cities that are circular-shaped, this fringe, and therefore zone of interaction, is small whereas the distance from the city centre to the edge is large. This, on one hand makes it difficult for wildlife to populate more central areas (cf. ibid.) and on the other hand citizens have difficulties accessing the rural surroundings.

Cities that have a more radial form have so-called green wedges that lie between built-up zones, sometimes even reaching the centre of the city. Often, these wedges were formed due to linear natural structures such as streams or mountain crests and not as much due to deliberate planning. Wildlife can migrate easier in this kind of shape and citizens are in closer proximity of those green space (cf. ibid.). Since wildlife populations can be quite sensitive, it is important to carefully consider the planning of green structures. Besides number and size, their interconnectivity and mutual cohesion as well as linkage to the rural surroundings have a great impact on their suitability as urban habitat. To maximise the possibility of interactions of citizens with nature, continuous green is best. It is irrelevant if these green structures are publicly accessible or private, as it does not make any difference for wildlife. Connecting public open green space with private gardens therefore is legitimate from the wildlife point of view (cf. Goddard et al. 2010 in: Snep & Clergeau 2012). From the citizens' point of view, however, greenery that is publicly accessible is preferred at least by those who are not in possession of private green space. Also, providing suitable habitat in urban areas does not only have positive effects. Depending on the kind of habitat and present populations, wildlife that is not appreciated in housing zones or the city centre might be attracted. It therefore should be carefully evaluated what green space is to be provided to citizens as well as to the wildlife so that both benefit from it or at least are not experiencing disadvantages.

It has been shown that continuous open green space is not only important for wildlife, it is equally important to people as they use it for recreation, sports and aesthetics on different scales. Examples for the use of open green space on different scales are the short walks with the dog in the immediate surroundings multiple times a day, longer jogging tracks or multi-day tours in extensive open green space. In terms of accessibility of open green space by the citizens and the wildlife's ability to migrate, radial urban forms are therefore preferable.

2.2 Urban Modes of Transport

Besides urban green space, the mode of moving within the city is another big factor for sustainability. The way people move within the city largely influences their livelihoods, environmental effects and the shape of the city.

2.2.1 The Influence of Transport Technology on the City

The change of transport technology has altered the shape, structure and accessibility of the city.

Most European cities are centralised systems with a historic core; this means that the centre is accessible best and also works as the catalyst of development. Depending on the inherent society system, it has different functions: in medieval and baroque ages the town centre was the social centre, in the industrial age work places with the highest returns were located in the centre, the Central Business District (CBD), while the recent consumer society wants to find shopping opportunities at that location. Joining pedestrian zones with shops comes closest to this ideology. However, ground prices and visible dilapidation of the inner cities indicate the loss of centres in cities particularly in the United States but also parts of Europe. That loss is partly owed to reduced accessibility but also the increased popularity of suburbia in its various forms. The development of transport technology has highly influenced movement patterns within settlements and therefore forms and patterns of settlements as a whole (cf. Lichtenberger 1986). The image below illustrates how accessibility of the city centre changes with different means of transport.

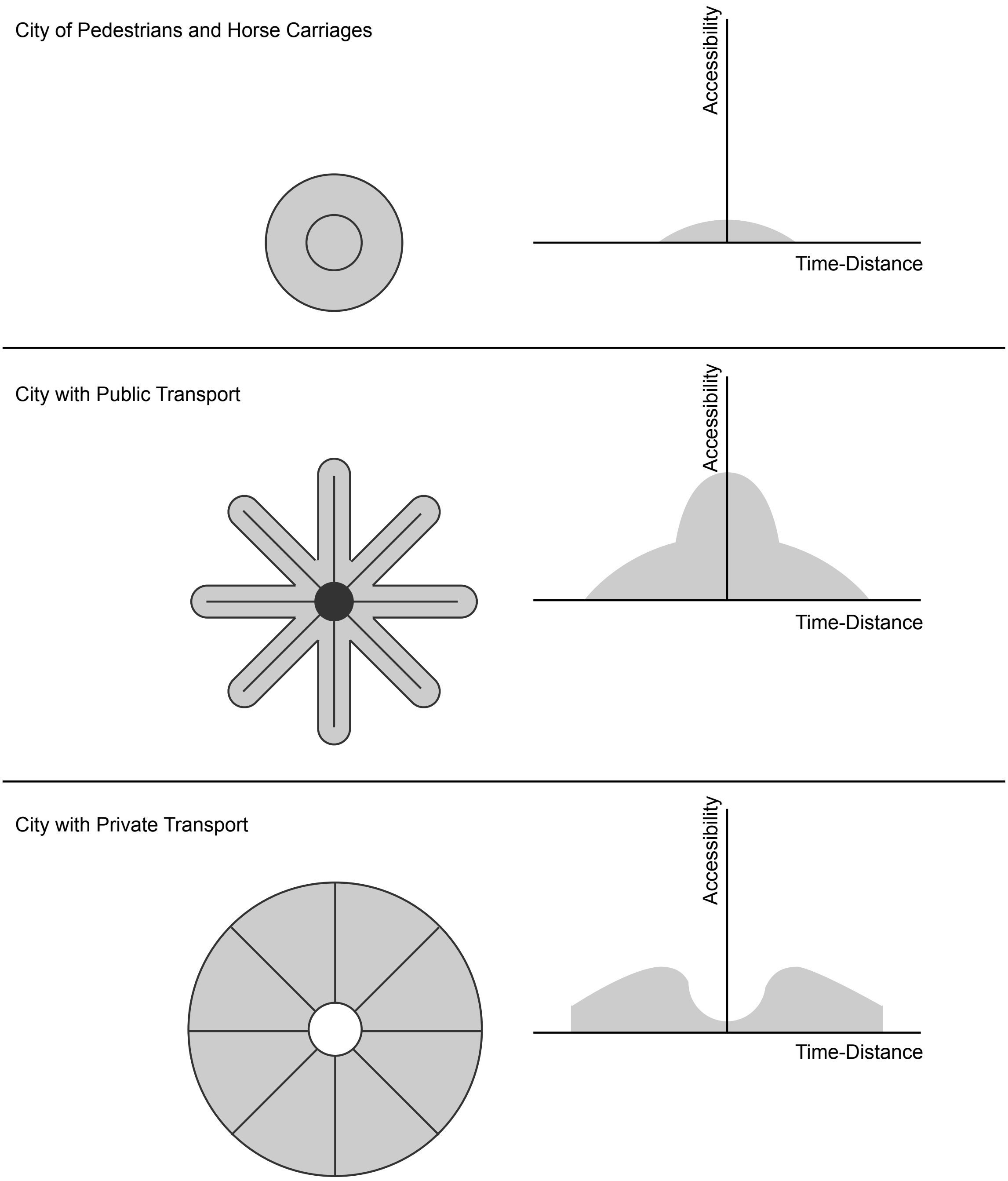

Figure 6: Accessibility of the city centre with different means of transport (based on Allpass 1967 in: Lichtenberger 1986:129)

With the change of technology the accessibility of the city centre has changed as well. Pedestrian and carriage cities are circle shaped. The introduction of tramways leads to a radial, star shaped formation. Depending on the size of the city, urbanised wedges are being connected with each other and therefore rings created. In larger cities, like Vienna and Berlin, sectors between the wedges got locked at the periphery and development remained weaker between the radiant and the circular means of mass transport. As long as public transport remains the primary means of transport, the city centre remains the location with the best accessibility of the urban space and agglomeration. Accessibility of the centre decreases with increase of individual automobile transport due to traffic jams and parking difficulties (cf. Lichtenberger 1986). Other technological developments, particularly in information technology, with personal computers, the internet or mobile phones have possibly further encouraged spatial decentralisation of households and businesses (cf. Nelson 1999 in: Nuissl & Siedentop 2012).

2.2.2 Constraints and Opportunity of Transport and Accessibility

The difference between transport and accessibility, as used in this thesis, is that transport is seen as the actual movement from one place to another whereas accessibility expresses the amount of opportunities that can be reached within a certain timespan, as defined in the following.

In urban and regional planning, accessibility is one of the main terms as it is a goal to ensure and increase accessibility as the link between the use and overcoming of space. Accessibility defines how many of such opportunities can be found within a certain time span from the viewpoint of a selected location. It can be increased, and therefore improved, in two different ways: a) by reducing the time that is needed to go to the same destinations or b) by enlarging the catchment area to go to a larger number, more interesting, important or attractive destinations within the same period of time (cf. Cerwenka et al. 2007).

Ewing and Cervero in their 2010 study on land use and travel behaviour come to the conclusion that accessibility is the key factor when determining the amount of driving of people and households. Their meta-analysis is based on numerous published studies on that topic. The better a location is accessible, the lower is its driving rate. Locations with high accessibility play a role almost as important in decreasing driving rates as other planning factors combined such as neighbourhood density, mixed land use or street design. According to Ewing and Cervero, it is likely that development of any kind in a central location generates less automobile traffic than well-designed, compact developments with mixed land use in remote locations (cf. Cervero & Ewing 2010 in: Benfield 2010). The city core is characterised by high densities, mixed-use and good regional accessibility, leaving minimal automobile usage by people living close to the city centre. Besides this, intersection density and street connectivity encourage walking. The study also showed that while mixed land use does encourage walking and cycling, linking work and housing places has an even bigger influence on the choice to walk and therefore commute by walking. Other influential factors that encourage slower modes of transport are: distance to a store, location and accessibility of public transport. The latter correlates with reduced use of cars and increased walking but not as much as location and street networks are. It is shown in research that the use of cars declines while walking goes up in walkable neighbourhoods in smart locations. However, Benfield diagnoses that there are too many automobile-dependent environments and an increasingly growing demand for walkable neighbourhoods that is not met yet (cf. Benfield 2010). Automobile dependency certainly is an issue today. With rising oil, and therefore fuel, prices, people are getting more aware about using cars to get around. As can be seen in the image below, Vienna (as well as other European cities) has rather low private transport energy use while at the same time having also a comparatively low urban density. People living in this city therefore can be regarded as being rather automobile independent. Instead of reducing automobile dependency, the main goal here is therefore to maintain and consolidate the already existing independence.

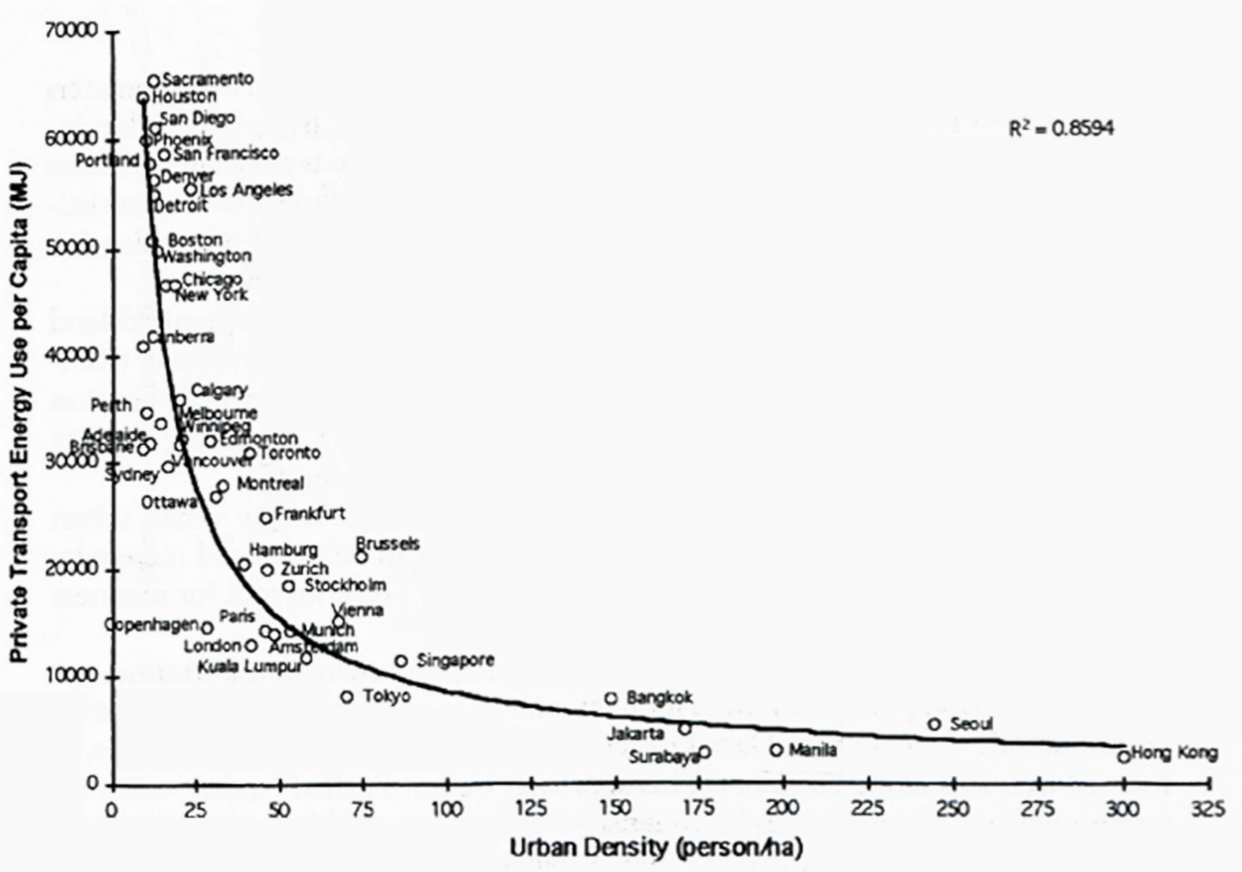

Figure 7: Energy use per capita in private passenger travel versus urban density in global cities, 1990 (Newman & Kenworthy 1999:101)

As cars became widely available to the general population, urban and regional development increasingly adapted to transport by individual motorised vehicles. When addressing automobile dependency and how to reduce it, one is often faced with arguments as of why this is not possible. Newman and Kenworthy (1999) have identified common myths about the inevitability of automobile dependence and argue why they are no reasons to continue planning for cars alone. They are mostly true for American cities and not necessarily for Vienna or other European cities. In the following, therefore only those myths are being explained that are relevant for Vienna and Klosterneuburg. Note that the numbers in this thesis do not correspond to the numbers in the book by Newman and Kenworthy.

1. *Wealth inevitably leads to automobile dependence, as people will always spend money to acquire larger areas of private space and cars. Since people constantly get richer, other urban forms and modes of transport automatically disappear.* When the sustainability approach became more and more popular, mobility and wealth have in fact become detached from each other. This was either due to the cultural preference of compact urban nodes, through stronger urban environments or just because of other priorities concerning planning.

2. *Where space is not an issue, automobile dependence is inevitable.* Low-density urban form does not automatically occur in very spacious countries.

3. *In the present age, automobile dependence is a characteristic of modern life. Cities that were developed mostly after 1945 are therefore more oriented towards car than older ones.* This is true in parts since the development of cities has changed from a rather compact form with streets made for walking over a more spread out form due to the introduction of tramways and finally the possibility for even lower densities with the wide availability of cars.

4. *Planning is not powerful enough to stop the automobile dependence created by land speculators.* Investors are able to make profit with sustainable land development but a professional praxis is required that makes sustainable development easier than development that relies on the use of cars.

5. *The standard procedures of transportation planning as well as traffic engineering lead to automobile dependence.* Those methods can be and are changed, partly due to community pressure for better public transport infrastructure and traffic calming.

6. *Local urban planning regulates automobile dependence.* Where people rely on the car, it is often difficult to introduce suitable alternatives. Particularly suburbs are difficult to deal with in that manner.

(cf. Newman & Kenworthy 1999)

As this argumentation shows, reducing automobile dependency is possible. In order to encourage people to walk, cycle or use public transport rather than the car, these modes of transport have to be made more attractive while travelling by car ought to become less attractive. Main approaches include:

- Calming traffic to slow cars down and create environments that are better suited to other modes of transport, such as walking and cycling.
- Provide legitimate alternatives to the use of cars by improving the quality of public transport, bicycle and walking infrastructure.
- Create multi-nodal centres, so-called urban villages, with mixed land use and higher density that are linked to public transport and lower the necessity to travel.
- Reduce urban sprawl and change the focus for development into the already urbanised areas.
- Balance external costs by taxing transportation more efficiently, using the generated income for the development of a more sustainable city.

(cf. Newman & Kenworthy 1999)

To successfully incorporate cycling and walking into the sustainability agenda it is necessary to connect them to the public transport system. This extends also the catchment area of the public transport and its services. Short distances can easily be overcome by walking or cycling and longer distances can be travelled by public transport. However, if people are encouraged to use public transport, the integration of the different transport modes is crucial, as people have to get to and from public transport stops either as pedestrians or as cyclists. If land use is compact and mixed, distances to amenities are generally being reduced and therefore walking and cycling encouraged. Another reason to encourage non-motorised modes of transport is that their infrastructure is cheaper to build and operate than roads for motorised vehicles (cf. ibid.). One aspect that is not further discussed here but is important nonetheless: when building this infrastructure it is not only necessary to reduce everyday distances but also to make it accessible for all.

2.3 Approach to the Sustainable City

As discussed in the first chapter, sustainable cities secure liveability and productivity in social, economical and ecological terms in the long-term while using mostly renewable resources (see page 7). In the chapters before the importance of (access to) continuous open green space and strategies for reduced automobile transport was shown. The findings there lead to the realisation, that there are urban forms that are more sustainable than others and also the configuration of the land use within the city plays a role when trying to create sustainability.

One major objective of urban and regional planning that has been around since the emergence of that profession is the reduction of urban sprawl. In this chapter it is discussed why this is an important goal and how favourable urban forms look like. Urban villages provide a concept that is offered as a guideline for developing and restructuring cities in a sustainable manner and are therefore introduced later in this chapter as well.

2.3.1 Favourable Urban Forms

Urban forms are determined by intentional planning decisions as well as indirect and coincidental effects caused by decisions concerning society and the environment. Different backgrounds of culture and economy also reflect in urban forms through different ways of urbanisation (cf. Cadenasso & Pickett 2011). Through time, these forms have changed drastically. Walled cities in early times were physically as well as socially separated from the surroundings. During the industrialisation they expanded beyond the former city walls and became permeable to trade goods and gather workers for the production of those. Later on, in post-war times, cities were further separated into new suburbs, districts of commerce and older central, lower density, cities, leading to cities as parts of a greater network (cf. Alig et al. 2004 in: Cadenasso & Pickett 2011). Density in this context can either mean the number of housing units per area unit or the ratio of built-up to open land. For this thesis, the latter is relevant as it shows in the (two dimensional, ground) morphology of the city.

Uncontrolled urbanisation often leads to low-density sprawl that takes up a lot of land, leading to high costs in the building of technical infrastructure and fragmentation of the rural areas. In order to being able to persistently provide sufficient land to the different demands of the ever increasing population it is necessary that settlements grow in a controlled manner.

The levels of urbanisation and how intense rural areas are used are also strongly interlinked. Rural areas are consumed by activities related to urban lifestyles such as tourism, recreation and holiday flats, the transfer of disturbing land uses to the edge of the city or facilities to serve the increased production and flows of energy between the different communities in urban and rural areas. By reducing the land consumption the ecological footprint can be reduced as well and the decrease of regional biocapacity is slowed down if not stopped. However, when managing land consumption, not only the quantity of urbanised land is important but also its pattern in the non-urbanised surroundings and its effects on environmental characteristics (cf. Nuissl & Siedentop 2012).

Urban sprawl usually develops in one of three forms: contiguous/continuous, leapfrogging or linear, as is illustrated in the image on the opposite page (cf. Nuissl & Siedentop 2012).

In contiguous/continuous development areas are urbanised directly adjoining to the existing urban fabric around the city. Its structure is mostly compact, only interrupted by topographic elements. Land use can be mono-functional or mixed with industrial uses in close proximity to radial routes of transport and residential as well as commercial use around sub-centres. While public transport systems work well in this form, the accessibility of open green space from within the centre can be low (cf. ibid.).

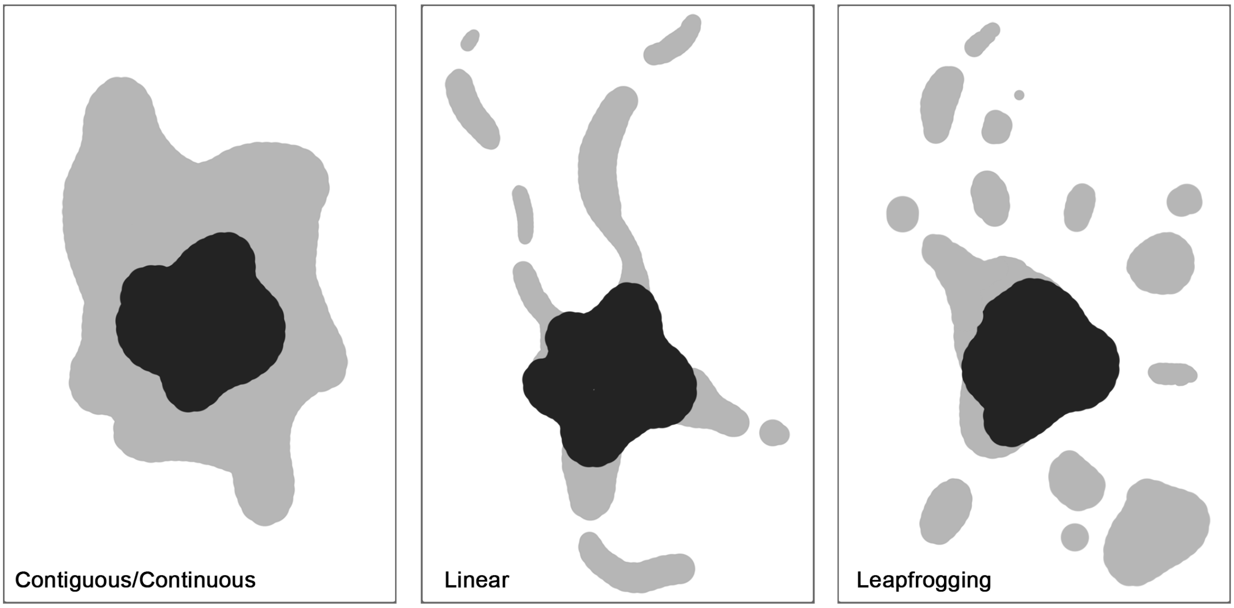

Figure 8: Types of urban sprawl (Source: by author, based on Nuissl & Siedentop 2012:7)

When urbanisation takes place along main transport infrastructure, the settlement patterns develop linear. Commuters usually prefer mono-functional residential areas; large-scale industrial or commercial use such as warehouses and shopping centres are common. This urban form is disadvantageous for natural habitats because they are being fragmented. Another negative effect is that the provision of urban amenities is inefficient (cf. ibid.).

Development in form of isolated patches away from existing urbanised areas, so-called leapfrogging development, results in separated and detached urban structures in midst of open space. Land use is mainly mono-functional with distinct industrial, commercial and residential areas. New urban areas rely on the building of new transport infrastructure and cannot efficiently be served with public transport. Open green space is fragmented, however, the accessibility of it is high in general (cf. ibid.).

Negative effects of urban sprawl affect the ecological, economical as well as social environment. Sprawl leads to the necessity to travel more and further away, and to higher costs for providing services. Planners today are mostly aware of that and its realisation led to the recommendation of the European Spatial Development Perspective in 1999 to aim for cities with short distances, following the compact city model (cf. CEC 1999 in: Nuissl & Siedentop 2012).

Compact development in opposition to sprawl has several advantages:

- high-density compact structure and mixed land use encourages the reduction of long distance journeys and therefore walking and cycling (cf. Moughting & Shirley 2005)

- lower costs for infrastructure development and maintenance than with disperse growth (cf. Frick 2008, Nuissl & Siedentop 2012)
- less land sealing and energy consumption as well as better frame conditions for social interactions due to the built environment (cf. ibid.)

However, concentric development comes with the following problem of continuous development: poorer accessibility of the surrounding open green space from the centre. Overly compact development therefore cannot be the ideal solution to restrain sprawl. A challenge for urban and regional planners is therefore to find strategies to marry the twin elements of open space and built-up space, with the benefits of compact development while keeping resulting negative effects to a minimum.

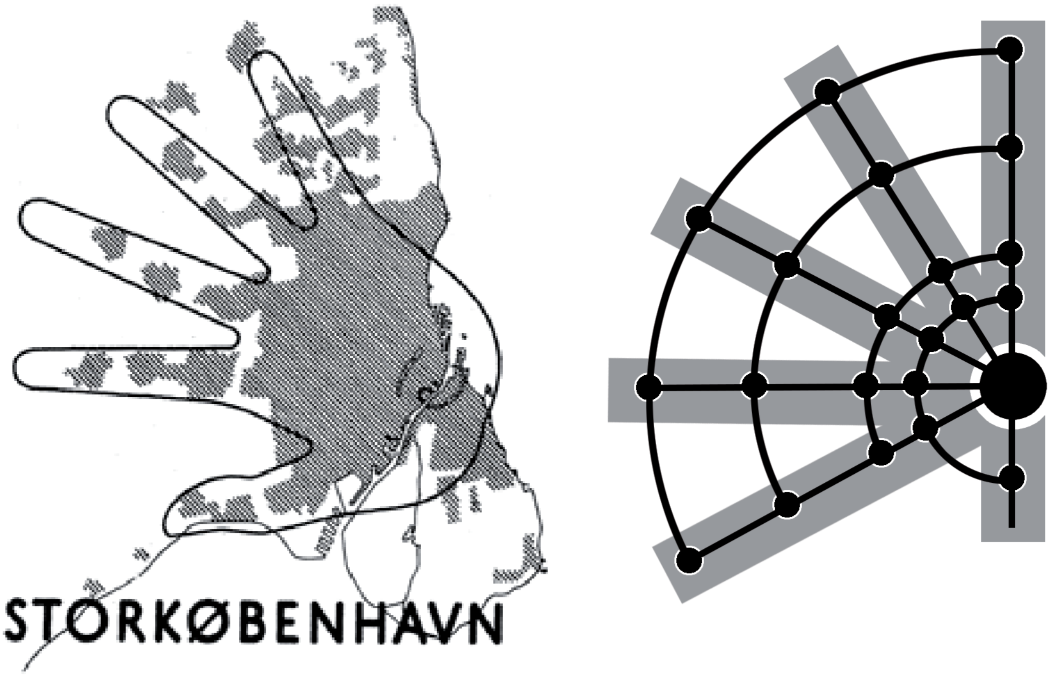

Figure 9: Copenhagen Finger Plan (Source: Government.no, s.a., modified by author)

One concept that appears to be feasible is the Copenhagen Finger Plan. Urbanisation takes place along public transport routes that lead to the city centre, providing good access to the open green space between those rays as well as to the centre. As will be seen in the next chapter, these are fractals properties.

2.3.2 From Local to City-wide

In the current "Information Age City", the boundaries of different functions are blurring. For instance work and home were formerly distinctly separate, while these categories now increasingly overlap due to teleworking (cf. Newman & Kenworthy 1999). Also because of these blurring borders between categories, functions and roles, mixed land use is advisable. New Urbanism, originating in the United States, implements an increased proportion of mixed land use back into urban development. Increasing density and introducing more mixed-use areas response to both goals of environmental enhancement and economic growth. Ideally, development following New Urbanism has the following characteristics:

- city and neighbourhood centres that are fine-grained and with a high proportion of mixed land use
- higher densities of housing and workplaces than conventional suburbs
- good accessibility of amenities that leads to
- the capacity to provide a variety of different kinds of buildings, which may adapt to changes over time
- a physical framework to enable the easy generation of employment by supporting small businesses, working from home (teleworking) and part-time multiple employment

(cf. Morris & Kaufman 1996 in: Newman & Kenworthy 1999)

A concept that implements and extends these characteristics is the model of urban villages. Bernick and Cervero (cf. 1997 in: Newman & Kenworthy 1999) determined that the level of public transport use in cities is mostly affected by density and that mixed land use additionally encourages slower forms of transport such as cycling and walking as well as lead to a generally higher local activity. Holtzclaw (1990 in: ibid.) and Neff (1996 in: ibid.) showed that one kilometre that is travelled by public transport could substitute as much as ten kilometres of travel by car. This number varies according to various circumstances but lies averagely at five. Cities can therefore be made more sustainable, hence equitable, liveable and efficient, if those qualities are strengthened within a coherent development and design strategy. This planning approach also acknowledges the desire to add community and neighbourhood values to redeveloping and new areas in the city. To be able to provide efficient infrastructure, Newman and Kenworthy (cf. Newman & Kenworthy 1999) suggest concentrating growth into urban villages and restricting it at the city edge. It should be aimed for clustered development with distinct centres of services and places for community activities. Other key elements of urban villages include:

- a central rail station
- vast landscaping such as attractive public green space but also private gardens, including green rooftops and balconies
- a mixture of different types of housing, including public, private and cooperative, with emphasis on families where it is possible, leading to spatial internal residential spaces as well as community areas
- extensive infrastructure for children to create a safe environment for creative activities in close proximity of their homes
- opportunities for recreation, including sports facilities of various kinds

- community facilities, if not within the 'village' close by, including schools, child care facilities, libraries but also centres for elderly people and possibly small urban farms
- areas that are dedicated to storing recreational equipment securely, for people who appreciate the focus on community but require additional space
- aiming for a traffic-free environment that focuses on people by locating parking places underground and linking pedestrian with bicycle infrastructure
- public spaces with defining design attributes such as water features, street furniture, art installations or playgrounds
- a good connection to the wider city with public transport while maintaining a high degree of independence concerning the meeting of needs of the local community

(cf. Newman & Kenworthy 1999)

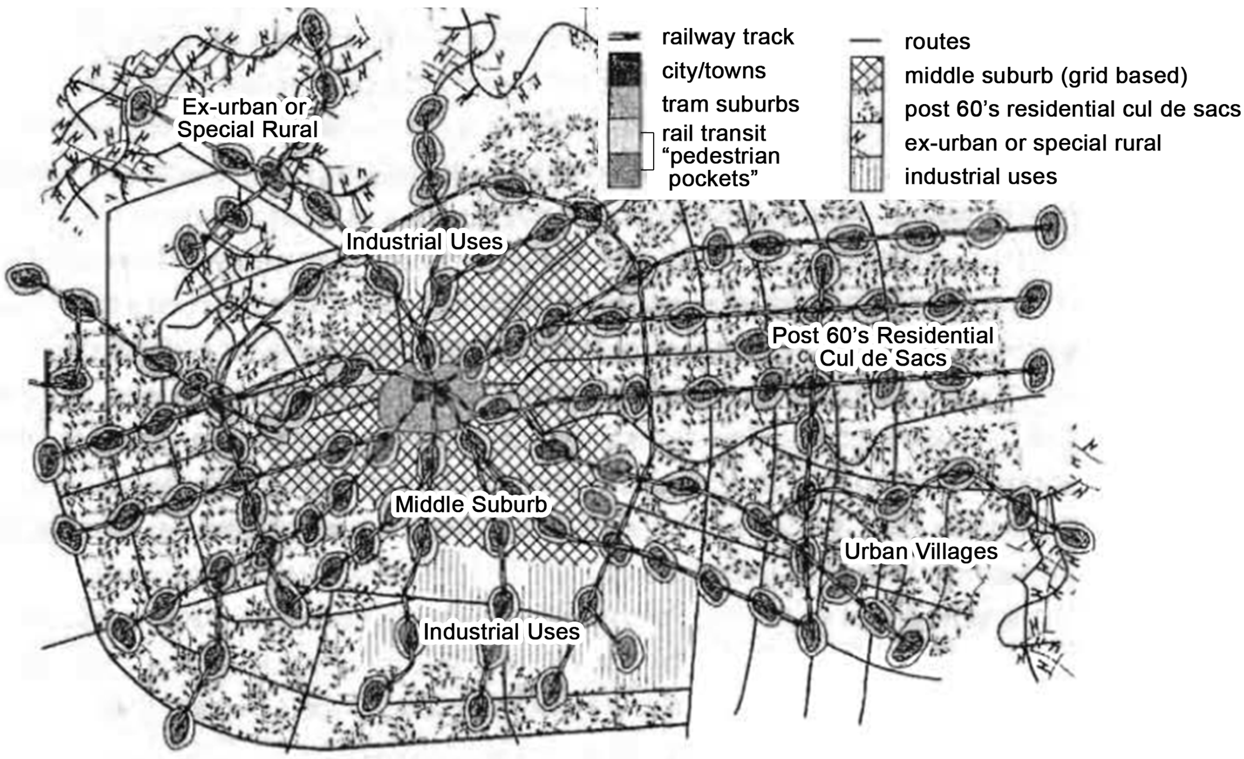

Figure 10: The future sustainable city (Source: Newman & Kenworthy 1999:185, modified by author)

In order to create a sustainable city, Newman and Kenworthy (1999:184ff) describe four necessary steps on the planning level:

1. *Revitalisation of the inner city* is key since its features are (usually) already oriented towards public transport and walking. The existent dense and mixed land uses with appropriate design characteristics encourage face-to-face activity. These qualities can then be spread into the suburbs by calming traffic in neighbourhoods and providing smaller sub-centres with inner city qualities that are supplied with good public transport

infrastructure.

2. Development has to take place *around* the *existent public transport infrastructure*, the railway system in particular. Timetables are to be coordinated with each other in order to allow for an easy use of the system.

3. To make urban sprawl less attractive, a combination of different investment in highways that allow citizens to reach the green surroundings and changing zoning procedures to conserve rural areas at the city fringe is needed. This strategy is more likely to be accepted if not only the sustainability goal is emphasised but also the market-based, economic advantage is apparent.

4. The *extension of the public transport network* into currently under-served suburbs supports the establishment of new urban villages. A challenge here is the funding of new railway infrastructure. However, involving land development around train stations helps with financing and making the establishment of new sub-centres more feasible. This supports the provision of more local amenities and increases the accessibility of other destinations within the city, without having to rely on cars.

Balancing the priorities of the different modes, particularly encouraging the use of public transport, cycling and walking by linking different land uses is the main objective. Creating and sustaining feasible local sub-centres that generate improved self-sufficiency help achieving this goal. By linking these sub-centres with each other by public transport, the city benefits on an economical, social and environmental level. Economic benefits arise as such cities are globally competitive and offer good urban environments for living and working. Such cities are likely to automatically focus on central areas and connected sub-centres, which in turn favours providing quality public transport and pedestrian infrastructure. Socially, the city profits from the community movements to reclaim urban open space, bringing the community together rather than separating it with private spaces. Environmental benefits consist of the decreased use of resources and lower production of waste as well as improved liveability. This is achieved by changing to technologies for water provision, waste management and energy supply that are more on a community-scale, including community gardens that are intensively cultivated (cf. Newman & Kenworthy 1999).

3. Multi-Scale Planning as a Sustainable Approach

So far, sustainability goals have been examined on a rather intuitive level, based on qualitative observations rather than quantitative findings. One sustainable approach, which aims at achieving the earlier discussed goals by applying strict scientific, quantitative findings for better reliability, is *Multi-Scale Planning*.

In the following, *self-organisation* and *complexity theory* is discussed and why urbanisation following *fractal* logic leads to sustainable urban forms and structures. Finally it is explained how the software *MUP-City* uses these insights in order to support planners in making decisions by providing a computer-based system to test different options through scenario development.

3.1 Complexity & Self-Organisation

Urban dynamics can be regarded as continuous reciprocity of planners and their plans while the final urban form and structure cannot be determined by either of them. Basically, the city is regarded as an artefact, the result of intentions and needs of people. Planning brings in the rational aspect that is needed to implement those intentions and needs (cf. Portugali 2009).

Planning theory and practice today are based on the presumption that city characteristics are predictable and that their behaviour therefore can be forecast when the right data, information and models are provided. Recent theories suggest however, that cities are in fact complex systems that behave non-linearly and self-organisationally (cf. Portugali 2000). Human systems, such as cities, are complex and adaptive, and subsets of other complex and adaptive ecosystems (cf. Jokinen et al. 1998 in: Newman 2009). Generally, the city was perceived as a place with a number of distinct structures such as a central market place, clear routes that connect the centre with other areas, e.g. suburban zones, neighbourhoods or sub-centres, and separated industrial areas. The city is presumed to be surrounded by farmland. However, this traditional picture is no longer valid as cities have been recognised to be a lot more complex (cf. Batty 2005).

There are various elements that influence the evolution of the city. Batty identifies five drivers that are essential for understanding the manner of change: randomness, historical accident, physical determinism, natural advantage and comparative advantage. Randomness implies that decisions are made without particular reason and can only be explained by whim. What is meant by this term is that additionally to deliberate decisions there is a degree of “noise” to making decisions since the people in charge are not a homogeneous mass. Historical accident is a little easier to understand: cities were often founded based on the practicability at that time. This still influences cities today in form of comparative advantages. It can be safely assumed that decisions are often made based on expected comparative advantages and that this leads to a diversity of spatial structures within the bigger context of systematic organisation. Physical determinism covers the possibility of urbanisation of certain areas due to physical reasons. Those physical restrictions can be seen as the geometric and geographic framework in which development takes place. Natural advantage and comparative advantage finally deal with the natural, physical, form of advantage and the economic, man-made one (cf. Batty 2005). Each of these categories includes a variety of influence factors that add to the complexity.

The spatial structure of cities is the result of a history of constant change that happens incrementally (cf. Salingaros 2005). Human problems are in general met in an efficient manner by following rather simple rules of self-interest and self-governance in order to react to influences from the surroundings. Human settlements are hence characterised by self-organisation. Adaptations take place on a small scale; beginning at one person that influences the household, in a next step the neighbourhood and eventually the whole town. It is highly suspected that in order to create sustainability in urban systems, bottom-up evolution is essential. Because so many small adaptations happen on a small scale, the final result becomes incredibly complex so that it is impossible to design it in a top-down approach (cf. Mehaffy & Salingaros 2011; Alexander 1964 in: Batty 2005).

Complex systems are normally in a condition that is far from equilibrium and comprise chaos, fractal structures and similar phenomena. One popular way to make self-organisation visible is the Bénard experiment. The French physicist Henri Bénard made the observation that, when heating a liquid in a vessel from below, heat is transferred by conduction and it is not possible to observe any macro-motion as long as the differences in temperature between hot bottom and colder top is low. An increase in temperature difference, however, leads to an unstable, chaotic movement after which suddenly a notably ordered pattern emerges. The first random moving molecules begin to coherently move in rolls of a much larger size than the molecules themselves. In a round vessel a hexagonal pattern can be observed that forms through the hot liquid that rises in the centre of the convection cells and the falling cooler liquid on the walls of the cells. As there is no external power forming this pattern, it spontaneously emerges by self-organisation (cf. Portugali 2000).

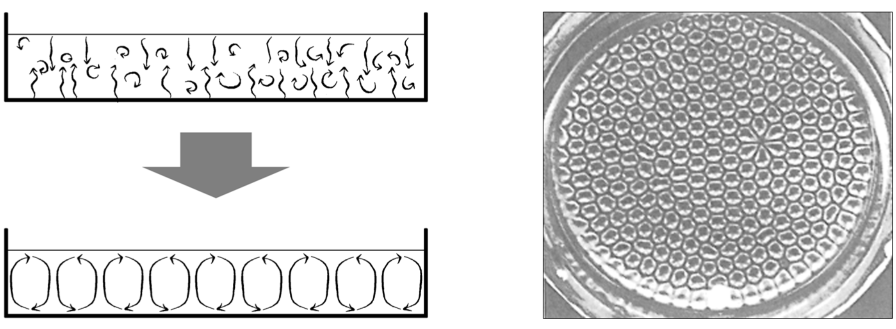

Figure 11: The becoming of Bénard cells (Source: by author, based on Portugali 2000:50)

The Bénard experiment shows three main characteristics of self-organisation (cf. Portugali 2000):

1. Open systems, which therefore interact with their surroundings, can reach spatio-temporal structures as a result of energy and matter flow and are able to maintain them in conditions that are far from equilibrium.

2. This allows spontaneous self-organisation and also the emergence of new structures and behaviours. Self-organised systems can therefore be regarded as being creative.

3. Two aspects of complexity can be found in self-organised systems: it is impossible to explain causal relations between their countless elements and a complex network of feedback loops interconnects these elements in a non-linear way.

3.1.1 Development in Bifurcations

Bifurcations are qualitative changes in the dynamics of a dynamical system that are caused by changing parameters (cf. Izhikevich 2007). The behaviour of social systems as well as of ecosystems is typically hard to predict since uncertainty is a characteristic of complex adaptive systems. Therefore, our prognoses for the future are merely brief guides (cf. Spash 2002 in: Newman 2009). Cities are not regarded as chaotic but as ordered structures that can be explained by complexity theory. Looking at cities in the long term, their evolution shows a long period of a more or less stable state that is followed by a shorter time span of intense fluctuations or chaos that eventually leads to a new level of steady state and stable structures. The evolution of cities is therefore not continuous but happens via bifurcations. Similar to what can be observed in the Bénard experiment. Each evolutionary progress is a transition to a controlled, steady, macro state that origins in a chaotic micro state. This interplay of chaos and order can also be seen in daily routines within the city, for example in the movement of cars or pedestrians that is typically alternating between stable and unstable motions (cf. Portugali 2009).

As an example, the image on the opposite page shows the evolution between the Early Bronze Age and the Iron Age for settlement systems in Palestine. From top to bottom: sequences of order and chaos, the evolutionary process as interplay of agriculture and urbanism that contains interruptions by the collapsing urban system, and the calculated changes of population (cf. Portugali 1994, 2002 in Portugali 2009).

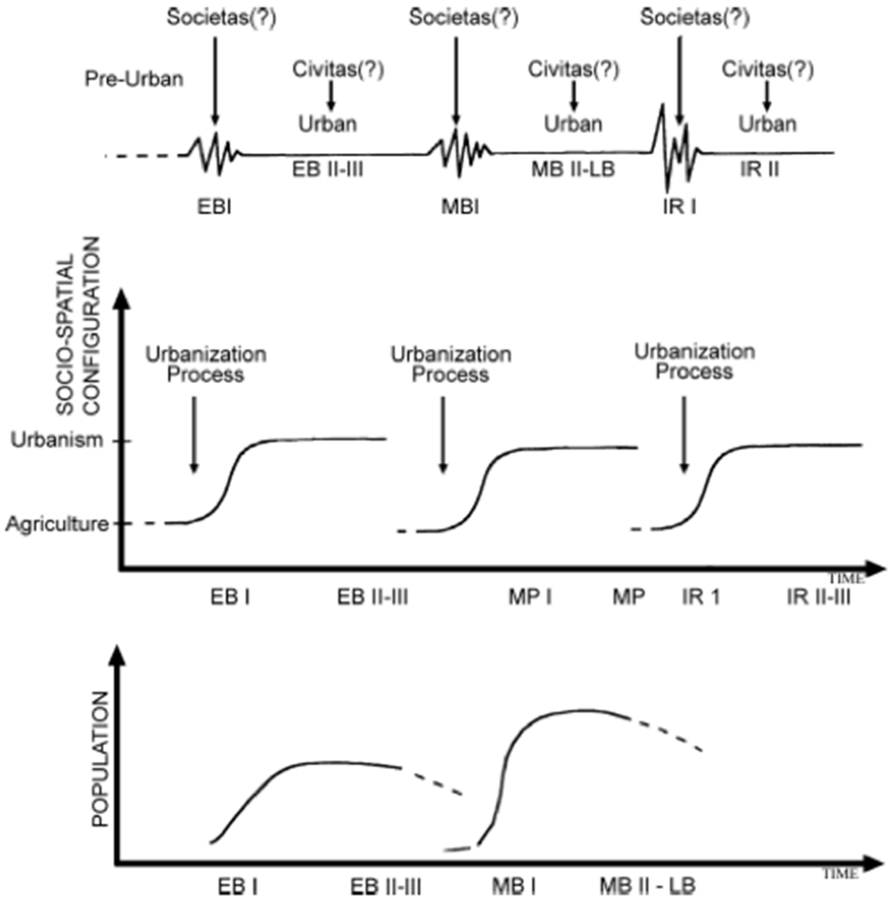

Figure 12: The evolution of settlement systems in Palestine from the Early Bronze Age period to the Iron Age (Source: Portugali 2006 in: Portugali 2009:15)

3.1.2 Hierarchy and the Power Law

Basic organising devices to describe and measure urban functions across different spatial scales are hierarchies. They provide a framework for relating the local to the global scale and vice versa as they link elements of urban systems to urban systems themselves on different scales, while structural elements are recurring on those scales (cf. Berry 1964 in: Batty & Longley 1994).

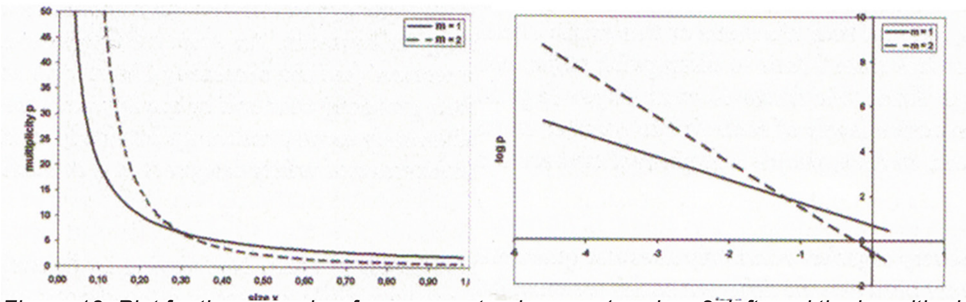

Figure 13: Plot for the power law for exponent-values m=1 and m=2, left, and the logarithmic equivalents, right (Source: Salingaros 2005:66)

A strong hierarchy is visible with the Central Business District (CBD) within a city that is completed with additional, smaller district centres throughout town, a higher number of neighbourhood centres and a large number of local centres. For the leisure and the educational systems an identical structure exists (cf. Batty & Longley 1994). This regularity that can be observed in various natural phenomena following the rank-size rule or rank-size distribution, which is explained by the power law, a universal rule for the distribution of sizes. Salingaros describes the formula of the power law to be “one of the few scientific formulas that the urban designer can use to create more coherent and more human urban environments ” (Salingaros 2005:67).

The most important, and quite straightforward, formula is shown below. The variable m has an empirically determined value that ranges between 1 and 2, c is a constant that is not further explained by Salingaros in the consulted literature, x indicates the size of an element and p how many of these elements there are (cf. Salingaros 2005).

$$px^m = c \qquad \Rightarrow \qquad p = c / x^m$$

3.1.3 Central Places as a Hierarchical Conception

Based on these concepts of hierarchy are concepts of central places such as Howard’s Garden Cities (1902) that are supposed to function independently from larger, central cities and the theory of central places by Christaller (1933, cf. Batty & Longley 1994). Howard wanted to reorganise the industrial metropolis in order to re-introduce the human scale. His concept of the garden city is meant to cater for 250.000 people of whom 60.000 live in the central city and the rest in six surrounding smaller cities. However, the hierarchy here only exists between the different towns. Much later the differentiation within the city introduced a hierarchy with the neighbourhood idea (cf. Lichtenberger 1986).

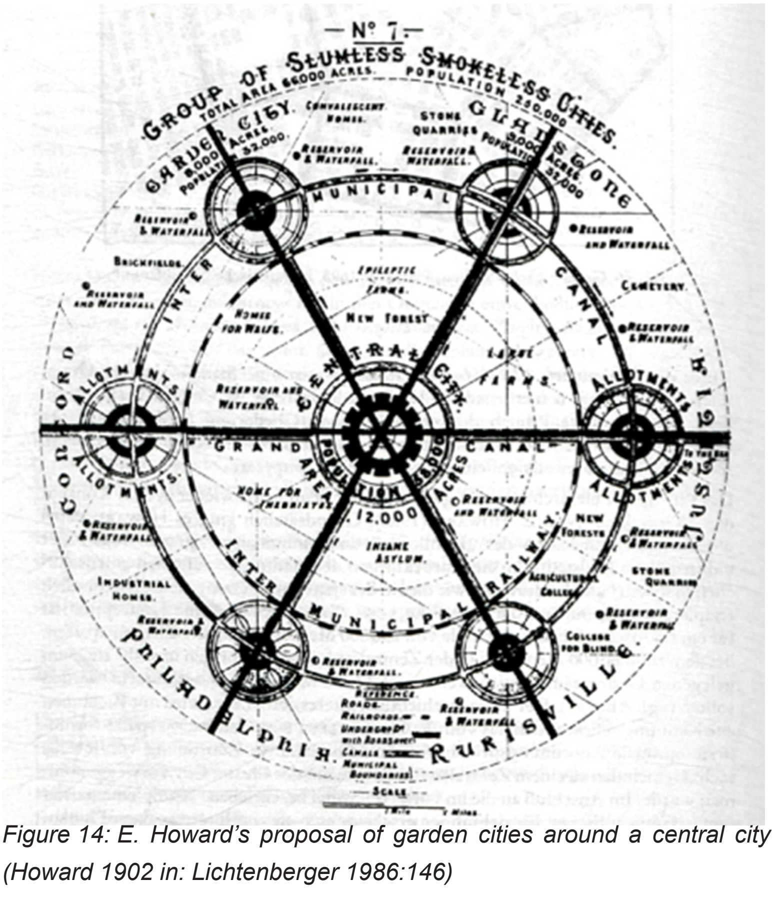

Figure 14: E. Howard’s proposal of garden cities around a central city (Howard 1902 in: Lichtenberger 1986:146)

The city is seen as a central place that interlinks the region and other cities within a hierarchical network of central places. While Christaller (1933/1966 in: Portugali 2009) determined the hierarchy of cities solely by their tertiary activities, Lösch expanded the concept and regarded the city as a place for all types of "production, consumption, transportation and political activities" (Lösch 1954 in: Portugali 2009). The image below shows the spatial demand cone with its market area on top, the development of market areas from the large circle to the small hexagon and on the right side Lösch's derived system of central places with their market areas (cf. ibid.).

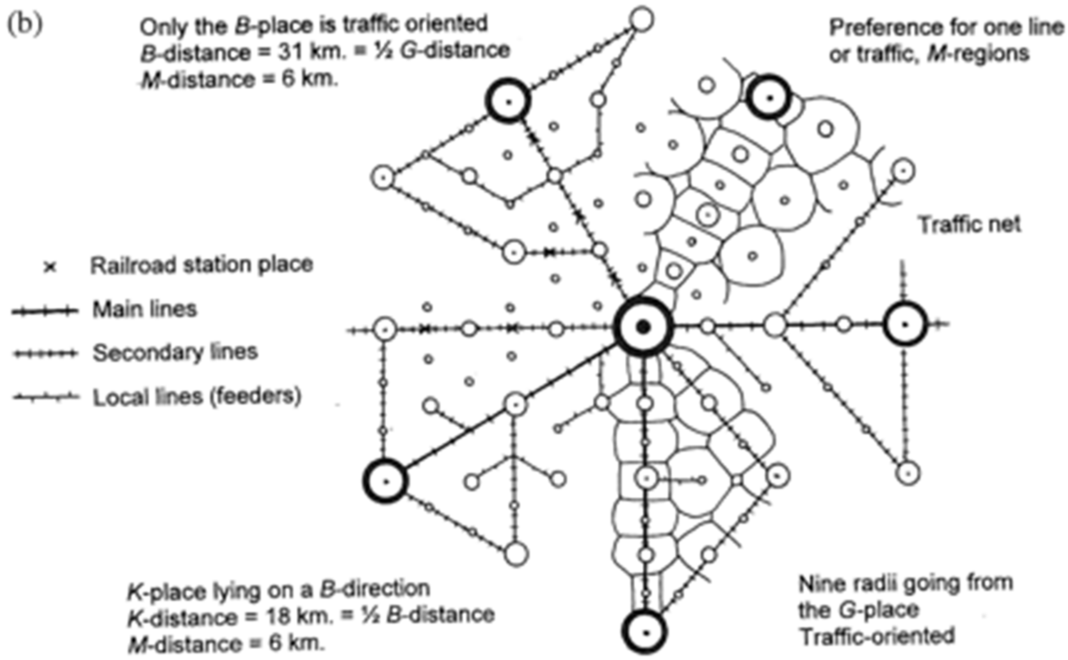

Figure 15: System of central places developed according to the traffic principle (Source: Christaller 1966 in: Portugali 1999:22)

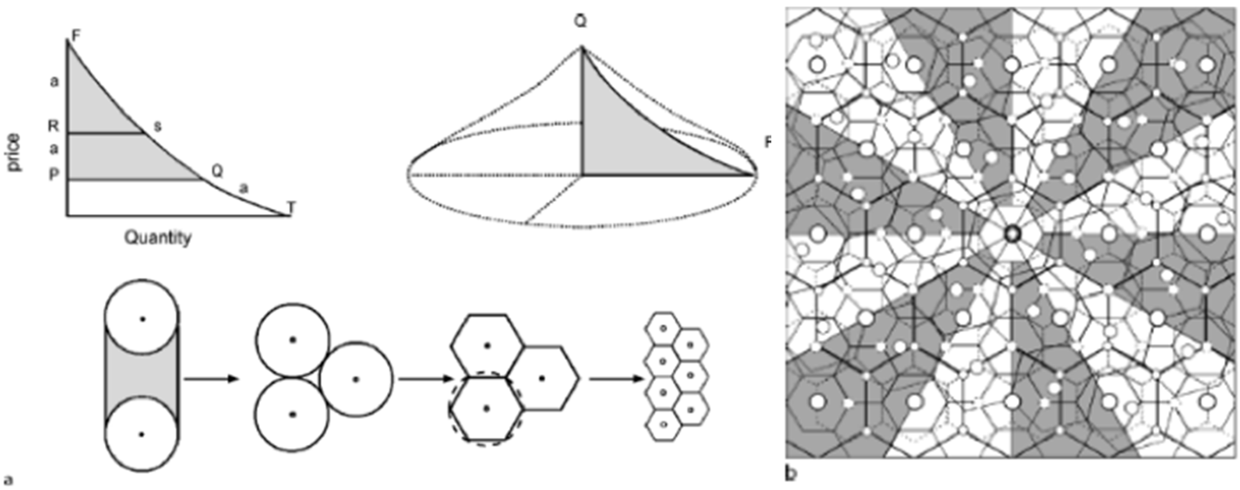

Figure 16: Derivation of Lösch's system of central places. (Source: Lösch 1945 in: Portugali 2009:5, modified by author)

3.2 Fractals and the Fractal City

Human instinctively get a natural feel by the scaling hierarchy of urban elements, and react correspondingly. Relating to one’s surroundings happens on the smallest scales; therefore the urban environment should supply humans who are in it with information so they are able to connect to it. In order to create a functioning, liveable [and sustainable] city, the different, distinct, scales have to be linked to each other, from the smallest to the largest. Mathematically speaking, meaningful environments are those that show fractal characteristics. Therefore it can be argued that fractal, well-interconnected cities equal human cities (cf. Salingaros 2005).

Mandelbrot is widely known for having developed a (mathematical) language to describe fractals in order to describe and analyse the geometry of nature in opposition of Euclidean geometry. Characteristic for fractals is that their irregularity and fragmentation is identical at all different scales (cf. Mandelbrot 1991). Fractal cities are following an inverse-power scaling law: there are few large elements, multiple intermediate sized elements and many small sized ones with a high connectivity (cf. Salingaros 2005).

When talking about fractal cities it is meant that the broken, fractal lines can benefit urban planning as it for example makes human interactions easier and is more permeable for pedestrian paths rather than taking mathematical structures literal. The two main characteristics of (mathematical) fractals are that they have structure on all scale levels and that they are self-similar. The latter means that parts of a fractal are similar to other parts of the same fractal, also on different levels of scale (cf. ibid.).

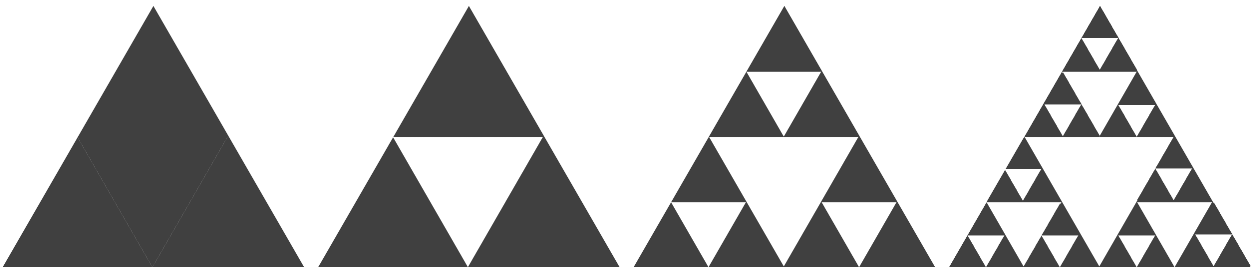

Figure 17: Sierpínski Triangle as an example of a simple fractal, with an equilateral triangle as initial form (Source: by author)

A popular example for a real world fractal is the calculation of the length of coastal lines. The smallest scale is specified by the observer, it could be several meters or as fine as a grain of sand. The length of the coastal line depends on the length of the measuring rod that is used. It increases with the decrease of the length of the measuring rod (cf. Mandelbrot 1991).

Traditional pedestrian cities are fractal because they work on all scales due to continuously incremental additions in opposition to newer cities where large parts were built within shorter periods of time and work better on larger scales (and with automobiles as main means of transport). The city lives from its interlinkage of different, complementary nodes. In order to establish and maintain those connections, the transport network has to work on multiple layers. Additionally, the transport infrastructure has to be adequately fine-grained in order to provide the choice of alternative means of transport and creates numerous possible paths. Mono-functional areas on the other hand do not encourage interaction and exchange of information and therefore do not add to the liveliness of the city. Another aspect that leads to lively cities is the diversity within area units. Kauffman (1995 in: Salingaros 2005) has found that a minimum variety of different types is needed in order create an autocatalytic set. For cities this means that a diversity of nodes needs to be close to each other in order to create a lively city. Those nodes not only include shops and services, workplaces and homes but also green spaces. Public green space should be distributed also on all scales, from one large green area to small parks in neighbourhoods.

The connection of nodes has to take place on all scales in order to function. Some types of physical connections are competing with each other, such as transportation on ground level. Naturally, bigger and stronger connections, such as established by car, replace smaller and weaker connections such as pedestrian-based ones (cf. Salingaros 2005).

3.3 Using a Fractal Logic for Planning: MUP-City Software

The MUP-City software is a so-called decision support system, a computer-based geo-information system that supports decision-making concerning urban and regional planning questions. The explanations of MUP-City in this chapter was taken from Tannier et al. (2010a) and can be found in detail and with exact formulas in the final report on the initial project (Tannier et al. 2010b).

MUP-City (Multi-scale Urban Planning for a sustainable City) is a computer based decision support system that is being developed at Université de Franche-Compté et de Bourgogne to create and evaluate scenarios of urbanisation based on multi-scale and fractal logic. The software follows four main principles:

1. Reduction of urban sprawl that is too diffuse, disperse and far away from local centres in order to build an efficient public transport system and to secure good accessibility of different amenities.

2. Improvement of the diversity of built-up forms to avoid standardisation of landscapes and to encourage social diversity.

3. Reduction of the fragmentation of built-up areas to conserve biodiversity and valuable landscapes but also agricultural areas.

4. Preservation of open green space that reaches into the urban centre in order to ensure

good ventilation of higher density areas and good accessibility to green areas for recreational purposes.

These goals are tried to be achieved by following a fractal logic that allows for good accessibility and variety in amenities (cf. Frankhauser & Genre-Grandpierre 1998, Cavailhès et al. 2004 in: Tannier et al. 2010a) while at the same time minimising the fragmentation of built-up and non-built-up space (cf. Frankhauser 2000 in: Tannier et al. 2010a). The other reason is that it is believed that certain forms of fractal cities allow the minimisation of land consumption without having to increase the density of built-up areas (cf. Thomas et al. 2007 in: Tannier et al. 2010a). There are three objectives implemented in the model: minimisation of the number and the length of travels by car by providing good accessibility of a variety of urban and rural amenities, reduction of land consumption while meeting the qualitative and quantitative demand for housing, and avoiding fragmentation of built-up areas where the positive effects of high accessibility and environmental benefits are being sufficiently provided.

As the name implies, the main feature of the software is its multi-scale approach, based on fractal principles. To find areas that are suitable for further urbanisation, four additional rules are implemented: accessibility of shops and services (based on daily and on weekly frequency), accessibility of open green space and proximity to the existent transport network. These rules are applied on different scales, from building-size to great parts of the scrutinised area.

Objectives	Rules
Avoidance of fragmentation of built-up and open space	Ensuring high accessibility of open space by preserving its connectivity
Minimisation of the number and length of travels by car and ensuring high accessibility of rural and urban amenities	Ensuring high accessibility of commercial and service centres of daily frequency
	Ensuring high accessibility of commercial and service centres of weekly frequency
Limitation of land consumption	Proximity to existing roads

Table 1: Urbanisation objectives and rules that are applied in order to achieve them (Source: by author, based on Tannier et al. 2010a:7)

In order to be able to model the area under scrutiny, layers that hold information of the existing buildings, amenities on two levels (level 1 for daily and 2 for weekly frequency) and road network therefore have to be created in a Geographic Information System, short GIS. In the next step a decomposition is carried out. This creates a grid whose cells each contain information on the presently existent buildings, accessibility to amenities of different kind and distance to the existing road network.

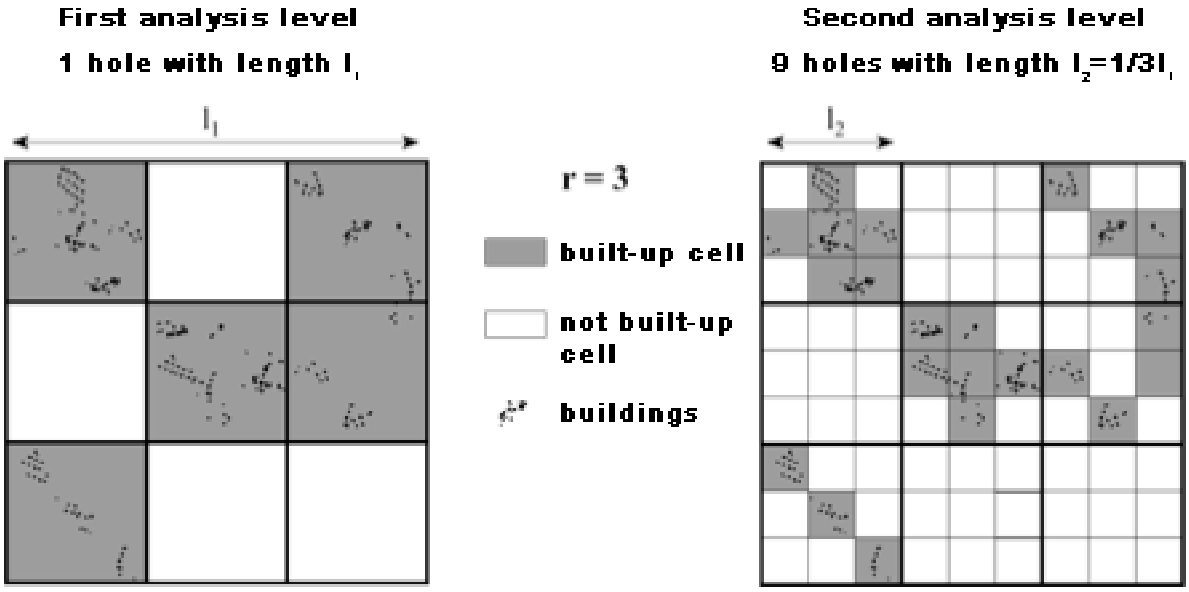

Figure 18: Multi-scale decomposition (Source: Tannier et al. 2010a, modified by author)

In the version that is worked with for this thesis, 0.8beta, also information on the distance to green areas is included.

The decomposition is carried out on multiple scales, down to where the cell size equals the size of the buildings, 20m. Each hole contains 9 cells that each become holes on the next level and contain 9 more cells. The number of cells that a hole contains is determined by the reduction factor, which is set at r=3 as this has proven most suitable in the context of urbanisation. The reduction factor also determines the side length of the cells:

$$l_2 = (1/r)l_1$$

In addition, the calculation of the fractal dimension D is possible using the reduction factor r and the number of built-up cells N on each scale level:

$$D = \frac{\log N}{\log 1/r}$$

The fractal dimension can be seen as a kind of urbanisation model as it expresses the homogeneity of the spatial distribution of built-up and non-built-up areas across the different scales (cf. De Keersmaecker et al. 2003 in: Tannier et al. 2010a). A fractal dimension D=1,46 corresponds with an observed value N_{obs}=5 when the reduction factor r is 3. This is characteristic for high internal diversity and a favourable hierarchy in the urban system. The number of urbanised cells can be raised to N_{max}=6 without losing the multi-scale characteristics. However, the fractal dimension should be kept below 1.8 in order to maintain the hierarchy of open spaces (cf. Frankhauser 2004 in: Tannier et al. 2010a). Since the observed number of urbanised cells Nobs is the mean value of the number of urbanised cells in each hole across the different scales, it is possible that N_{obs} is in some cases superior to N_{max} even if N_{obs} is generally inferior to N_{max}.

In order to create fractal structures, an iterative function system is used. This is a system of mathematical functions that allow the step-by-step construction of a fractal based on matrices of a fractal generator.

The earlier mentioned diversity within cells is calculated with the help of the Zysno-Zimmermann-Operator as follows:

$$Y_{ij} = \left[\mu(n_j)^{\mu(\delta_j)}\mu(d_{ij})\right]^{1-\mu(d_{ij})} \cdot \left[1-(1-\mu(n_j)^{\mu(\delta_j)})(1-\mu(d_{ij}))\right]^{\mu(d_{ij})}$$

Y_{ij} expresses the accessibility of a cell i to a cluster j

$i = (1,2,\ldots k)$ is the ensemble of cells

$j = (1,2,\ldots l)$ is the ensemble of aggregated shops and services, i.e. *clusters*

n_j is the number of shops and services within a cluster

δ_j is the diversity of amenities, i.e. the number of different types of amenities within a cluster

d_{ij} is the measured distance, following the street network, between a cell i and a cluster j

The evaluation of the accessibility of a cell is given by φ_i and calculated as follows:

$$\varphi_i = 1 - \prod(1 - Y_{ij})$$

The functions $\mu(n_j)$, $\mu(\delta_j)$ and $\mu(d_{ij})$ for shops and services that are frequented on a daily and weekly basis are evaluated based on fuzzy logic, as can be seen below:

MUP-City strictly follows the principle of fractal urbanisation that leads to the preservation of open space on a global down to a local scale. Therefore the user can only choose additional cells for urbanisation as long as N_{max} is not reached, and if they lie within a hole that can be urbanised. Therefore the choice of N_{max} and r, that subsequently influences the multi-scale decomposition, highly affects the form of urbanisation that is proposed by MUP-City.

The formerly mentioned four rules are applied to evaluate each cell of each hole in terms of their suitability for urbanisation. In order to do so, for each rule certain criteria are implemented:

1) *The evaluated cell has to connect with a built-up cell and the building of the evaluated cell must not cut off access to open space from the surrounding urbanised cells.*

Criterion: Number of non-built-up cells around each cell, in a Moore neighbourhood, that directly connects to the cell that is being evaluated.

2) *The evaluated cell has to be sufficiently close to the next centre of shops and services that are frequented on a daily basis.*

Criteria: Distance between the evaluated cell and the centre of shops and services that are frequented on a daily basis and number of the diversity of establishments in each centre.

3) *The evaluated cell has to be sufficiently close to the next centre of shops and services that are frequented on a weekly basis.*

Criteria: Distance between the evaluated cell and the centre of shops and services that are frequented on a weekly basis and number of the diversity of establishments in each centre.

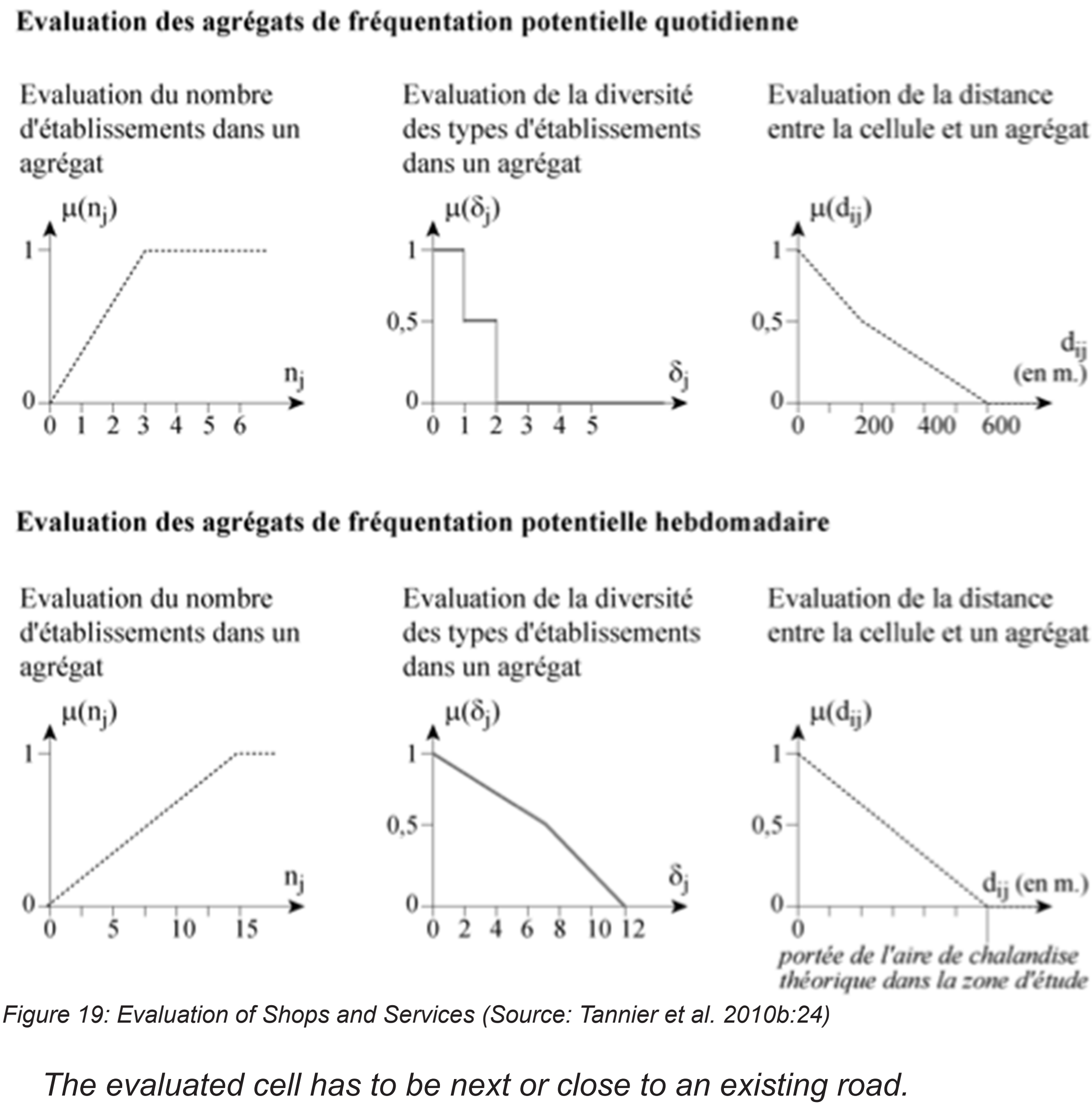

Figure 19: Evaluation of Shops and Services (Source: Tannier et al. 2010b:24)

4) *The evaluated cell has to be next or close to an existing road.*

Criterion: Distance to the existing road network.

All distances are measured along the existing street network.

Each rule returns a figure between 0 (not suitable at all) and 1 (maximum suitability) in each cell that expresses the suitability for urbanisation concerning the specific rule. In the next step, those results are aggregated to determine the average overall suitability for urbanisation for each cell. The rules are deliberately not weighted because the aim of MUP-City is to test different urbanisation scenarios rather than suggesting one perfect solution.

The ex-post evaluation is based on eight criteria:

- the average distance of each built-up cell to the closest shops and services of daily frequency
- the average distance of each built-up cell to the closest shops and services of weekly frequency
- the average number of shops and services within 400m of reach, i.e. within walking distance
- the average number of shops and services within 2000m of reach, i.e. within cycling distance
- the part of built-up cells that have at least one adjoining free cell
- the average number of non-built-up cells adjacent to every free cell
- the average distance of every built-up cell to the limits of the built-up area
- the part of built-up cells within 5m of the limits of the urbanised area

(cf. Tannier et al. 2010b:29)

Since the software only indirectly includes the time component, it is a static cellular automaton. (A short introduction to cellular automata can be found in the appendix of this thesis.) However, by repeating the urbanisation of cells, the passing of time can be simulated in discrete time periods in opposition of continuous.

An overview over the process of scenario development with MUP-City is shown on the opposite page.

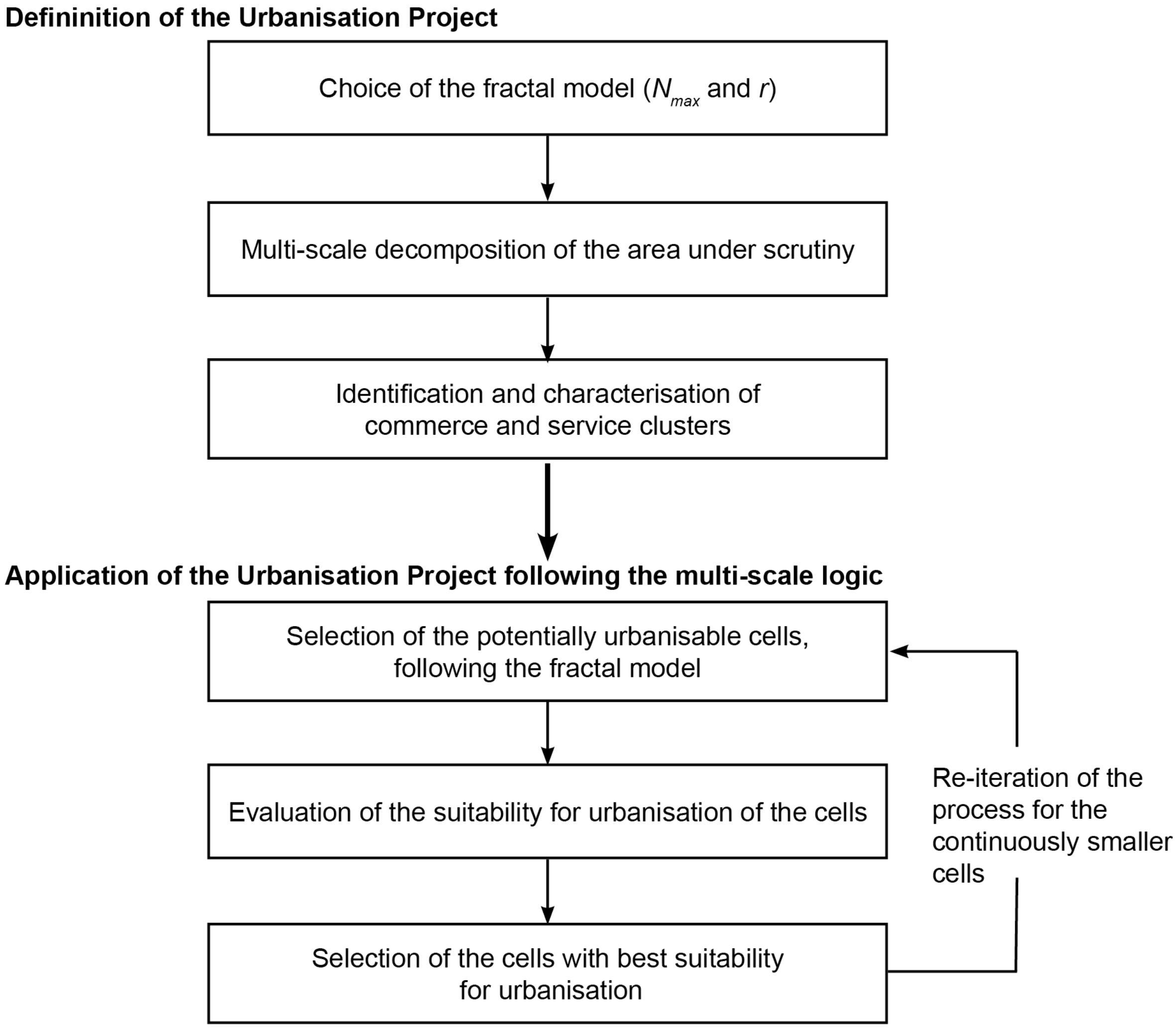

Figure 20: Process of Scenario Development with MUP-City (Source: adapted from Tannier et al. 2010a:12)

II Practical Application of Multi-Scale Planning

In this second part of the thesis, the process of applying MUP-City to a small city in the periphery of a metropolis is being examined.

First, the city that is being scrutinised with MUP-City, *Klosterneuburg*, is introduced. To enable a critical examination of the results that the software provides, several aspects are looked at: the *natural setting* between the two landscapes of the Vienna Woods and the Danube Valley, its *historical development* and the *planned future development* on the local and the regional scale.

After this, the process of the *data preparation* is described. This section covers the technical aspects that are important for using the data with MUP-City as well as working with publicly available data and the open source software QGIS.

Finally, two scenarios are developed with MUP-City. The existing state is analysed, examining the accessibility of cells on different scales under the viewpoint of the supply with daily- and weekly-frequented amenities and public transport of different areas within the city. It is also looked at the suitability of cells for urbanisation in the future if amenities as well as existing street network stay unchanged. A second scenario then is developed for a part of the town to test how the accessibility of certain areas alters if amenities and public transport stops are changed and which cells are under these changed circumstances suitable for future urbanisation. In this scenario it is also shown how future urbanisation could look like in discrete time spans.

4. Area under Scrutiny – Klosterneuburg

For this thesis, the city of Klosterneuburg was chosen to demonstrate the functioning of the software MUP-City. It is suited to this purpose as it is rather small and well distinguishable from its neighbour towns.

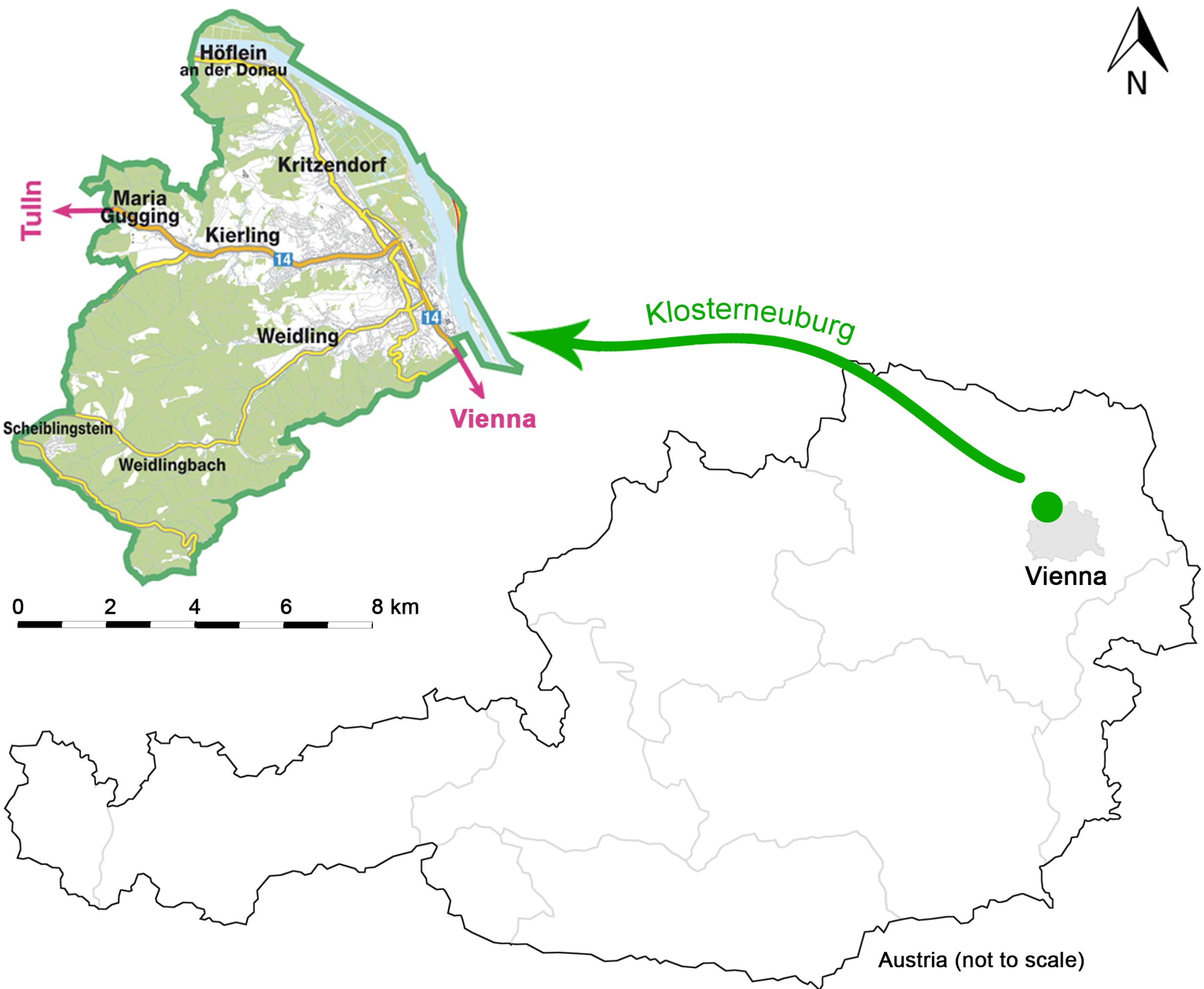

Figure 21: Location of Klosterneuburg in Austria (Source: ALEXXW 2009, modified by author) and overview of Klosterneuburg with its cadastral subdivisions (Source: Schubert & Franzke, s.a., modified by author)

Klosterneuburg lies in the North of Vienna in the federal state of Lower Austria and has roughly 26’000 permanent residents. The total area of $76km^2$ is shared by the cadastral subdivisions (cf. Stadtgemeinde Klosterneuburg s.a. a). In its history, Klosterneuburg underwent quite some changes and even became briefly the 26^{th} district of Vienna in 1938 together with the villages of Gugging, Kierling, Höflein, Kritzendorf, Weidling and Weidlingbach. When the town regained independence again in 1954, these villages were incorporated into Klosterneuburg, thus becoming the third largest town in Lower Austria (cf. Stadtgemeinde Klosterneuburg s.a. b).

While the central town of Kierling has a somewhat urban flair, the other cadastral subdivisions are clearly rural. What sticks out when visiting Klosterneuburg are the numerous small houses near the Danube. They are mainly used as weekend homes and as summer huts and particularly in warm seasons these neighbourhoods are very vital.

Figure 22: The church and the main road of Höflein (by author)

The position in midst of open green space allows for countless outdoor activities. Along the Danube there are a couple of restaurants and lodging houses particularly advertising to active guests, as can be seen in the image below.

Figure 23: Signs for the Danube Cycle Track, a restaurant and a hotel and the train station in Kritzendorf (by author)

4.1 Natural Setting between Vienna Woods and Danube Valley

The municipality is located between two major landscapes: Vienna Woods and Danube Valley. Being also at the edge of the Alps, the landscape is characterized by numerous ridges (cf. Fink 1992), which results in the town being quite hilly as well. This, amongst other factors, allows for wine growing, which is vastly done in Klosterneuburg. The vineyards have a distinctive impact on the scenic perception of the region. Also, being positioned between forest and wetlands puts the town in the ecologically beneficial situation of not acting too much as a barrier within single habitats of the same kind.

The flood plain at the Danube consists of various channels with different positions and connections to the stream and to the ground water and is an important reservoir of the latter. The town's water supply is partly provided by the flood plain (ibid.). This part of town is particularly popular for sports and recreation and also hosts the major infrastructure for those types of use, including an outdoor swimming pool and the indoor swimming pool and sports centre "Happyland". However, there is also the danger of floods, which has led to visible structural measures.

The Vienna Woods as biosphere reserve has been acknowledged by UNESCO in 2005, which makes it this kind's largest conservation area in Austria. The declaration as biosphere reserve made it necessary to classify different zones: core areas and care zones, as well as development areas (cf. BPWW 2010a).

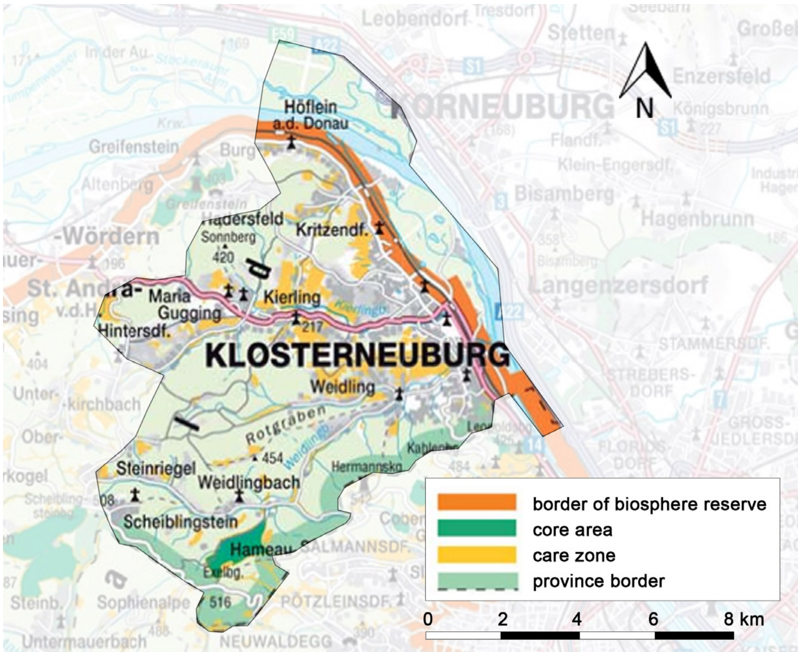

Figure 24: Biosphere reserve in Klosterneuburg (Adapted from Schubert & Franzke 2011)

Core areas are areas that are solely reserved for nature and therefore are mandatory to be protected by law. In Lower Austria they have been declared as nature protection areas and exclusively consist of woodland (cf. ibid.). As can be seen in the image above, in Klosterneuburg only one relatively small patch of forest in the South falls into that category.

Considerably bigger areas have been declared as so called *care zones*. Those are meant to conserve and take care of biotopes that have been anthropologically created or are largely influenced by human use and have developed a high biodiversity because of that. Meadows and pastures are typical examples for such types of landscape. At the same time those care-dependent zones function as buffers to protect core areas from impacts (cf. BPWW 2010b). A fair amount of those are in Klosterneuburg vineyards from the monastery and numerous other winegrowers.

The areas of the Vienna Woods that are not explicitly declared as core or care areas are *development areas*. They take up by far the most space and are meant to be the people's space for living, working and recreation. It has to be considered to take care of the environment also in those areas and to develop economic ways that are benefiting people and nature equally. This can for example be environmental friendly and socially compatible tourism as well as the manufacturing and commercialisation of such products (cf. ibid.). It can be observed, that wine plays a major role in Klosterneuburg. Not only are there quite a lot of winegrowers but the town also accommodates its own wine- and fruit-growing educational institution on secondary school level.

Similar natural and anthropologically made landscapes are also found in northern Vienna. Particularly the district (Ober-)Döbling resembles Klosterneuburg remarkably with its vineyards and the scenic Höhenstraße (literally translated "high road") which connects the two cities through the wood and over the two hills Kahlenberg and Leopoldsberg. Erich Wonka (2011a) has shown in a recent study that it takes equally long by public transport, up to 45 minutes, to get from the greater part of Klosterneuburg to the centre of Vienna as it takes from the outer districts of Vienna, such as Oberdöbling. This adds to the likewise perception of those areas and people looking to move to one of the mentioned places are likely to consider the respective other.

4.2 Historical Development

Figure 25: View from Kahlenberg upon Klosterneuburg in 1649 (Source: Merian in: Röhrig 1980:7)

Archaeological discoveries, which can seen in the city museum, suggest that the Klosterneuburg area has been populated since the Neolithic period. However, settlement development really began in the 11th century after the Romans had taken over the Celtic settlement in circa 15 BC, abandoned it again roughly 500 years later and left only a sparse rest population. Margrave Leopold III initiated the building of the monastery, which still is the main landmark of the town, in the early 12th century. In the Middle Ages the old Roman walls were adapted and served as the first town wall around what would later become the “upper town”. The area around today’s St. Martin was the second town core and a third one was built with the so-called “lower town” around 1300. Originally the town on the other side of the Danube, now Korneuburg, belonged to Klosterneuburg as well but the frequent flooding separated the two cities until they divided officially in 1298. This was also the time when the lower town was expanded. Since this part was poorly protected by built structures, it was destroyed and rebuilt multiple times. Until 1900 the town only slightly expanded into the Kierling valley. However, between 1870 and 1875 the Danube regulation was carried out and significantly changed the landscape. Up to then, the town had direct access to the water and between the new course of the Danube and the town, wetlands formed. The Danube regulation led to the town losing access to the river as important traffic route which in turn allowed the new rail route “Kaiser-Franz-Josefs-Bahn”, opened in 1870, to gain in importance. People from Vienna at that time enjoyed spending the summer in Klosterneuburg and the train made it much easier to go there. It was common that people from Klosterneuburg would let their own apartments to the Viennese and moved either to the attic or to small huts in the vineyards (cf. Wonka 2011b).

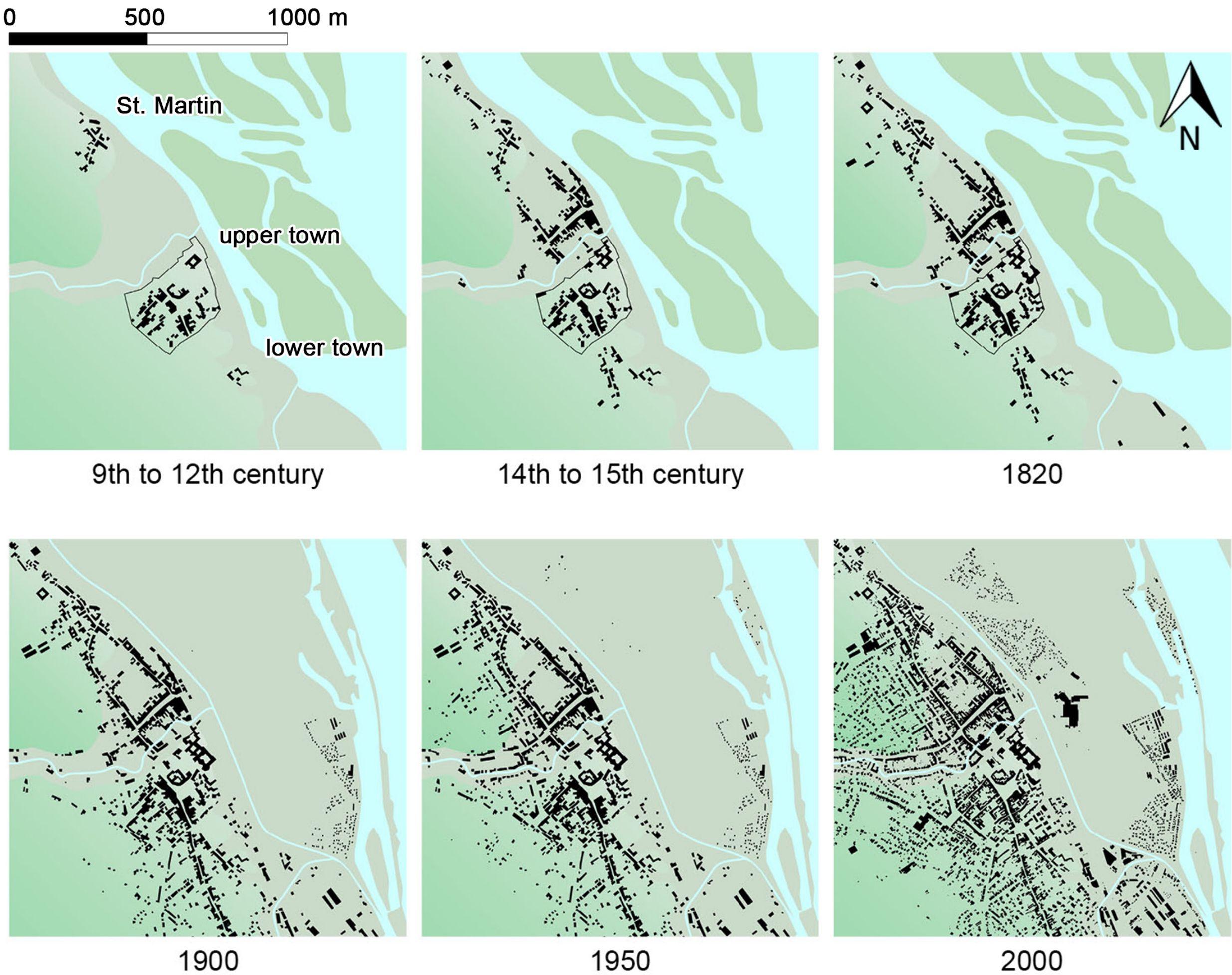

Figure 26: Development of the historic centre around the monastery (by author, based on Wonka 2011b:6ff.)

Since Klosterneuburg is in close proximity to the capital, which had poor sewers, bad water supply and low air quality at the time, it was planned as a garden city to provide better conditions for people moving out of the capital. However, the two World Wars delayed further development until the Russian occupying army left Klosterneuburg in 1955. The following rebuilding of the town was taking place mainly in the immediate proximity of the town area and the valleys that were easy to reach by public transport. In the 1960's a construction boom began and together with the desire of the people to have a "house in the green" as well as the greater distribution of cars, it became popular to start building away from the existing settlement, resulting in sprawl. In order to reduce sprawl, zoning of residential areas has not been expanded since 1987; meaning that since that time, additionally built residential buildings have increased the density of housing and population (cf. ibid.). However these measures do not prevent plots away from being urbanised land being sold and built on.

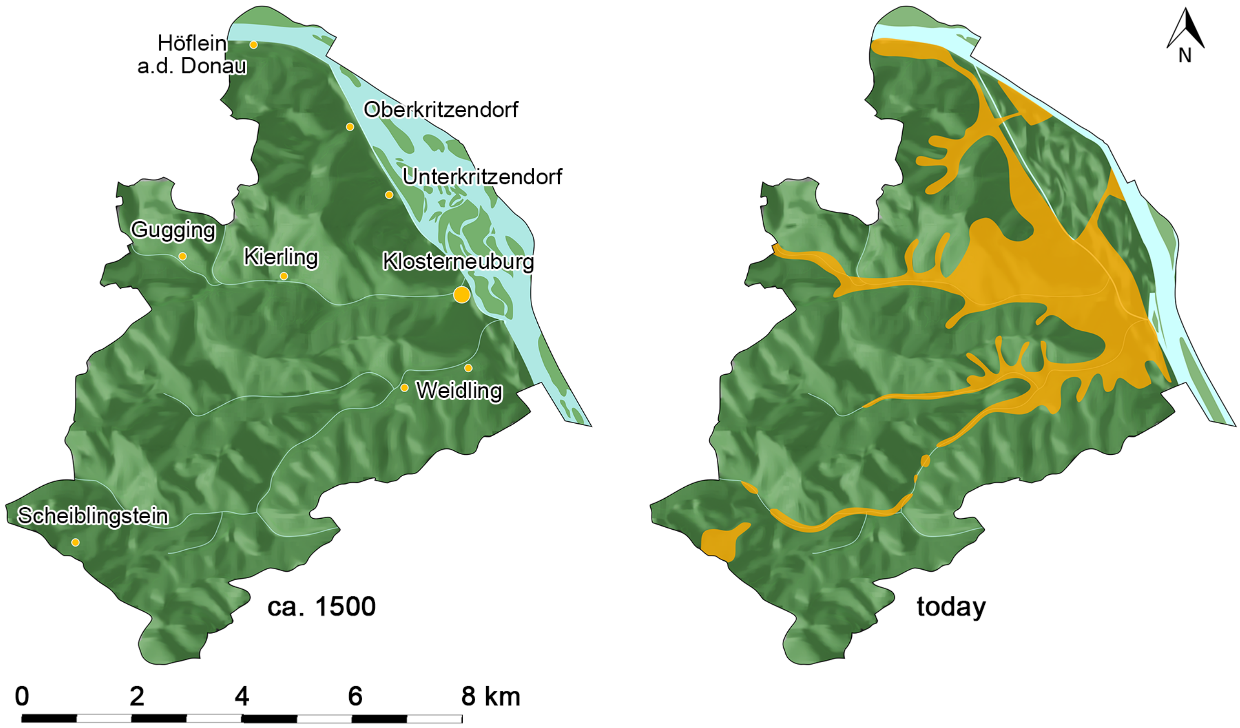

Figure 27: Larger scale spatial development (by author, based on historic and recent maps, NASA 2009)

The illustration above shows that development took mainly place in valleys, along main roads, due to the topography. Individual villages grew together and show the typical linear structure. With the vaster distribution of cars, plots further away from the main transport axes became more attractive, ultimately leading to sprawl.

By far the greatest part of people having a secondary domicile in Klosterneuburg is from Vienna. A popular way to fulfil the desire of city residents to be in the nature is to own or rent a garden plot. Particularly when it is warm enough to go swimming in the Danube, people spend a lot of time in their second homes (cf. ibid.). While such allotments, which are located mainly in the wetlands, are a comparatively cheap alternative to single family houses, there is still the danger of flooding. Therefore buildings that are being built there have to be built on pillars to be on the one hand relatively safe from the water and on the other hand to make sure that the water can drain without problems. However, it can be observed that many people circumvent this regulation by using the space underneath their building in different ways, for instance as storing space. In case of flooding this action leads to greater damage and poorer drainage.

Figure 28: View from Leopoldsberg upon Klosterneuburg, facing north, in 2012

4.3 Planned Development

When talking about the desired future spatial development of Klosterneuburg, one has to take two levels into consideration: the smaller, local scale and the larger, regional one. Three development plans and concepts are concerned with the municipality and are therefore discussed in this chapter: the Lower Austria Central Place Development Programme, the *Vienna City Development Plan (STEP 05)* and the *Klosterneuburg Development Concept.* These plans and concepts are consistent concerning general objectives, which include preservation of the natural surroundings and improvement of accessibility, particularly by public transport.

4.3.1 Regional Development

Klosterneuburg lies in Lower Austria for which the Central Places Development Programme (in German originally: “Zentrale-Orte-Raumordnungsprogramm”) came into force in 1992. The main objectives of it are to provide central facilities in suitable central places. Depending on importance, range, necessary number of users and clients, and frequency of use of the available facilities, central places are divided into six levels, I being the lowest and VI being the highest level. Within the settlement structure the concentration of the central facilities should be located in a way that a local centre is created.

Klosterneuburg has been defined as a level III central place. This means that the municipality should perform as a regional development centre in economical, social and cultural areas. It is therefore important that it is easily accessible from surrounding towns, including a great part of the population being able to access it with public transport. Another aspect is to provide both sufficient and diverse work places other than agricultural ones to maintain the central place as an important location for work.

Concerning the function and equipment this specifically means (cf. Zentrale-Orte-Raumordnungsprogramm § 11):

- availability of higher education, administrative and health care facilities, recreational, amusement, leisure and sports facilities.
- general secondary schools, secondary schools with professional training and high demand, a small swimming pool, a venue with 500 to 800 seats
- qualitative and quantitative rich and specialised supply with goods and services that satisfy short, periodic and long term needs
- the entire municipality should have at least 25.000 inhabitants, of which at least 5.000 live in the centre of the built-up settlement area
- the maximum distance to a level III central place should be 20 road kilometres and it should be accessible with public transport within one hour

The development of independent regions is meant to take some pressure off the development dynamics in Vienna and its immediate surroundings. Today's spatial development takes place mainly near transport infrastructure and connecting regional lines. This leads to network-like growth with junctions of greatest accessibility in city regions. Former edges and increasing urbanisation of areas close to the city have led to what is known as Zwischenstadt or edge city. For a people- and nature-sensitive development it is therefore regarded as practical to follow principles of decentralised settlement concentration and support development cores at junctions of high-ranking rail and road networks. Other principles that are regarded as important are: clear definition of settlement limits, compact settlement shapes and preservation of green areas between compacted areas (cf. Stadtentwicklung Wien 2005). To realise these principles and enable consistent regional development, it is important that municipalities coordinate their plans and measures with each other and with the federal states.

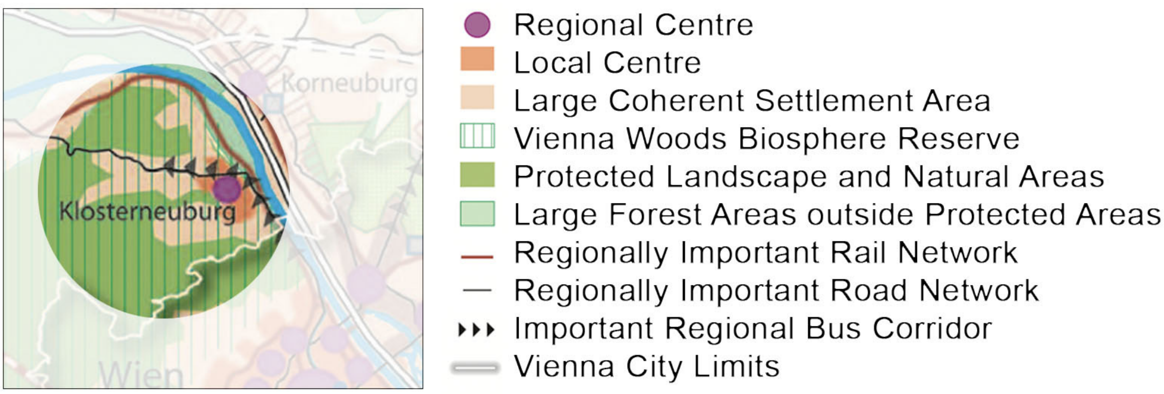

Figure 29: Regional relevance of Klosterneuburg as in STEP 05 (Stadtentwicklung Wien 2005:101, adapted by author)

There are ongoing cooperation between Lower Austria and Vienna, the latest city development plan of Vienna *STEP 05* therefore features some aspects that are relevant for Klosterneuburg as well: as can be seen in the image on the opposite page, Klosterneuburg is relevant as a regional centre and important corridor for the regional rail, road and bus network.

4.3.2 Local Development Concept - ÖEK 2004

With the ÖEK 2004 ("Örtliches Entwicklungskonzept") the most recent local development concept came into force in 2005. It is meant to complement the local development programme that is formulated rather general, with more specific objectives, including an illustrative map. In this again, the importance of preservation of the natural surroundings and compact growth of the settlement are emphasised. According to the ÖEK 2004, the municipality can host a maximum of 35.000 residents, most of which would be living in the core centre. As most people are and will be living there and this centre is also the one that is best accessible from within town as well as from outside by different means of transport, central facilities and services are supposed to be located there. This includes administrative facilities for 35.000 residents as well as regionally important central facilities that coincide with the ones mentioned in the regional development plans.

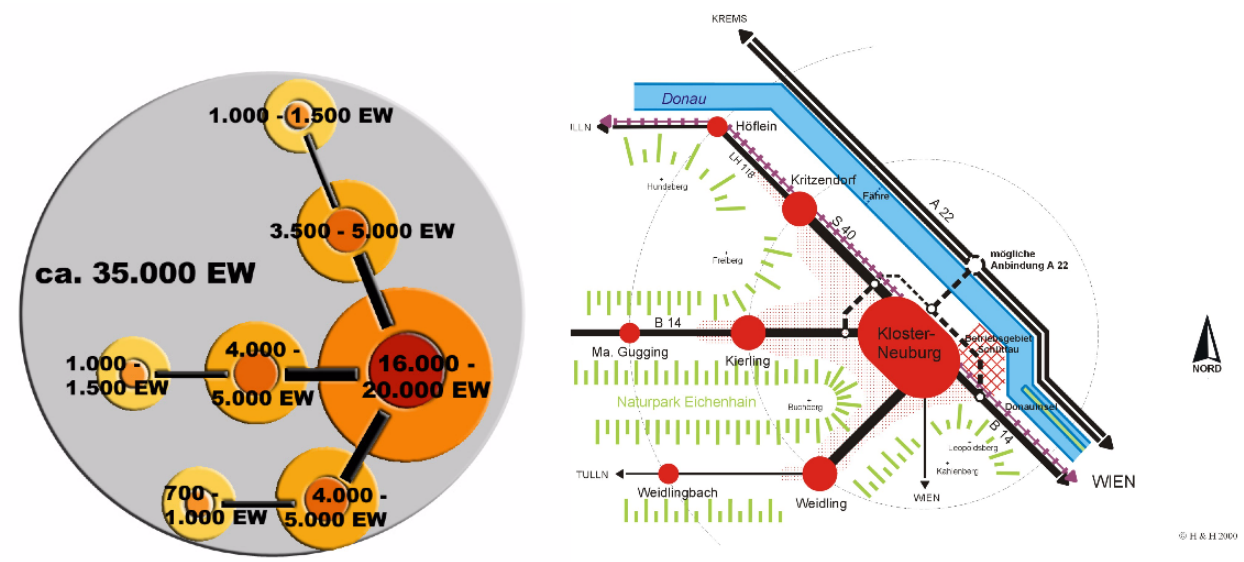

Figure 30: Potential number of residents (left) and functional model (right, Source: ÖEK 2004)

It is apparent that the concept of central places is not only taken seriously on the regional level, but also on the local scale. Smaller centres in the cadastral subdivisions Kierling, Kritzendorf and Weidling are meant to supply residents with basic shops and services, aim for compact housing and the preservation of the historical townscape and cultural assets. The objectives for the local centres that are the furthest away from the historic core are also to supply residents with basic services and additionally to preserve the historical townscape and cultural assets. Also in this order it is stated that along the axes compact settlement forms are to be initiated.

Other objectives include making Klosterneuburg more attractive for businesses to create a diverse mix of industry sectors, commerce, services and craft on the one hand and on the other hand to make it more attractive as a place of excursions and recreation. The latter is to be achieved by improving and making use of the various functions of the Vienna Woods, the wetlands as well as the historical allotment gardens and the open, agricultural landscape and by linking the different landscapes. The industrial area "Schüttau", which is next to the Danube in the South of town is considered as location for a retail park or shopping mall.

Concerning the traffic system, it is noted that new traffic is to be avoided and the modal split should be changed more in favour of public transport to increase the residents' quality of life and to clear the centres of through traffic. This is to be done by improving accessibility and regional connections.

The development concept features the same sustainability goals and measures that have been discussed in the first part of this thesis. Central objectives are, apart from the improvement of the accessibility of amenities and public transport and limitation of sprawl, the preservation of the environmental and cultural assets. Considering that the suggested sub-centres are the centres of the original individual villages, it could mean that strengthening those historic centres leads to over-all sustainability, including improved liveability, in Klosterneuburg.

The MUP-City software can help evaluating different development options. In the following chapter, this scenario development and option testing is explored for Klosterneuburg in order to find out where the software can be applied usefully.

5. Scenario Development & Option Testing

The *MUP-City* software allows the development of urbanisation scenarios in which fragmentation of continuous open space as well as built-up space is avoided while good connections between green and urban space are ensured. It therefore supports the creation of a built environment that is sustainable as well as sustaining (cf. Czerkauer-Yamu & Frankhauser 2011).

In order to develop scenarios with the software, extensive data preparation is necessary. After loading the resulting GIS-files in MUP-City and carrying out the decomposition, scenario development can begin. Besides analysing the existing state, one more scenario is developed that is concerned with changed amenities and changed public transport in one part of the town.

5.1 Data Preparation

For the preparation and processing of the required GIS files, the open source software Quantum GIS (QGIS), version 1.7.4 for Mac is used. In total, 5 layers are created:

Undevelopable Areas	Network	Buildings	Amenities	Public Transport
Areas that are not suitable for urbanisation due to topographical reasons, including water	The road network that can be used by pedestrians and cyclists	Existing buildings of all kinds	Shops and services, public facilities	Bus stops and train stations
8,2km^2 (10% of total scrutinised area)	330km	27.750 polygons 2,3km^2	270 points	150 bus stops 5 train stations

Table 2: Overview of GIS layers

It is worked with data provided by the planning department of Klosterneuburg as well as open data.

5.1.1 Study Area

The length of the selected study area is 9km as this allows covering a big area around the historic core. As can be seen in the image on the next page, besides the historic core of Klosterneuburg the cadastral municipalities Höflein, Kritzendorf, Maria Gugging and Weidling are included whereas the detached village Weidlingbach (of which Scheiblingstein in the South West corner is a part) has been excluded for the scenario development in this thesis. Reason for this is that the connection to the rest of Klosterneuburg concerning roads and public transport but also in the sense of feeling of belonging is virtually non-existent. It can be safely assumed that people from Scheiblingstein rather go to the nearby town Untermauerbach and to Vienna for shops and services, as both are much closer and easier accessible.

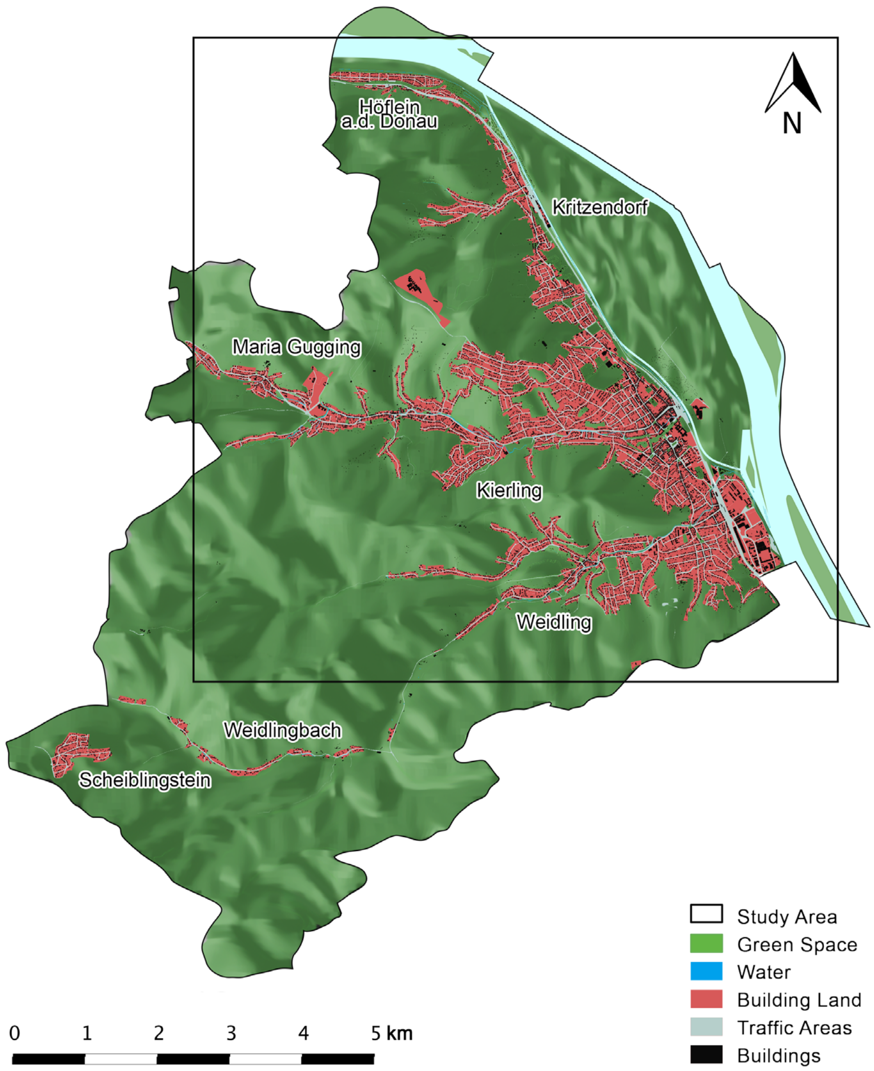

Figure 31: Study area (Data sources: Stadtplanung Klosterneuburg, zoning plan 2004 and roof areas 2010; topography based on SRTM-image by NASA 2009)

As the main city centre is located centrally within the study area, results for this area are therefore expected to be the most accurate. The results for outer areas will be less reliable because of an inevitable edge effect. This has to be taken into consideration when deciding on the area that is being studied and again when interpreting the analysis outcomes.

Not only Klosterneuburg but also the neighbouring towns St. Andrä-Wördern in the North West and Vienna in the South East are partly within the limits of the study area. Korneuburg, across the Danube, is technically also part of the study area, but since the only connecting road is at the North edge of Klosterneuburg, in Höflein, it is regarded as insignificant for the scenario development in this thesis and therefore deliberately not included.

In order to get sound results, data in the entire square that marks the study area has to be collected and processed. Since the planning department of Klosterneuburg could provide data from within the limits of the municipality, the rest was digitised manually.

5.1.2 Undevelopable Areas

Figure 32: Transformation, from left to right, of the SRTM image (NASA 2009) into contour lines, steepest built-up slope and the from this derived undevelopable areas (red)

Some areas are not suitable for urbanisation due to steep slopes. To determine those areas, the SRTM-image for the coordinates 48°N 16°E, publicly available from the SRTM-Website (NASA 2009), is used. The resolution of the raster cells is 90m and therefore allows for fairly accurate results.

As can be seen in the image above, only small patches of land are identified as undevelopable. Reason for this is that rather steep slopes have been built-up in the past and served now as the comparative slope. However, since the study area has only been classified into “developable” and “undevelopable”, it is not clear from this layer to what extend certain areas are actually suitable for development in terms of topography. While at this stage of the work this is not relevant, topography has to be taken into consideration later on, when cells for development are selected in the process of scenario development.

The Danube is also regarded as an undevelopable area and therefore included in this layer.

5.1.3 Network

As the focus in this thesis is on pedestrian environments, only those parts of the transport network are included in this layer that can be used by pedestrians and/or cyclists. This includes roads, bicycle tracks and walkways. Roads that are reserved for cars only, in this case the recently completed relief road that runs along the Danube, as well as special paths such as mountain bike tracks and hiking trails are not included as they are usually not used to get to shops and services.

The network layer is based on OpenStreetMap data (Karch & Ramm 2012) that is altered in the process. Not needed streets and paths are being removed, missing ones added and faulty ones corrected with the help of an Orthophoto that is being accessed via WMS (Geoimage 2011).

Figure 33: Development of the network layer (right) based on OpenStreetMap street data (left, Karch and Ramm 2012) and Orthophoto (middle, Geoimage 2011)

So MUP-City is able to correctly use the network layer, it is important to make sure that the lines snap to each other and consist of single segments and not multi-lines. The QGIS vector analysis tools “line intersection” and “multi to single parts” proved useful to identify non-snapping lines and mend them.

This is one of the most time consuming tasks as it cannot be relied on the accuracy of the used data since they can be altered by anybody and not all users pays attention to using correct categories to determine the type of the line (e.g. bicycle lane, highway, etc.) or that lines snap at intersections. When using OpenStreetMap data the accuracy therefore has to be checked and data has to be corrected if needed. When covering an area of this size it can however be assumed that reviewing existing data is still less time consuming than digitising every line by oneself.

5.1.4 Buildings

Figure 34: Alterations on the buildings layer (right) based on roof areas (Stadtplanung Klosterneuburg 2010) and Orthophoto (Geoimage 2011)

Klosterneuburg's town planning department provided GIS data on a number of topics for the purpose of completing this thesis. To create a layer with spatial information on the built environment, the files containing roof area data of the year 2010 is used.

Since the study area also covers some areas outside the town limits, the Orthophoto is used to complete the layer by digitising buildings in St. Andrä-Wördern and Vienna within the study area.

5.1.5 Amenities

In this thesis, the service levels concerned with daily and weekly frequency are looked at. Level 1 includes services that are frequented on a daily basis or several times a week such as schools, small grocery shops or bakeries; level 2 includes services that are frequented once a week such as supermarkets, pharmacies, post offices or pubs. Services that are frequented once a month or less would be on level 3 but are not included, as MUP-City in the version that is used for the thesis, does not include them in its calculations.

Based on earlier MUP-City projects, a classification is developed in regards of the particular conditions in Klosterneuburg:

Level	Class	Type	Quantity
1			
	Local Supply	Bakery	6
		Butcher	3
		Kiosk	8
		Corner Shop	0
		Organic Store	2
	Education	Kindergarten	12
		Primary School	9
		Child Care	4
	Health Care	General Doctor	23
	Finance	Cash Machine	9
	Sports & Leisure	Playground	17
	Public Transport	Bus Stop	150
2			
	Finance	Bank Office	11
	Cosmetics	Cosmetician	5
		Hairdresser	16
		Chemist	3
	Eating & Drinking	Café	6
		Bar	1
		Restaurant	13
		'Gasthaus'	11
	Car and Bicycle Garage	Car Garage	10

		Bicycle Garage	3
	Culture	Cinema	1
		Local Culture Centre	1
	Health Care	Pharmacy	5
		Dentist	11
	Shopping	Clothes	4
		Farmer's Market	1
		Flowers	5
		Household	1
		Supermarket	15
	Education	Library	3
		Secondary School	4
		Music School	1
	Government & Public Services	Lower Administrative Level	5
	Mail	Post Office + 'Servicestellen'	5
	Worship	Church	9
	Sports & Leisure	Sports Facilities	26
	Public Transport	Train Station	5

Table 3: Classification of Amenities

Note that even though public transport stops have been categorised as amenities, they are on a separate layer for the use with MUP-City.

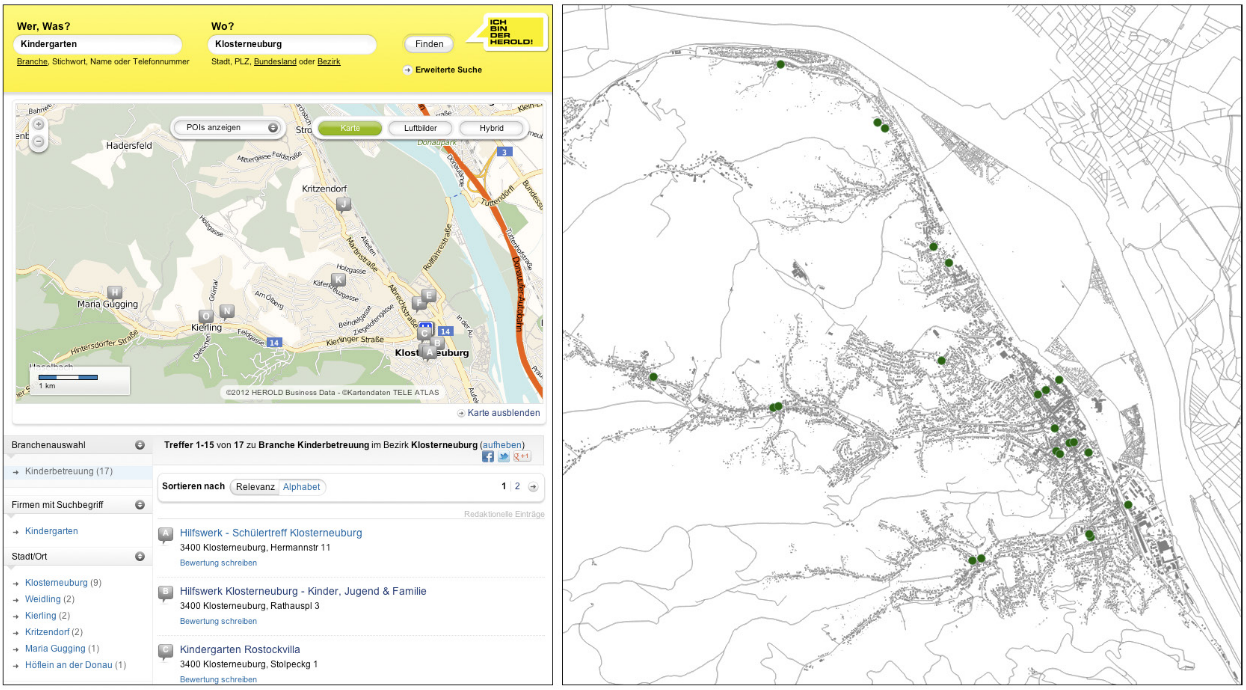

Figure 35: Education on Level 1 (right) based on Herold information (left)

The locations of shops and services were obtained from the online business directory Herold (2012). The official Website of the municipality (Stadtgemeinde Klosterneuburg b) provided information on administration and sports facilities, so the locations of those are taken from there and located with the help of the greenery GIS file provided by the town planning department and the earlier mentioned Orthophoto.

Since additionally to the website a print version of Herold is distributed to households once a year free of charge, it is assumed that it is used when people are looking for certain shops or services. However, since it is not obligatory to have one's business listed there, it is likely that some are overlooked in the process of data preparation and some that are no longer operating are included because they are still listed in the directory. The most accurate approach would be to go through town and register every business manually. However, this is very time consuming and highly impracticable for this purpose. Therefore, amenities that were listed in the online version of Herold on May 26 2012 are included in this thesis.

Amenities are digitised as points precisely on the respective addresses' buildings. Where there was no building for reference an accuracy of approximately 20m was aimed for.

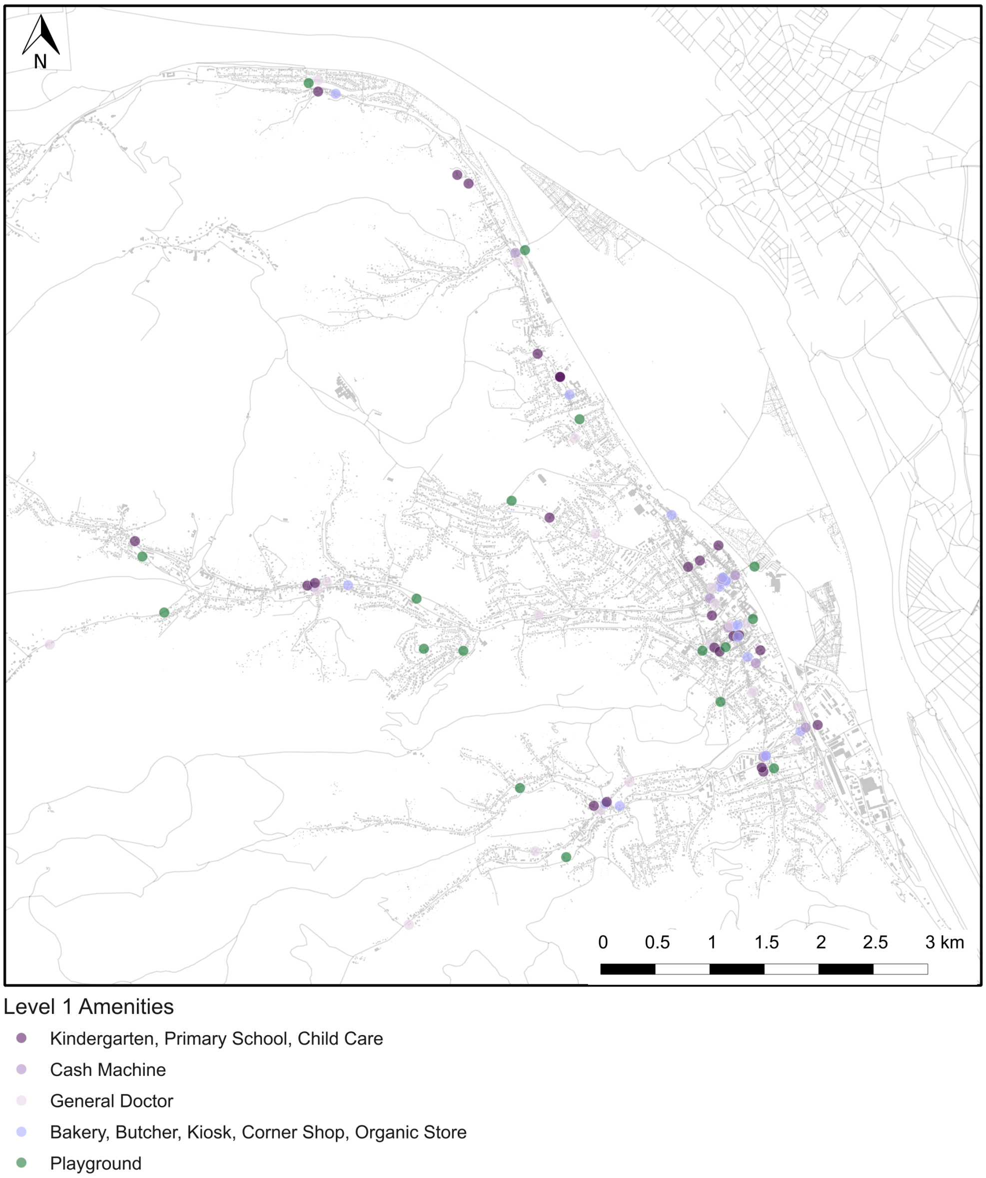

Figure 36: Amenities on level 1

Looking at the distribution of level 1 amenities, the historic core clearly stands out. The smaller local centres can be made out too, however they are not too distinct. While shops and children's education are in general closer to the centres, general doctors and playgrounds can also be found further away, in housing areas, which is quite customary and therefore comes to no surprise. One aspect that has to be noticed is that corner shops are included in the list of level 1 amenities but in fact do not exist anymore in Klosterneuburg as supermarkets have entirely replaced them.

On level 2 the historic core stands out even more. However, the sub-centres are not as easily distinguishable as on level 1.

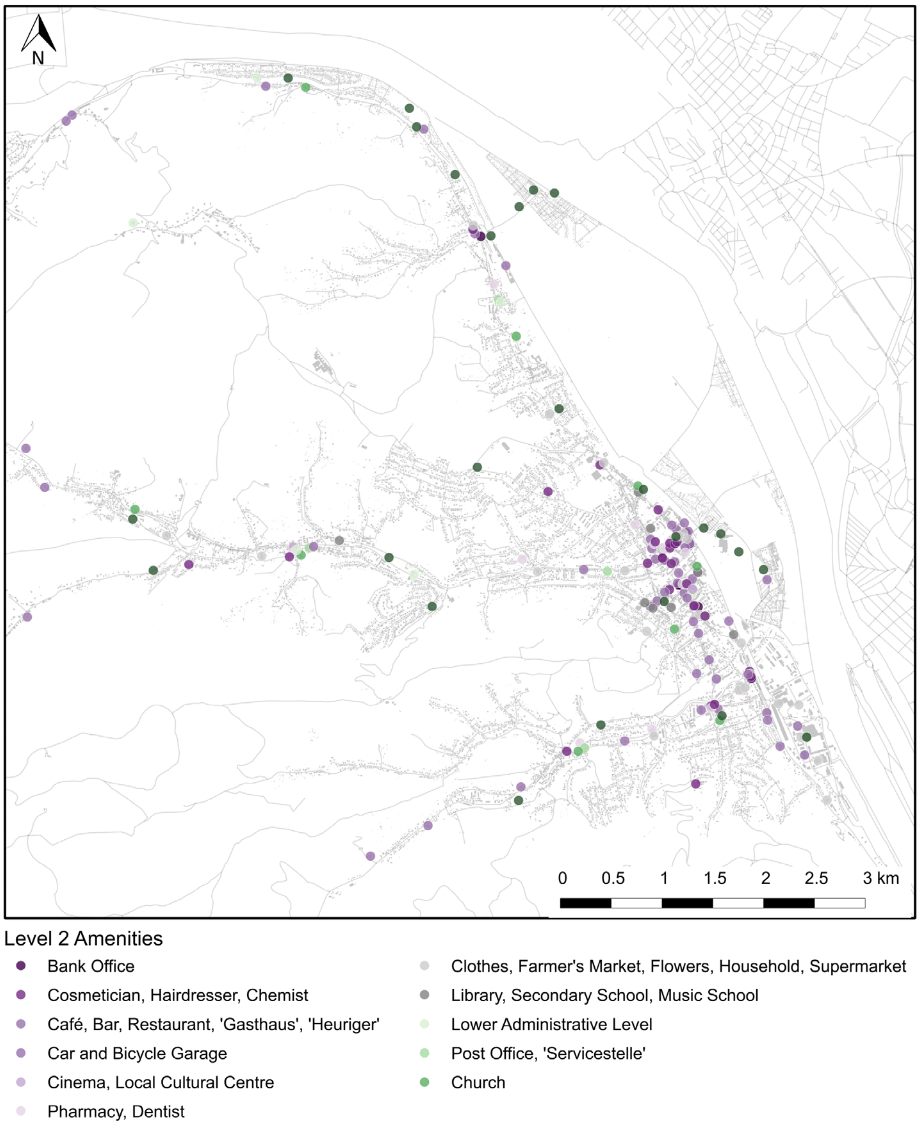

Figure 37: Amenities on level 2

As can be seen in the image on the opposite page, there are bus stops all over town, complemented with train stations. Only few areas are not supplied with public transport stops. One could quickly jump to the assumption, that adding bus stops to those places will massively improve their overall accessibility. However, it has to be taken into consideration, that these areas are a) difficult to access with big vehicles such as buses due to steep and narrow roads, which can be seen when visiting those areas and b) those areas are mainly inhabited by wealthy citizens who are unlikely to switch to public transport from their cars as it is a primary element of their lifestyle. However, it can be expected that accessibility of public transport is in general high in Klosterneuburg.

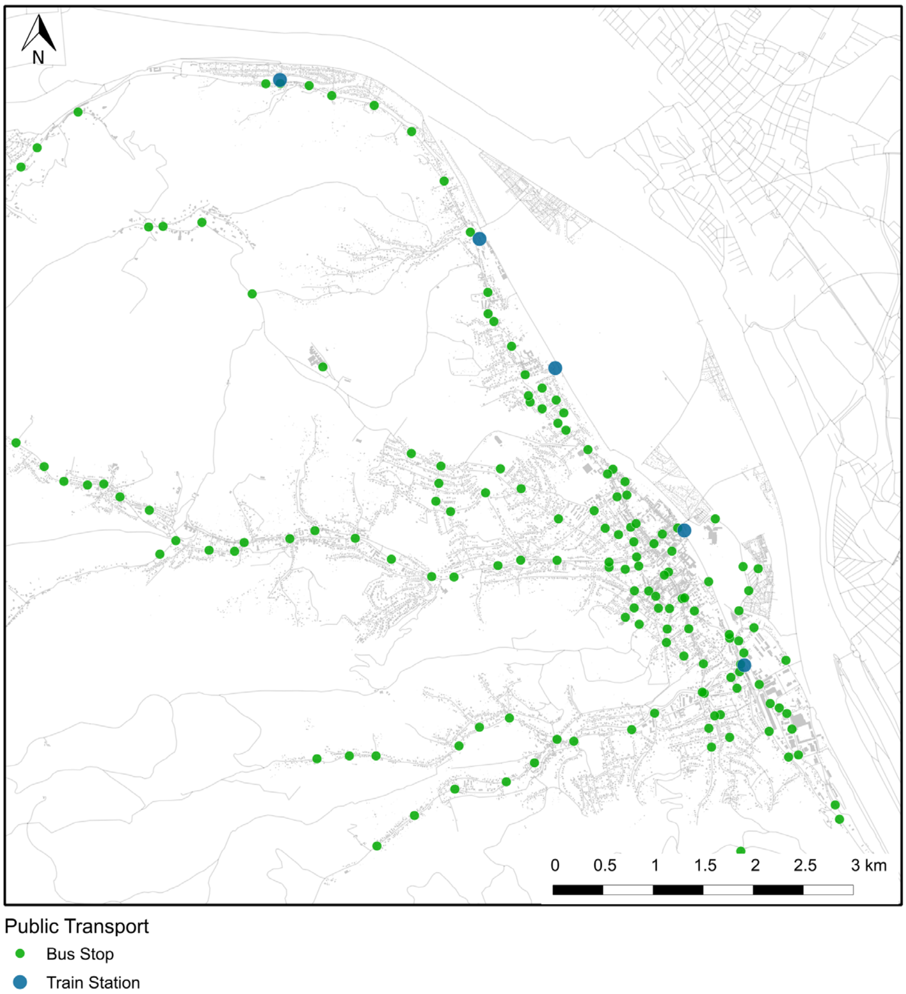

Figure 38: Bus stops and train stations

5.2 Scenarios

Based on these GIS vector files the decomposition is carried out. This step translates the vector information in a grid with urbanised and free cells. For each of the free cells the suitability for development is then determined according to:

- Diversity of supply by the closest service centres on different hierarchical levels
- Distance to service centres according to their frequency
- Distance to the existing traffic network
- Distance to the open landscape
- Distance to public transport stops

5.2.1 Scenario: Existing State

For analysing the existing state, the prepared GIS-files are added to a new project in MUP-City and the decomposition is carried out. Smallest cell size is 20m, which is approximately the length of a building, and while the scale goes up to a cell size of 1620m, this is not regarded as useful for the area under scrutiny due to its small total size.

The images in this thesis have been slightly cropped in order to remove visible edge effects that occurred in the process of the decomposition outside the area under scrutiny. This was done solely for the purpose of removing irrelevant visual noise and does not affect the meaning of the results for the scrutinised area.

Built-up Area

The decomposition makes the fragmentation of the built-up and free space visible. There are islands of open space within built-up areas as well as built-up structures in midst of open space without being connected to areas of the same type. Particularly the smaller buildings that have been built in the green stand out, while they can easily be overlooked on the GIS buildings-layer or on aerial pictures.

Looking at the different scales, the ratio of built-up and free cells varies. While on the largest examined scale with a cell size of 540m more than half of the area is built-up, it is only 12% on the smallest scale:

Scale	Total number of cells	Number of built-up cells	Built-up area (of 9447,84ha)	Percentage of built-up area
20m	236.196	28.488	1139,52ha	12,06%
60m	26.244	5.322	1915,92ha	20,28%
180m	2.916	942	3052,08ha	32,30%
540m	324	176	5132,16ha	54,32%

Table 4: Built-up area on the different scales

What can be learnt from this is that while the built-up area is only a fraction of the total area, it is rather dispersed and reaching far into the non-built-up area. The results are sprawl, fragmented open space and disconnected settlement structures, as can be also seen in the image below.

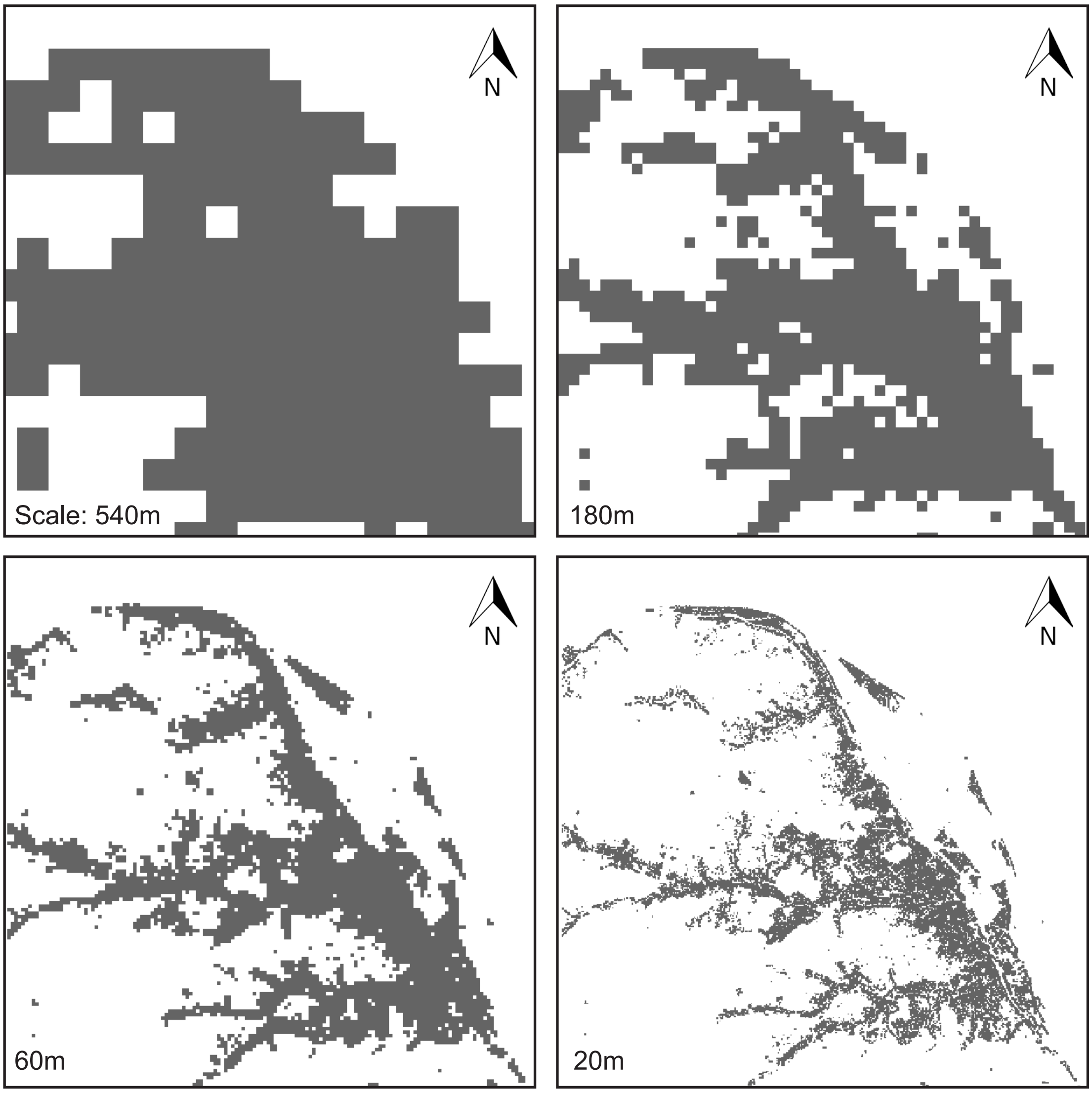

Figure 39: Decomposition of built-up (dark cells) and free space (white cells)

Accessibility

Level 1 amenities should be within walking distance (400m, see p. 40) of residential areas in order to secure the provision for the population. As expected, accessibility of amenities with daily frequency is by far the best in the historic core. While the accessibility around the sub-centres is quite good as well, there are large areas where it is poor. One strategy to increase accessibility in these areas is to introduce level 1 amenities there.

However, these results have to be taken with a grain of salt. It has to be checked which types of amenity exactly are missing. Also, since supermarkets are categorised as level 2 amenities, it is for instance possible that products that would be bought at little corner shops are bought from nearby supermarkets instead. This seems impracticable at first, but the idea behind this categorisation is that people go to smaller corner shops multiple times a week in order to buy fresh produce, such as vegetables and fruit, but accept longer distances to places where they can store up weekly on other food and supplies that stay fresh for a longer time period.

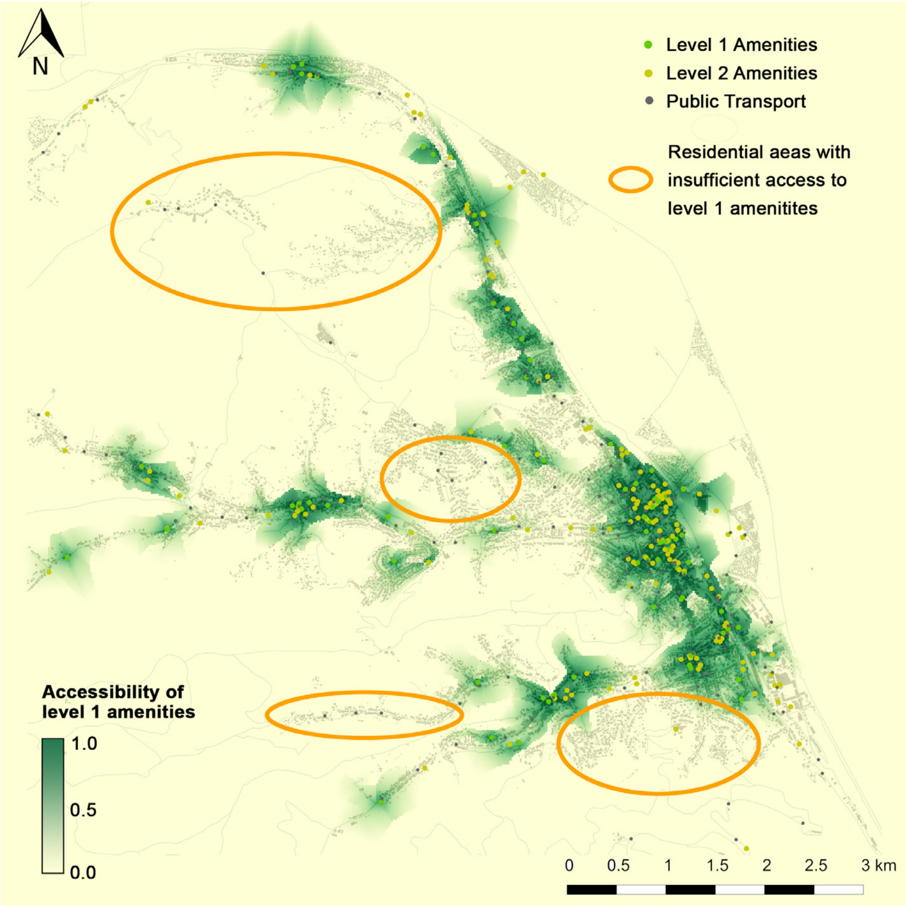

Figure 40: Accessibility of level 1 amenities (1=best, 0=worst)

Calculation of the accessibility of level 2 amenities was not working with the version that was used for this thesis, however it can be assumed that the resulting image would have looked similar as the one on level 1 accessibility. In the image on the opposite page can be seen that supermarkets are not only located in the centres but also in-between those areas, therefore improving provision for the population in those areas.

Accessibility of amenities with weekly frequency can be regarded as generally sufficient. However, the outer areas of Weidling, south of town, are rather poorly supplied.

It was already noticed during the data preparation in GIS, that Klosterneuburg seems to be crowded with bus stops. The analysis with MUP-City now reveals that in general accessibility to public transport in fact is high. However, there are some areas that lack public transport access completely. It is arguable if introducing bus stops there makes sense as the topography makes accessing these areas by bus difficult. The municipality has introduced a taxi call service that gets people to those difficult to reach areas as

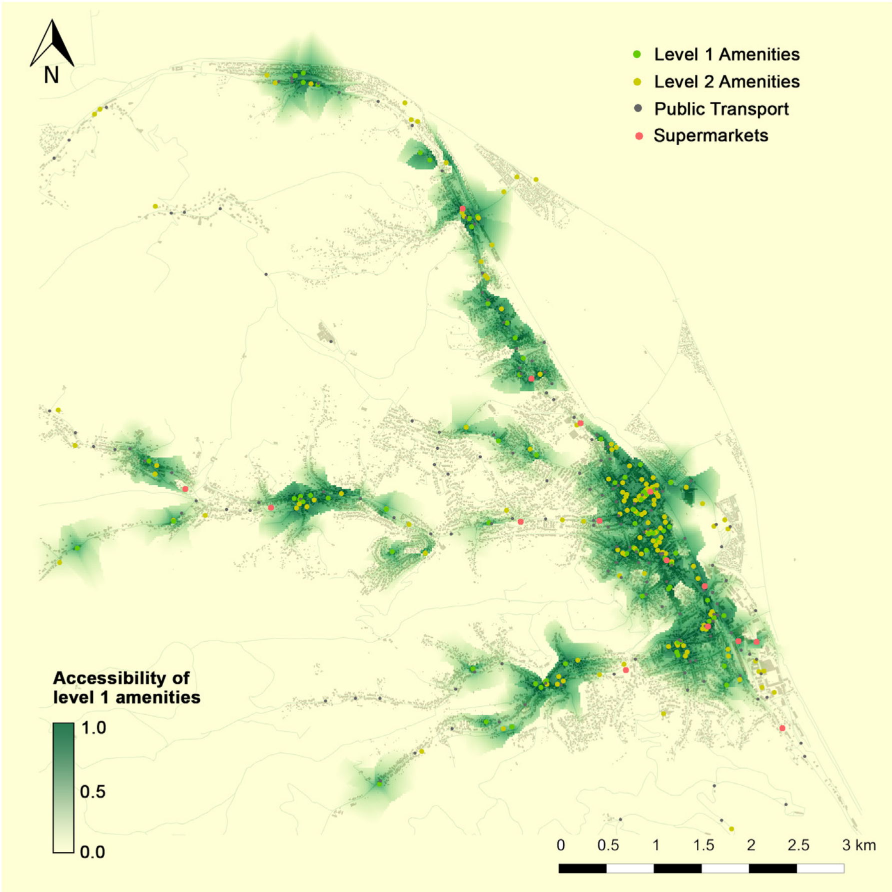

Figure 41: Accessibility of level 1 amenities, with overlay of supermarkets

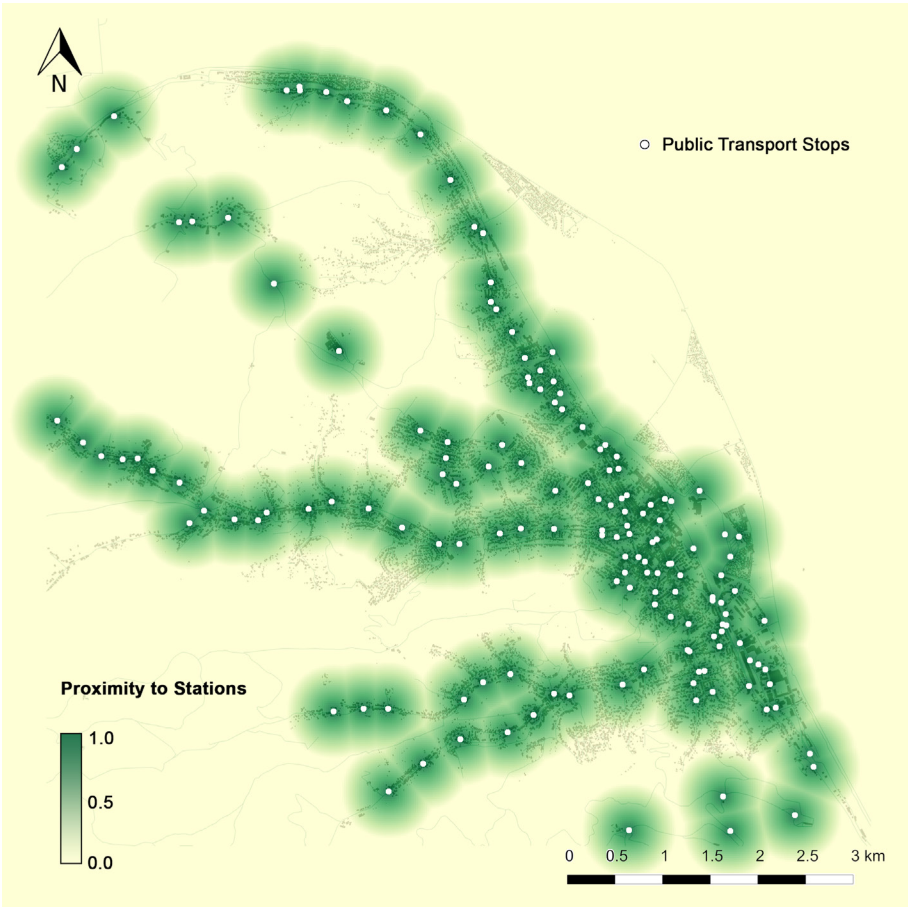

Figure 42: Accessibility of public transport

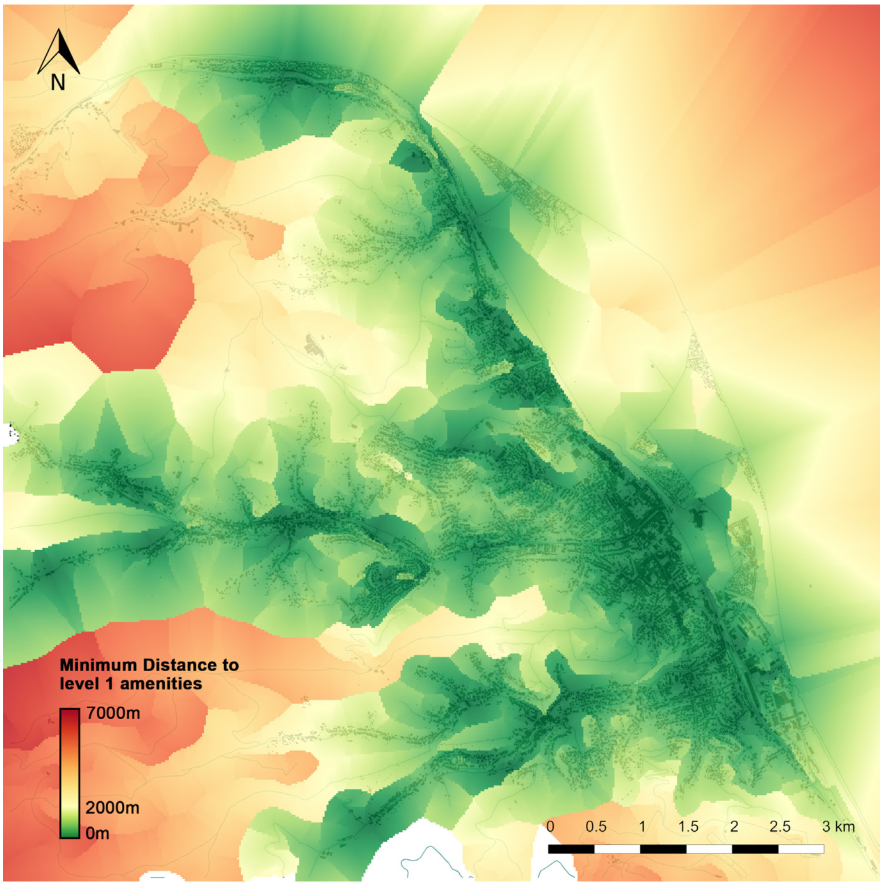

Figure 43: Minimum distance to level 1 amenities

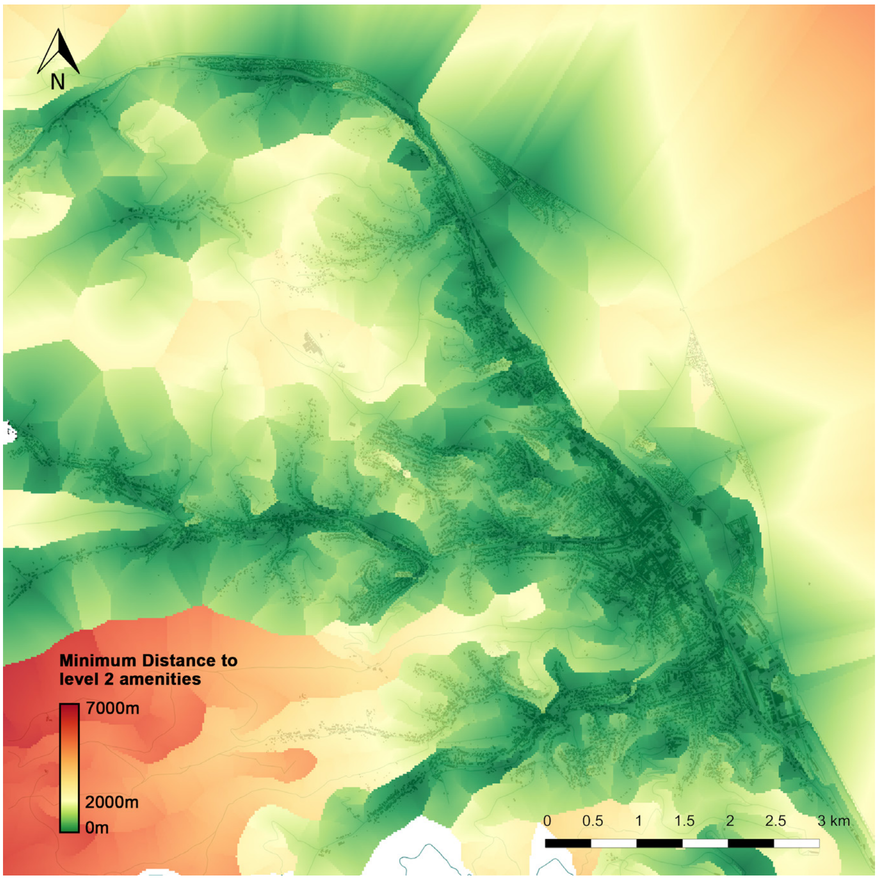

Figure 44: Minimum distance to level 2 amenities

required for a small fee that includes the price of a normal single ticket plus €2 for the service (cf. Stadtgemeinde Klosterneuburg s.a. d).

Even though the connection to local and regional public transport seems to be more than sufficient, particularly teenagers and young adults express dissatisfaction with it when being asked about that subject. However, this discontent has more to do with the fact that less trains stop in Klosterneuburg later in the evening and during the weekends, and buses as well as trains from and to other towns stop running rather early in the evening.

Minimum Distances

Since walking distance is defined as being 400m, all areas that are (dark) green in the image on the opposite page can be regarded as well supplied with level 1 amenities. There are only few built-up areas that are further than 1km away from the nearest level 1 amenity and very few further away than 2km (cycling distance).

The only areas that have been identified to be further than 2,5km away from the closest level 1 amenity are the restaurants in the Vienna Woods south and Hadersfeld as well as the part of St. Andrä-Wördern northeast of Klosterneuburg. Since St. Andrä-Wördern is only partially included in the study area, the poor results for that area can be attributed to the edge effect. As the town centre is just outside of the scrutinised area, it can be expected that it would strongly influence the results if it were included. Since the focus is on Klosterneuburg, this is not problematic though.

Fractal Scenario

Based on these results on accessibility as well as additionally the proximity to the existing road network it is possible to have MUP-City calculate the suitability for urbanisation of each cell on the different scales and propose what cells should be un-built (-1.0), stay free (0.0), stay built-up (1.0) or be built-up (2.0). For the following fractal scenario all rules have been taken into effect: proximity to road, accessibility to open spaces, accessibility of level 1 and level 2 amenities, proximity to public transport stations. N_{max} was chosen to be 5 because a favourable hierarchy can be reached with this (see p. 39).

The software suggests mainly cells at the edges for building. Reason for this is most likely the absence of built-up cells in the immediate surroundings as $N_{max}=5$ has already been reached in a lot of areas, particularly on the larger scales.

Based on the discussed criteria, MUP-City determines the interest of each cell. As can be seen in the next image, the most and most interesting cells are in the historic core, followed by fewer cells of great interest in the local sub-centres. Best value for a cell would be 1, for perfect interest. However, this was not reached in this example and is also rather unrealistic to achieve.

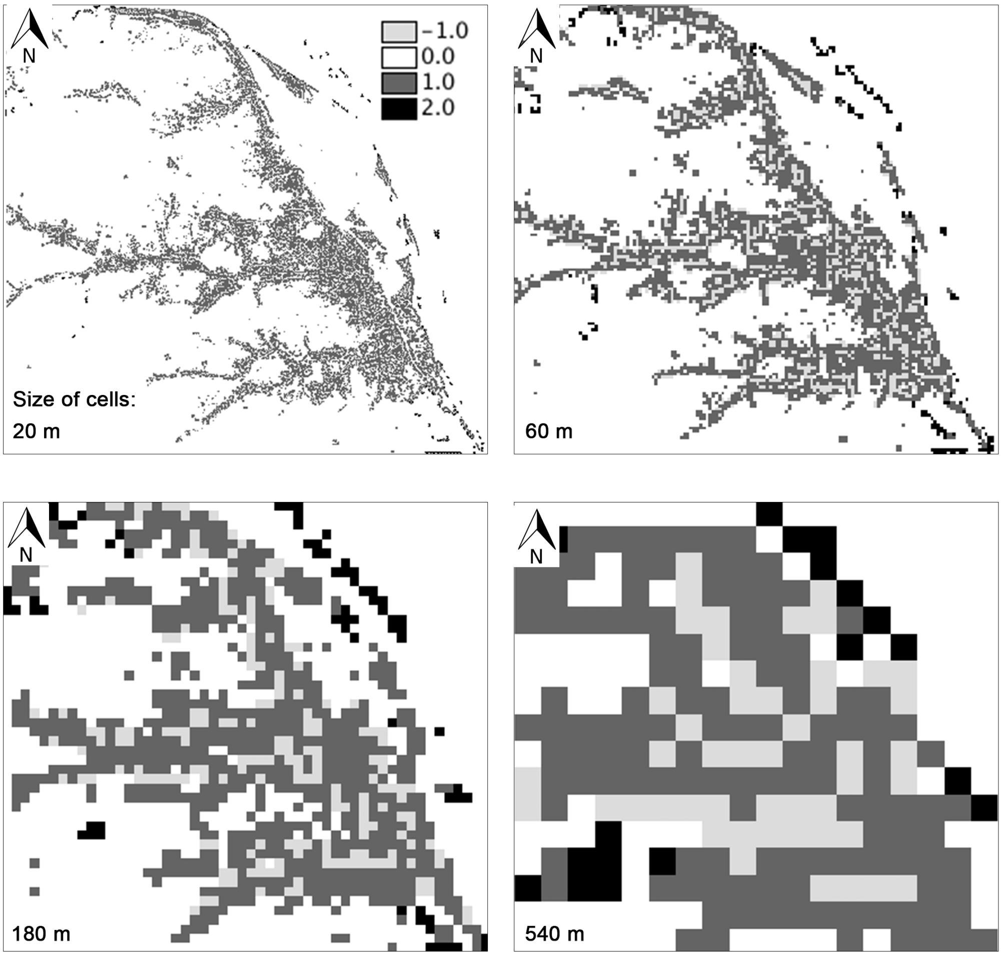

Figure 45: Suggested building of cells

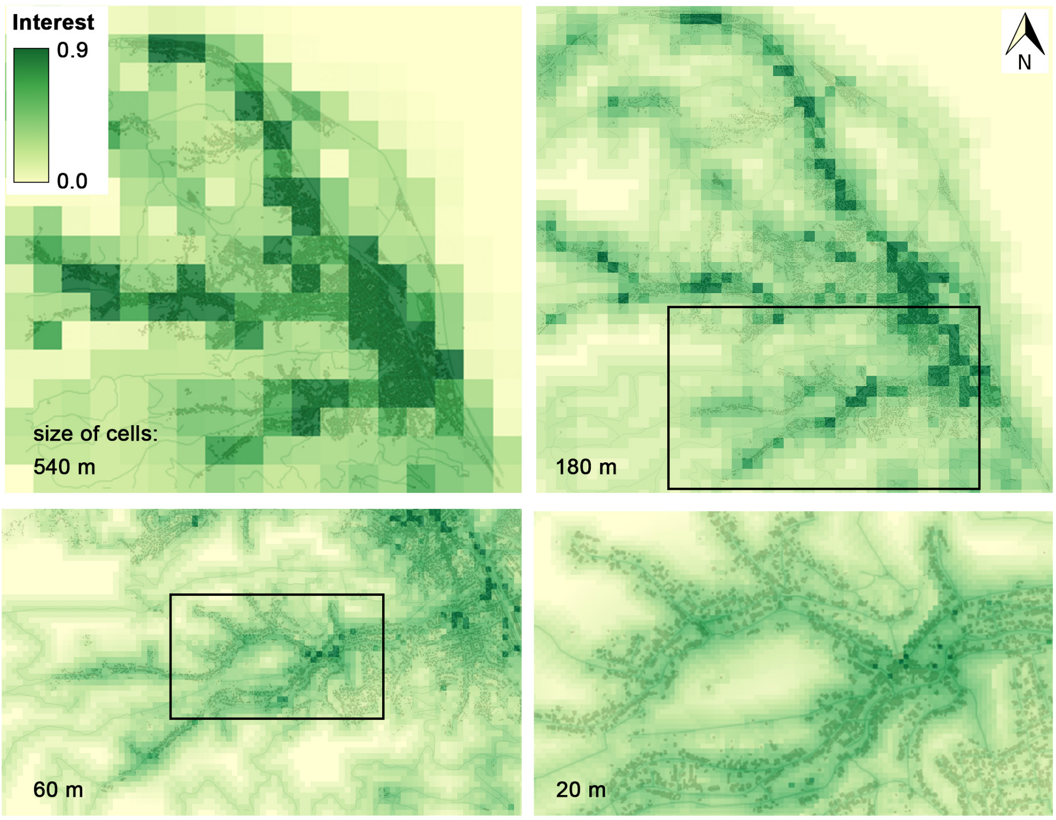

Figure 46: Interest of cells

Interactive Scenario

Besides analysing an existent state, MUP-City allows to develop scenarios interactively by choosing cells for building up from the highest to the lowest scale. In a first attempt to create such a scenario, the cells that were available for building were not as expected. On the largest scale, two cells outside of the town were considered best for future building:

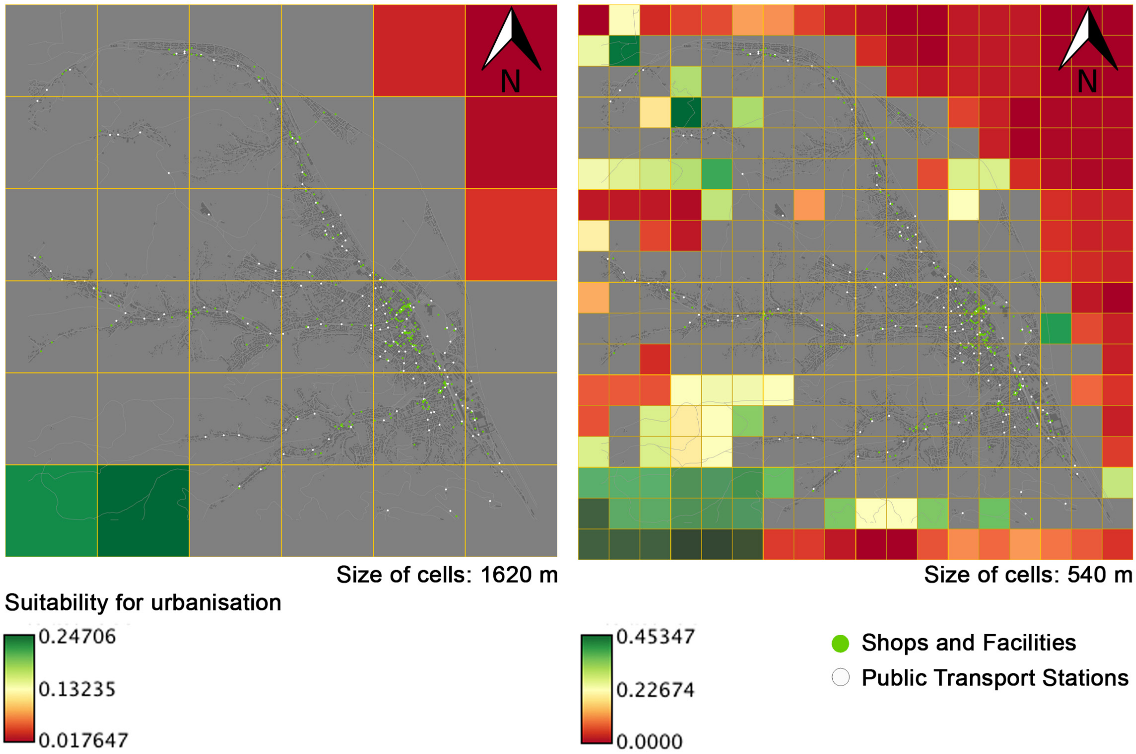

Figure 47: Suggested cells for building on the two largest scales in the first interactive scenario

Reasons for this unexpected result are most likely the close proximity to the road network as well as to open space of these cells. Additionally, particularly on the larger scales, N_{max}=5 results in a lack of cells that can be built-up, as the maximum of 5 built-up cells within a mesh has already been reached. This is due to the sprawl in the area, as discussed in the beginning of this sub-chapter. Therefore future building-up of cells is mostly possible on smaller scales in already built-up areas as part of a densification process, as shown in the image on the next page.

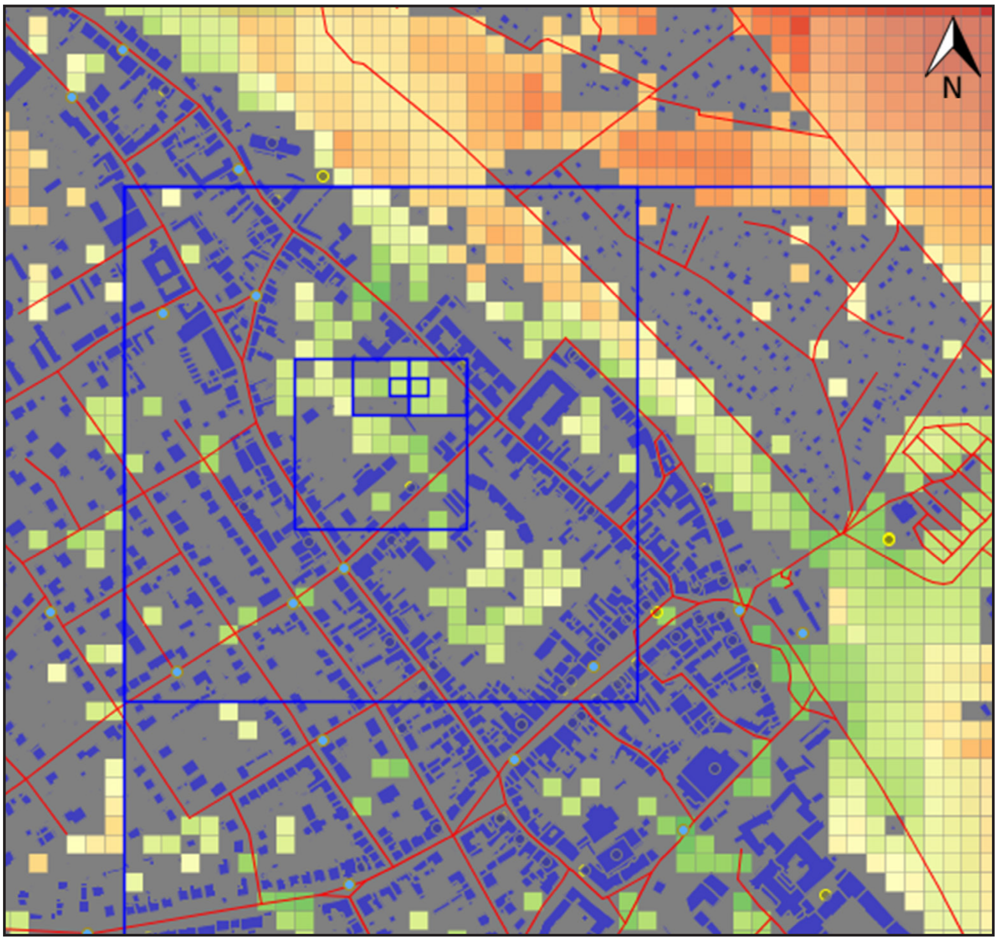

Figure 48: Cells close to the historic centre where densification is possible

5.2.2 Verifying assumptions

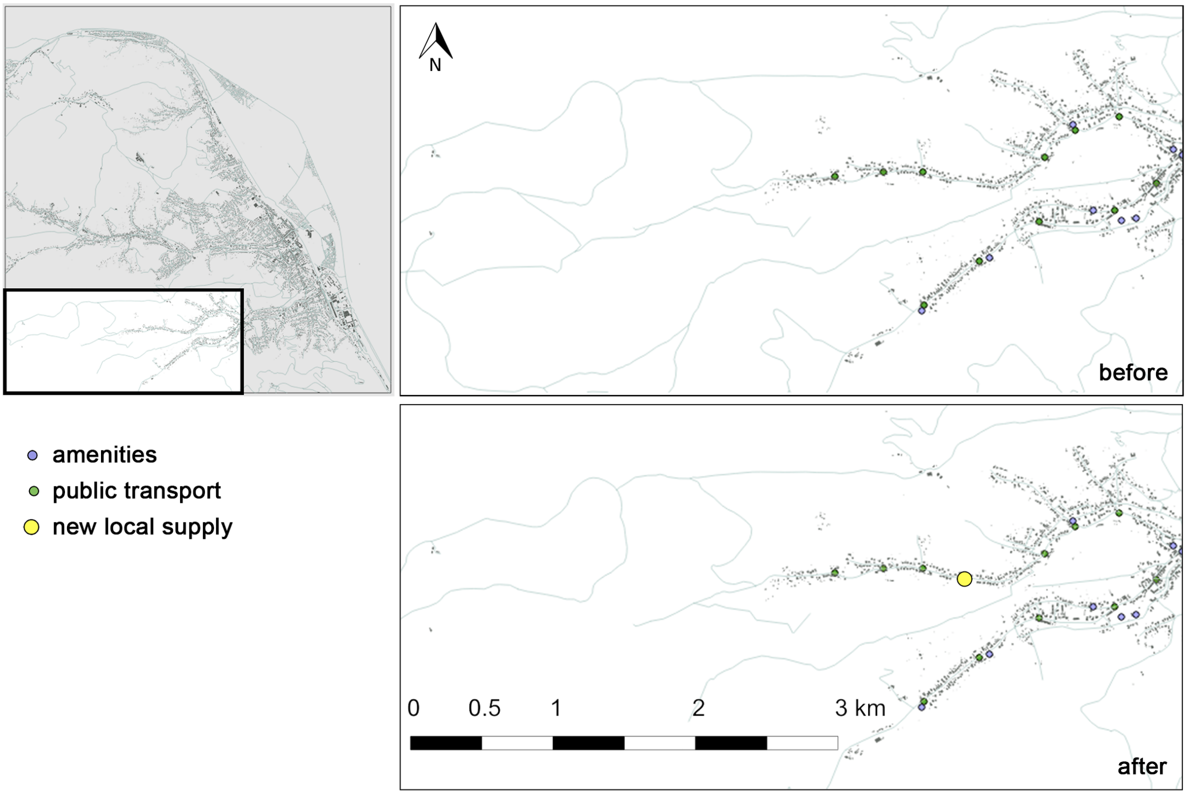

Figure 49: Alterations of the existing state

In order to verify the assumption about the proximity to the road network leading to high suitability for buildings, the roads in the southwest area are removed. Additionally, one local supply facility was added in the close by part of Weidling in order to test how strongly this influences the results.

As it turns out, these alterations hardly change anything concerning the suitability of cells to being built-up, as illustrated in the figure below.

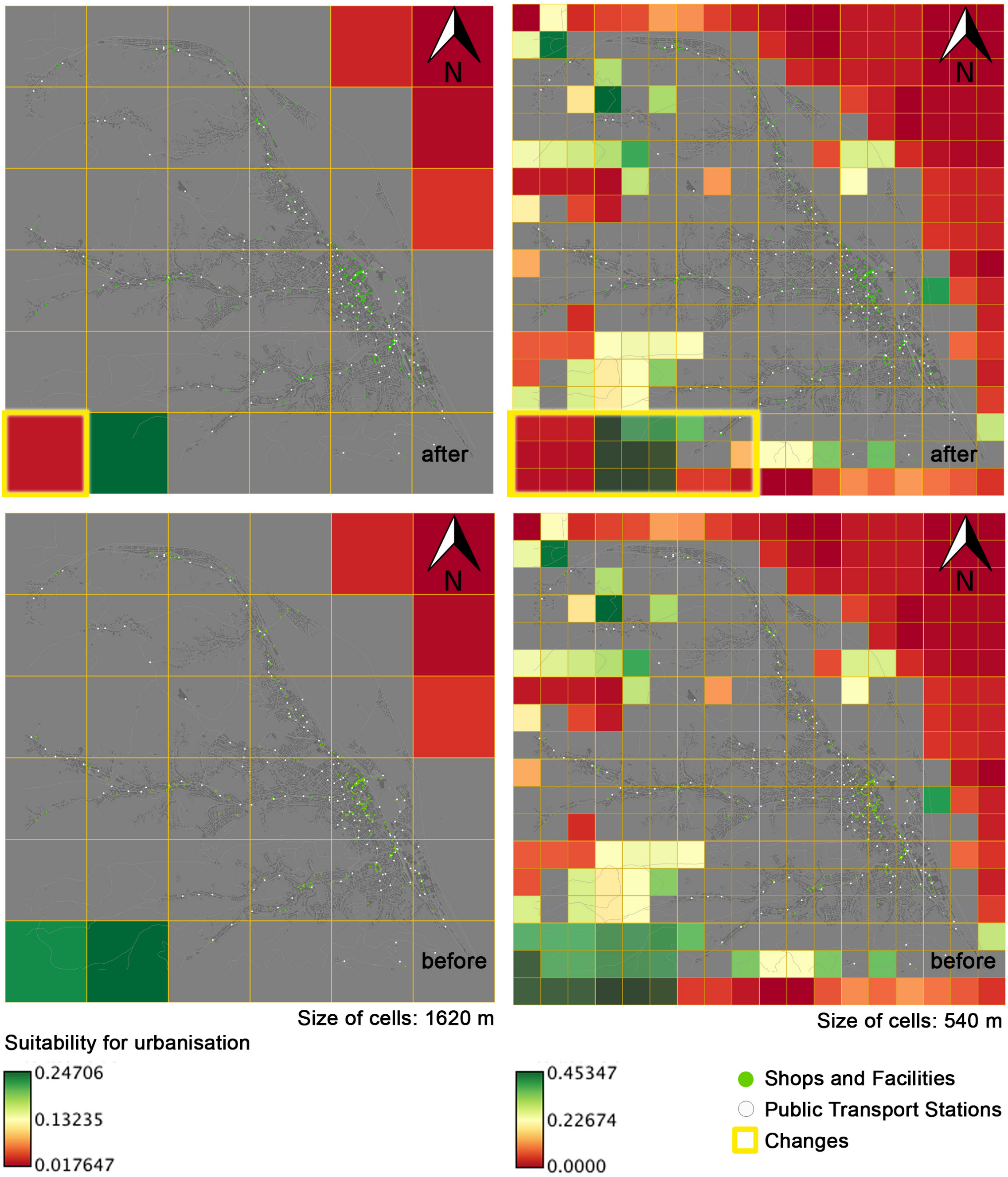

Figure 50: Suggested cells for building on the two largest scales after alterations

However MUP-City's suggestion for building-up cells is different than before. Besides suggesting areas along the Danube in the North-East, areas around Weidling in the South-West are proposed for future building activities as well.

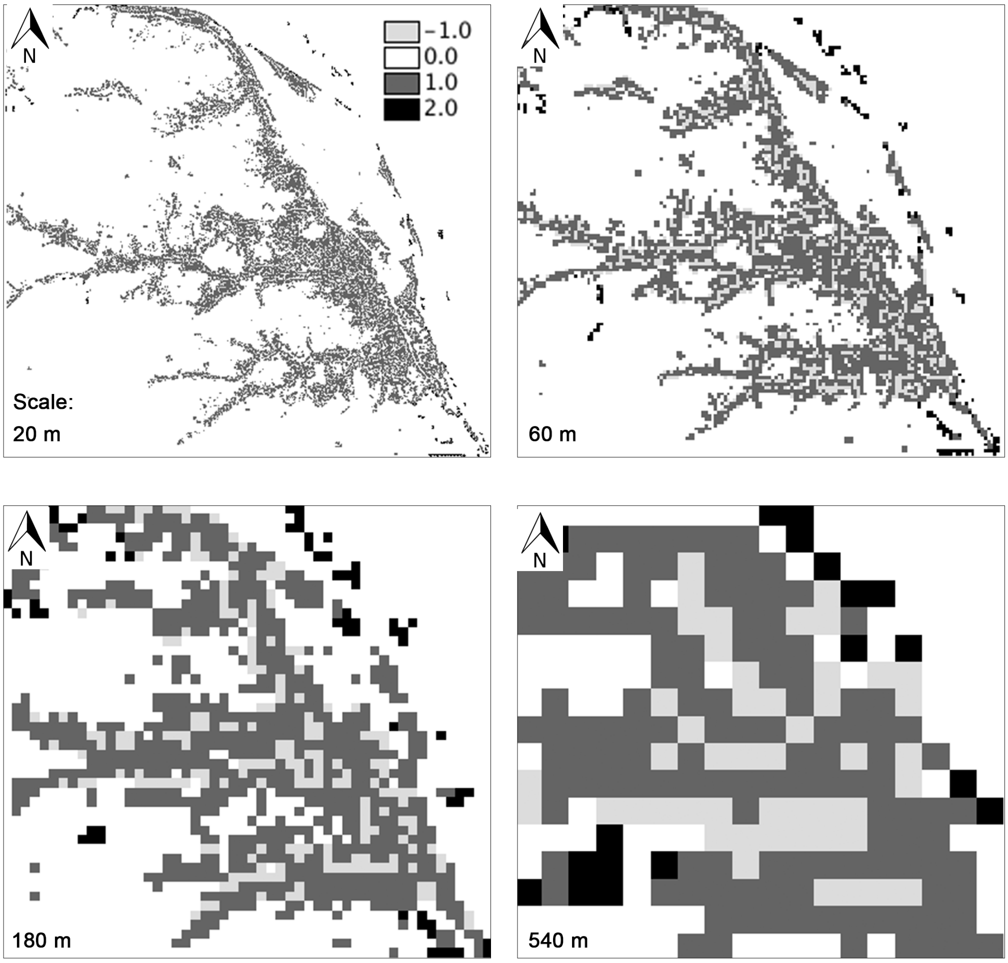

Figure 51: Suggested development of cells in Scenario 1

What can be learnt from this is that the availability of level 1 amenities has a substantial influence on the supply of built-up areas and therefore their attractiveness for being built-up.

5.2.3 Option Testing: Development of Weidling

Now that the software has been explored, it is being applied to a specific question: *how can building development take place in Weidling in a manner that accessibility of amenities, public transport and open space is satisfactory during all states?* For this purpose a scenario is developed in two steps based on the existing state.

<u>State 1:</u> introducing additional shops and services on both levels in order to strengthen the local centre. Level 1 amenities are introduced in areas that are currently under-supplied with them. Cells are then being built-up according to their suitability.

<u>State 2:</u> The road network is being expanded in order to gain access to formerly inaccessible areas. Amenities are introduced where they are expected to be needed and, if necessary, public transport stops added. Then the area is analysed as before and more cells built up in the process of the interactive scenario development.

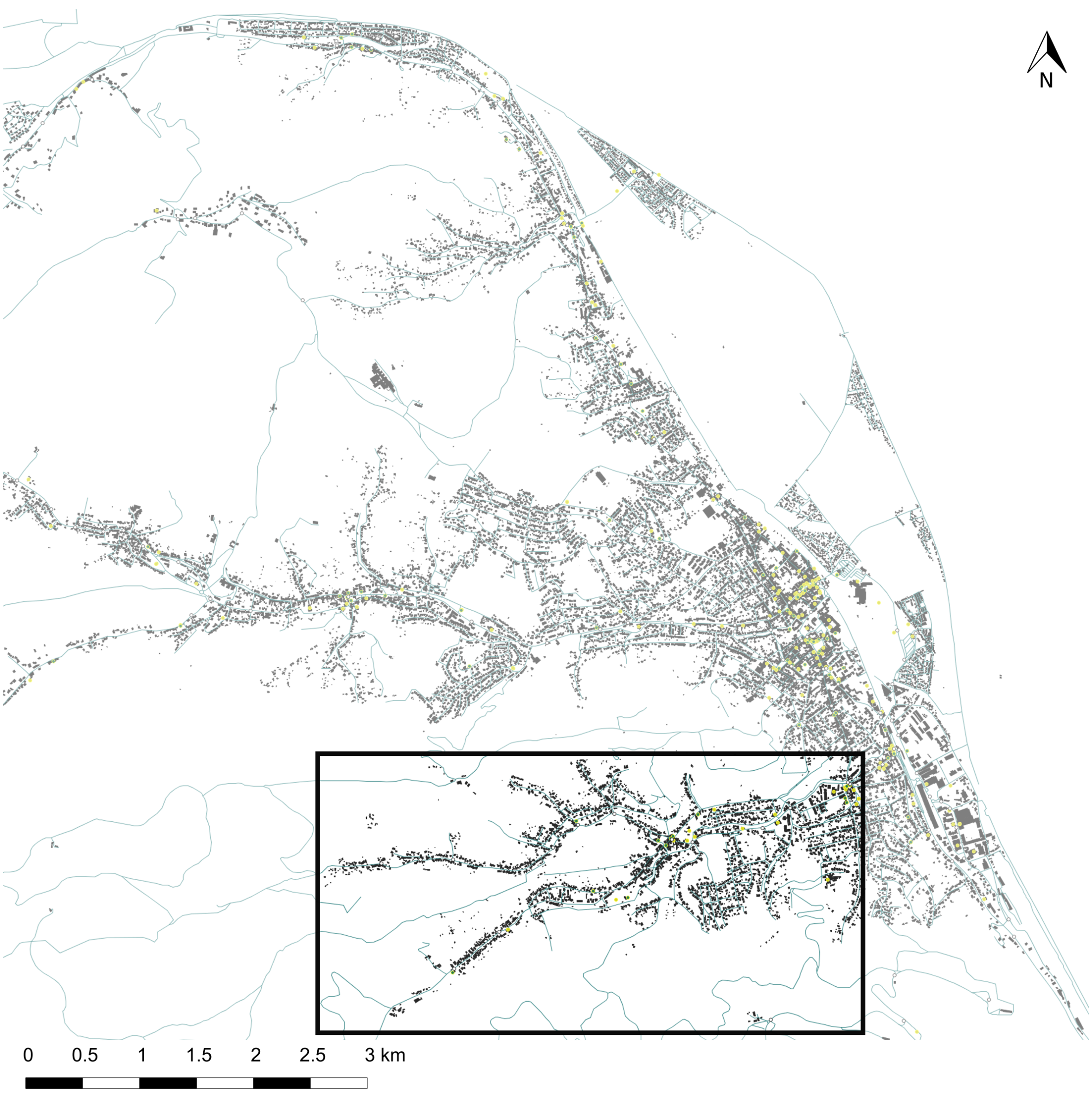

Figure 52: Area for which the scenario is developed

State 1

As can be seen in the next image, there are some areas in Weidling that currently have insufficient access to level 1 amenities, meaning they are further than 400m away from the closest. In the first state, level 1 amenities are introduced in these areas with regards to the existing types of amenities. However, in order to encourage building activities in and close to already built-up areas, the outer ends of the settlements are left as they are in this state.

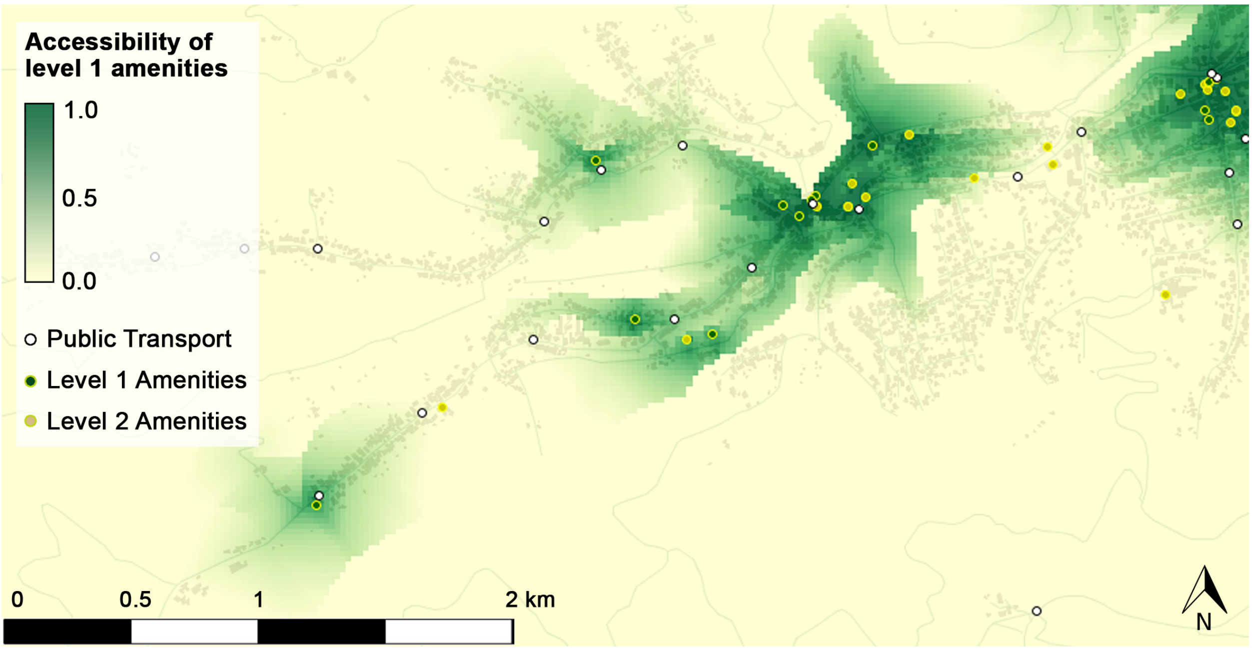

Figure 53: Existing state of level 1 accessibility in Weidling, cell length: 20m

For the local sub-centre an establishment for *local supply* was chosen on level 1 and one for *culture* on level 2. The choice of amenity class plays a role for the analysis in so far as MUP-City takes the diversity of classes within clusters into account. In order to get better results concerning suitability (and interest) for building-up in certain areas, it is therefore advisable to add classes of amenities that are currently not present. For the single amenities outside of the centre, the type is not as important for the analysis with MUP-City. The classes *local supply*, *education* and *health care* have been chosen for those. As location for those amenities existing buildings have been chosen.

The supply with public transport stations appears to be sufficient and therefore is not altered at this point.

Overall the accessibility of level 1 amenities increases, as can be seen in the image on the opposite page. Interest for building up cells is highest outside of the already built-up area on the larger scales. The key indicates though that these cells are not particularly suitable at all with the highest value being below 0.5 while 1 is the best. Only on the smaller scales it gets visible that there is potential for densification in the built-up area.

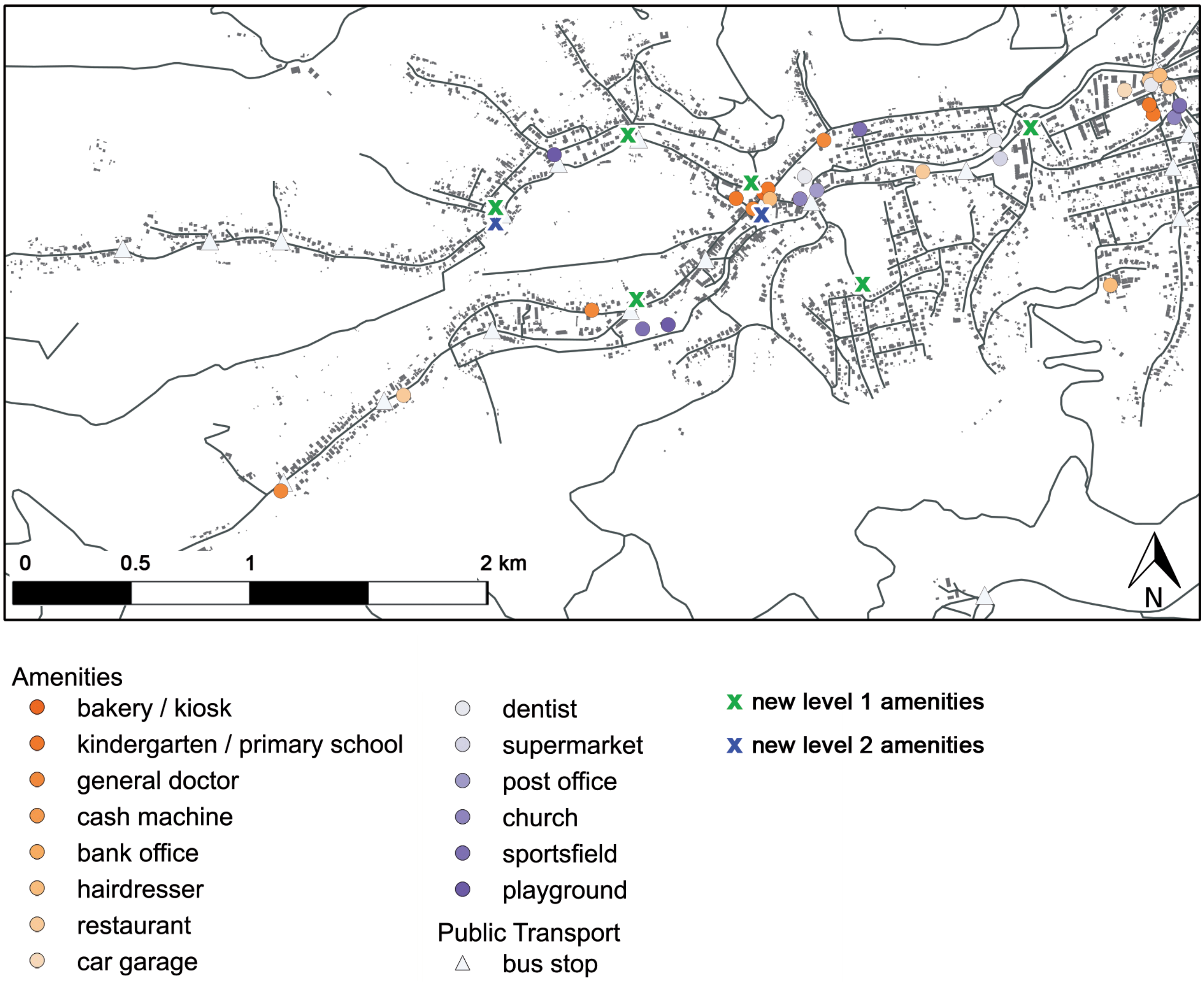

Figure 54: Types of amenities in Weidling

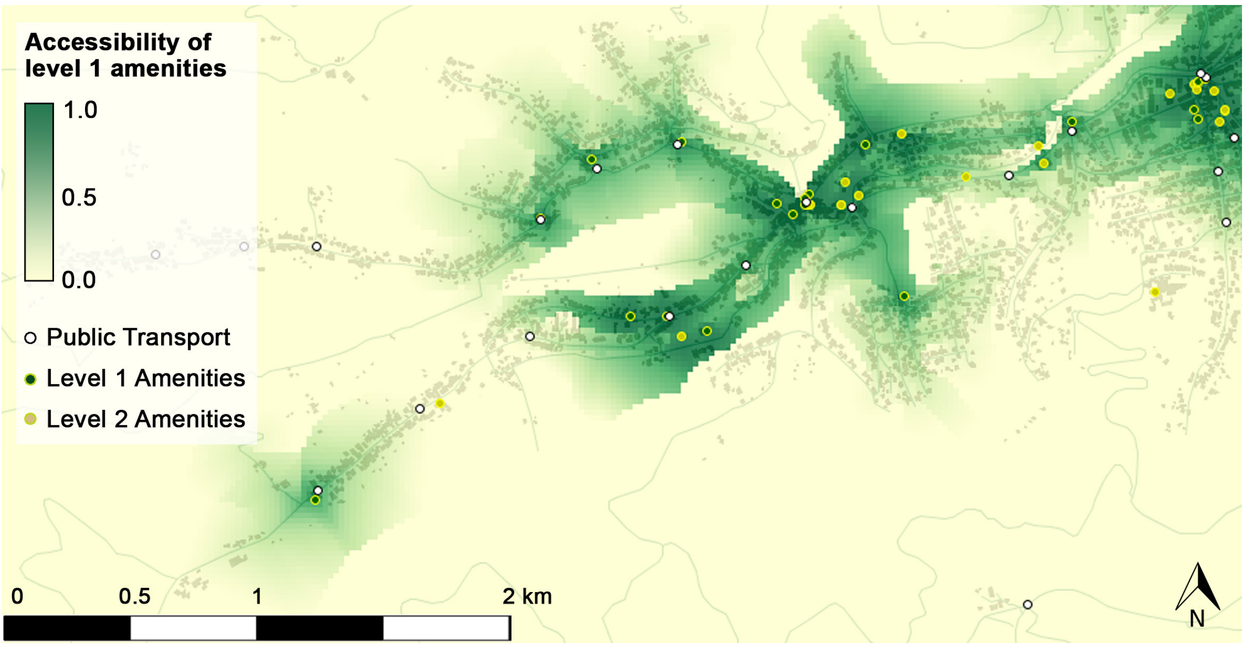

Figure 55: Accessibility of level 1 amenities in state 1

In this state it is therefore tried to build-up these existing gaps. While there are cells that are particularly interesting for this, it is however possible that building up these cells is still impossible according to MUP-City rules if N_{max}=5 has already been reached (or surpassed) in the corresponding meshes.

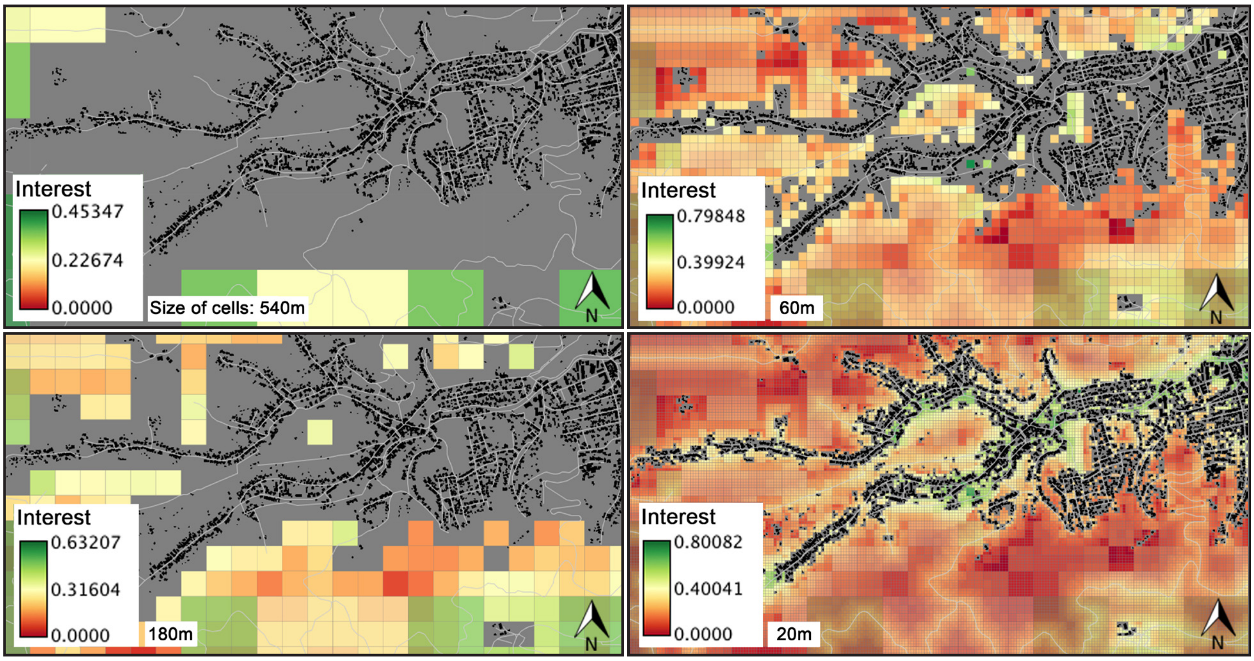

Figure 56: Interest of cells on the different scales in state 1

The first step is to chose cells on the 60m scale for building up. Only those cells are chosen that have an interest of 0.4 or higher in order to somewhat satisfactory supply them with amenities. A lot of cells are unavailable because small buildings are in the immediate surroundings, marking the corresponding cell as being built-up and therefore reaching or even surpassing N_{max}=5 for the mesh.

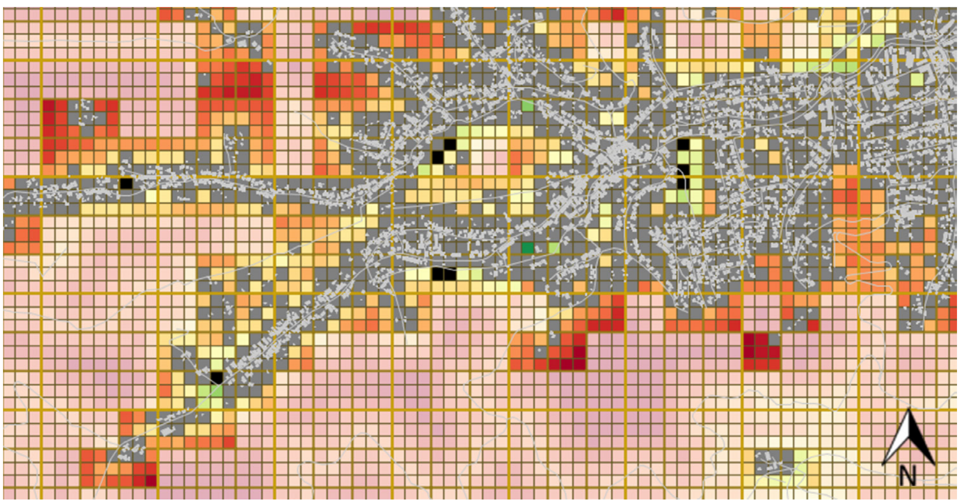

Figure 57: The selected cells on the 60m scale (black) in state 1

For simplicity cells are only being built-up in this scenario and not un-built; however in a different scenario the different outcomes could be analysed if not only building up but also un-building built-up cells was an option.

In the next step it is then zoomed in to the 20m scale in order to select cells on this scale. A challenge on this scale is to chose cells that do not cut off green space if built-up. MUP-City returns an error message if the user tries it anyway. Also, only cells that are within a mesh that is either already built-up or has been selected in the previous step can be built up. By selecting the cells it is only being decided that building in this square is permitted, not the type or size of the construction. Considering that zoning and building plans regulate exactly this, at the scale of individual lots, one application of MUP-City can be the testing of those plans.

As can be seen in the image on the following page, meshes that had been selected for building up on the 60m scale do not necessarily contain cells that are equally suitable for being built-up. There are two reasons for this: first, the colour scales are different on the different scales and second, the suitability is calculated for each cell on each scale individually, therefore there usually is diversity of suitability within meshes. The second is part of the application and therefore no bug but actually a feature. The first can be considered a problem though since it makes it impossible to compare the suitability on different scales. MUP-City offers the option to alter the colour scale in a manner that allows comparison, by setting value bounds for example. This option was not functional in the version that was used in this thesis though.

MUP-City offers to export the interactively developed scenario as shape-file that could then be used further in GIS applications. However, this feature does not work either in the used version. Therefore the building up of cells is done manually in QGIS in order to continue with state 2. As MUP-City recognises cells on the different scales only as being built-up or empty, simple and small shapes are used in place of real buildings. This is done in order to reduce the possibility of errors by accidentally crossing the border of cells and therefore marking too many and wrong cells as being built-up.

State 2

After adding new buildings, new level 1 amenities are introduced. While in state 1 the focus was on improving supply of built-up areas, undeveloped areas are closer looked at in state 2. Level 1 amenities are introduced in areas where future building activities could take place and therefore should be made more accessible, or more attractive for that matter. One additional bus stop is introduced between two existing ones where at this point are only few buildings. Also, one road in the Northwest is constructed and further existing roads connected with each other in order to possibly further improve accessibility. The alterations can be seen in the image after the following page.

Figure 58: Selection of cells on the 20m scale and their location in Weidling, state 1

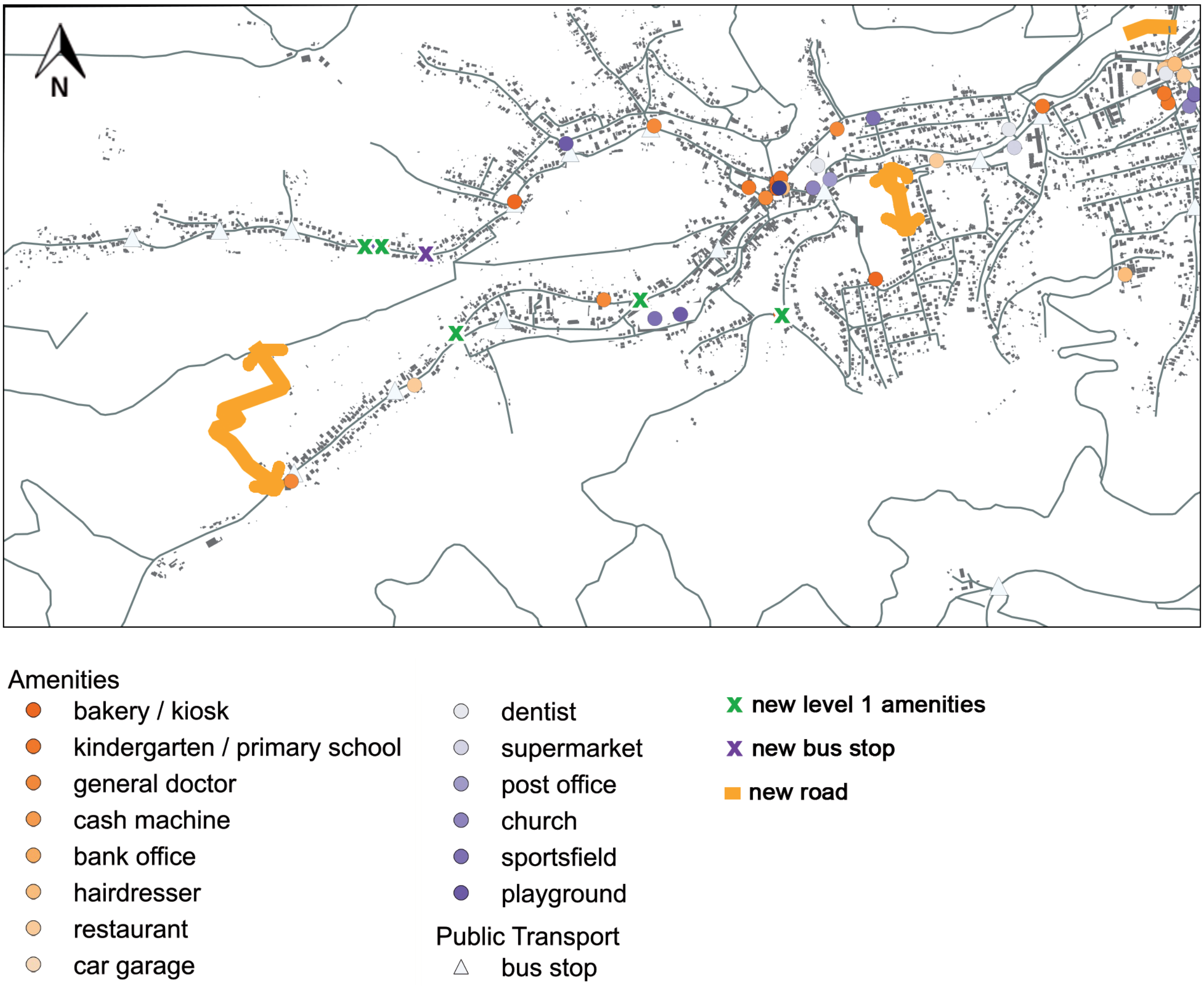

Figure 59: Altered amenities and road network in Weidling

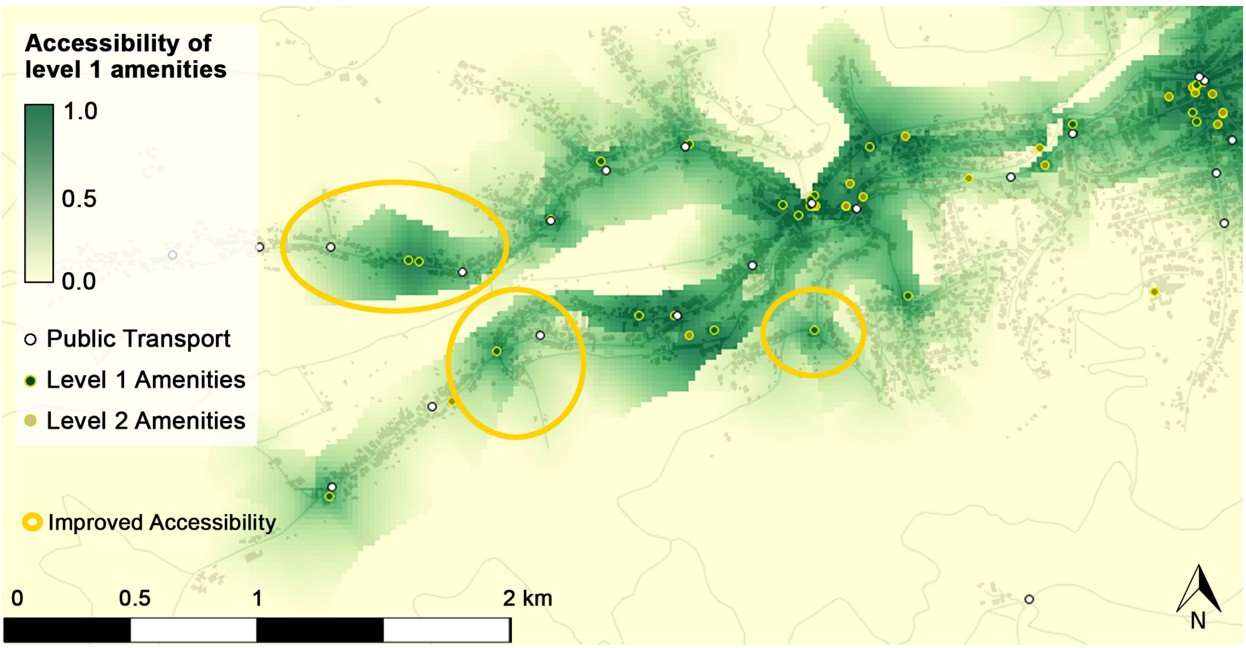

Figure 60: Accessibility of level 1 amenities in state 2

These alterations are contrary to common planning practice where usually amenities and other infrastructure is introduced after buildings are already in place and the demand for those is already there.

As in state 1, the altered GIS files are loaded into MUP-City and decomposed.

Due to the introduction of new level 1 amenities, the accessibility of those has improved in the areas where it formerly was low.

While the interest of cells on the larger scales remain unchanged, it has increased on the smaller scales. Areas that were previously not interesting for building up are now, particularly where level 1 amenities were introduced.

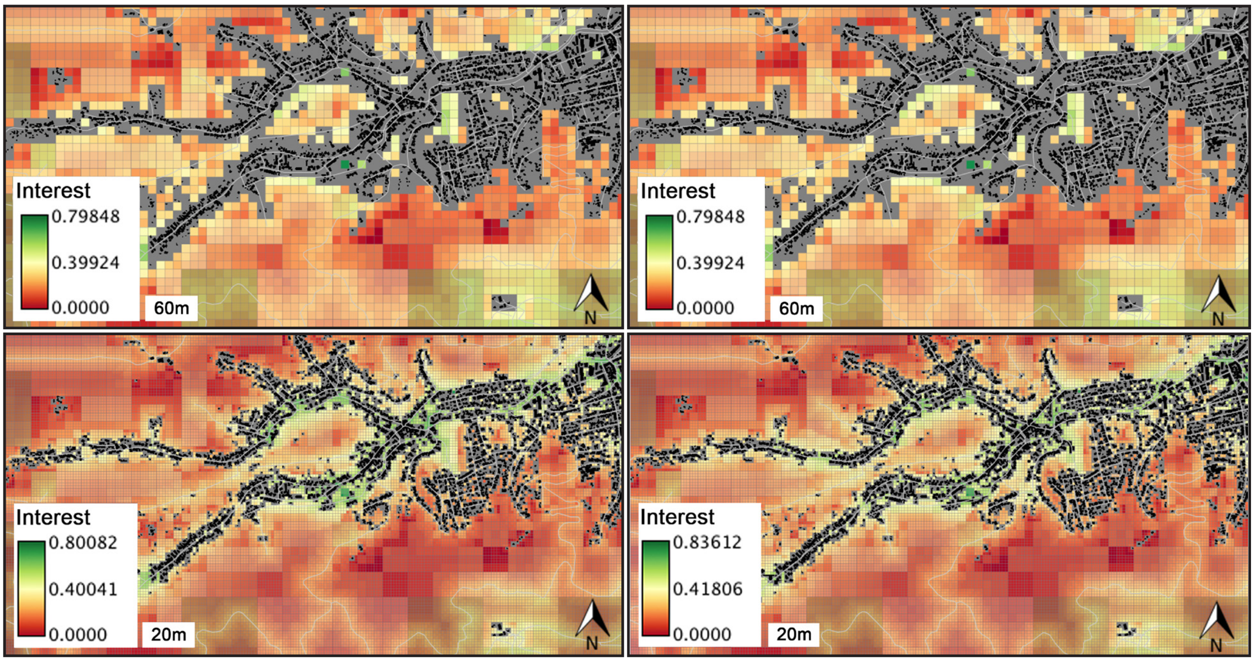

Figure 61: Interest of cells on the different scales in state 2 (right) compared to state 1 (left)

In the next step, these cells are being built-up in the interactive scenario. Again, only cells that have an interest value of 0.4 or greater are selected. The same challenges as before are encountered: interesting cells cannot be built-up because N_{max}=5 has been reached or because building them up would cut off open space. The image on the next page illustrates this process.

Connecting roads did comparatively little for the interest of the cells in their surroundings. Introducing amenities has a greater effect on the interest of cells in the area, as can be seen in the image above. However, in general only a limited amount of cells could be made available for building up. Reasons for this are that on one hand only very few amenities had been introduced and on the other hand the altered roads did no establish new connections to amenities.

The phasing scenario that has been developed shows that there is a very limited amount of land suitable for further development in Weidling in the current settlement and with the existing infrastructure, including amenities. While it is known that increased liveability and livelihood is strongly connected to the accessibility of different kinds of amenities and open space, MUP-City helps visualising this.

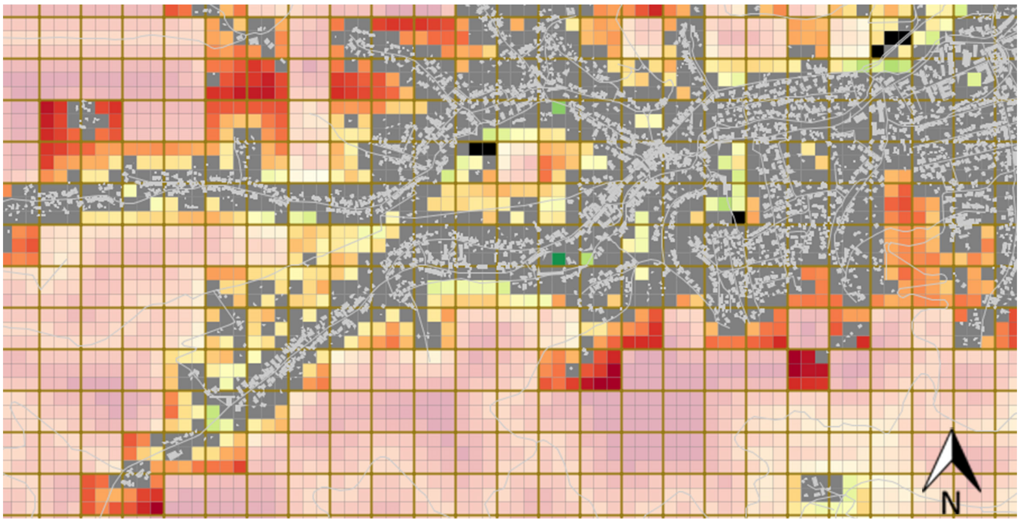

Figure 62: The selected cells on the 60m scale (black) in state 2

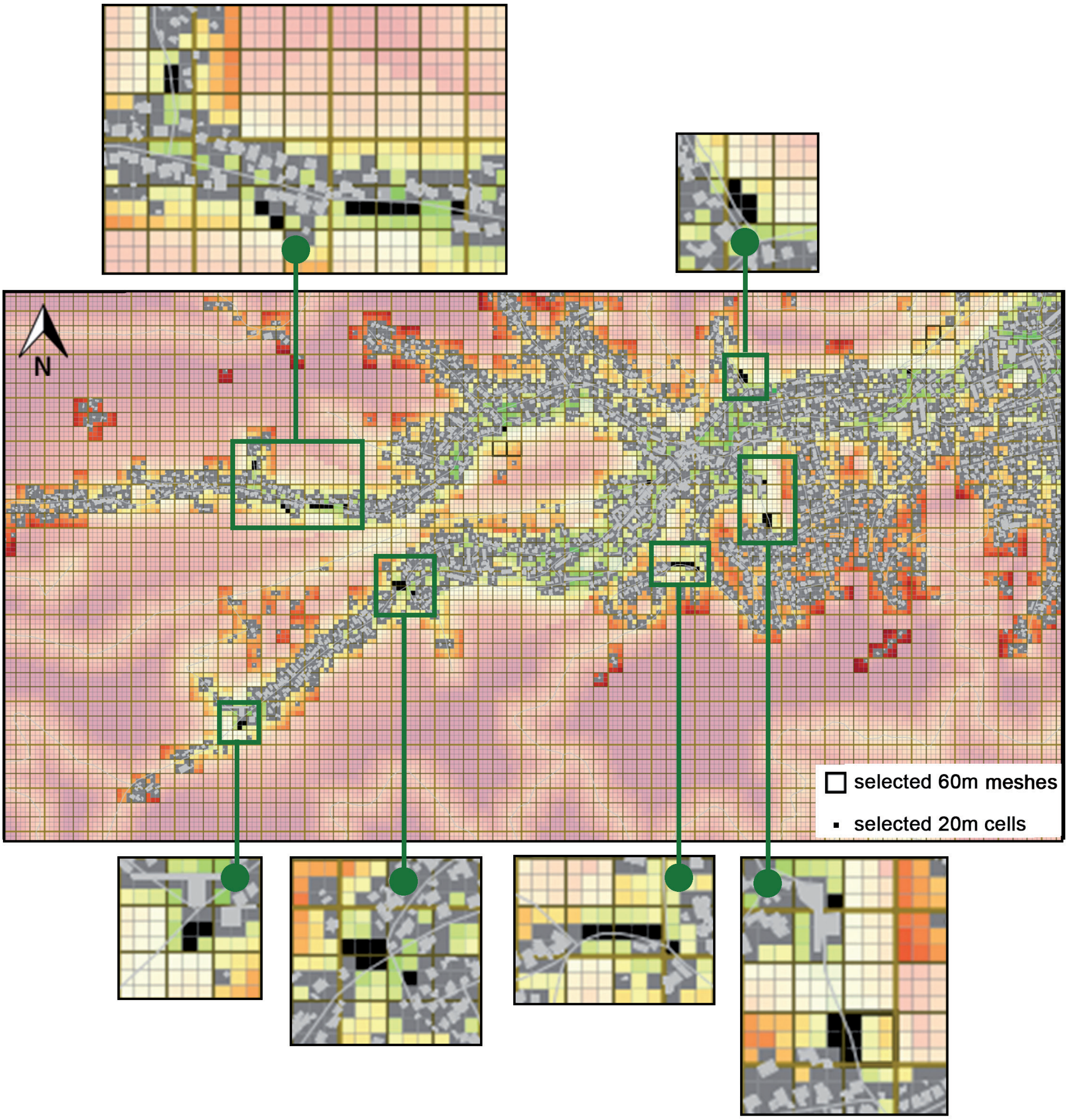

Figure 63: Selection of cells on the 20m scale and their location in Weidling, state 2

Considering the amount of changes that were made, these states cover only a relatively short time span. By altering the data on larger scales and by introducing a higher amount of amenities and road connections, a larger time span can be covered and changes in accessibility as well as cell-interest made more visible.

The phasing scenario shows that building close to already built-up areas leads to better accessibility of amenities of different kinds, which is favourable for reducing automobile traffic and increasing the livelihood of people living there.

III Conclusion and Outlook

Computer based models and scenarios can be useful tools to analyse and visualise different aspects of human settlements and help planners with the development of concepts, the testing of different options as well as the communication of the outcomes and proposals to decision makers and other involved people.

During the course of this thesis the application of the decision support software MUP-City on small cities in metropolitan regions was to be evaluated. Additionally, working with open source software and data was critically assessed.

MUP-City and Klosterneuburg

Klosterneuburg was chosen for the application of MUP-City in this thesis due to its close proximity to Vienna, the good accessibility by public transport from Vienna and because its size allows for examining a great part of it during the course of a master thesis. MUP-City includes several principles that have been identified to lead to sustainable development and that are also part of the regional development programme and the Klosterneuburg development concept. These are the reduction urban sprawl, increase use of public transport, access to and protection of open green spaces and access to shops and services.

The municipality of Klosterneuburg provided files concerning the local development concept as well as GIS-files with digitised roof areas, public services, open green space and land use plan, amongst others. This data served as a very useful basis to prepare the GIS-shape-files needed for MUP-City. Since geo information of that kind is always a snapshot of a certain moment in time, in this case mostly in the year 2010, the accuracy was checked and parts corrected where needed. However, the data proved to be still quite accurate two years later and only few parts were altered. This was mostly due to some building activities and buildings outside the city limits that were not included.

Due to its topographic setting the town historically developed mostly in a linear manner along the roads that connect its cadastral municipalities, resulting in a form that resembles a fractal, which is, however, fragmented. In a first step, MUP-City helps visualising the extent of sprawl through the decomposition, which results in cells on different scales that are either built-up or free. Concerning the hierarchical structure of different amenities, MUP-City initially clusters shops and services, which makes it easy to identify the historic core and sub-centres. However, this is not seen as the main asset by the author of this thesis, since this is information that can be interpreted from the GIS-layer itself as well. MUP-City evaluates each cell on different scales concerning their accessibility and suitability for urbanisation based on the input on buildings, existing road network, amenities of daily and weekly frequency, and open space.

For Klosterneuburg, the result is quite clear: densification of the areas around the sub-centres is favourable under the given circumstances, further sprawl is to be avoided. Since stocking up on floor numbers in the centre is in general more difficult than building in formerly free areas, it was interesting to what extent changing the defining factors makes more land suitable for urbanisation. The developed scenario shows that the areas with best suitability for being built-up are the gaps in the already built-up areas if access to amenities is to be satisfying. Therefore it is necessary to introduce additional amenities and to expand the existing network if settlement development is to take place outside that area.

While MUP-City does not provide fundamentally new findings, it helps simulating and visualising development strategies and their effects on accessibility of different kinds of amenities. For Klosterneuburg the software could be rather useful as the development concept and regional development programme feature the same principles of reduced urban sprawl, increased use of public transport, access to and protection of open green spaces as well as access to shops and services. MUP-City brings in the aspect of fractals that can help achieving those goals.

The software itself is work in progress, which sometimes leads to errors. After the bugs are resolved, it could be useful to adapt it in a way so it is less sensitive to data imperfections, mainly of the network layer. A great help would also be an improved interactive scenario development that allows to change the data base in the software itself, so that switching to other GIS software in between steps could be avoided.

Particular strengths include the comprehensibility of the visual figures, also for lay people, and the strong scientific basis, which make the software very suitable for the use also in small towns in order to support sustainable development.

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Images

Tables

Appendix

Modelling Cities as Cellular Automata

Models are used to illustrate and analyse the behaviour of systems. One way to model cities is by standard two-dimensional cellular automata. Such a model consists of a grid of cells, of which each can be in one specific state such as empty or occupied and have one of multiple possible properties such as “developed”, “undeveloped”, “rich”, etc. Based on certain transformation rules an iterative process creates the dynamics of the model by changing each cell according to those rules. These rules are always relating to the individual cell and its immediate neighbours (cf. Portugali 2000). When doing this, it is either used the Moore neighbourhood or the von Neumann neighbourhood, which differ in the surrounding cells that are taken into account. While the van Neumann neighbourhood is an orthogonal, axis-oriented system, the Moore neighbourhood also includes the diagonals, as shown in the image below.

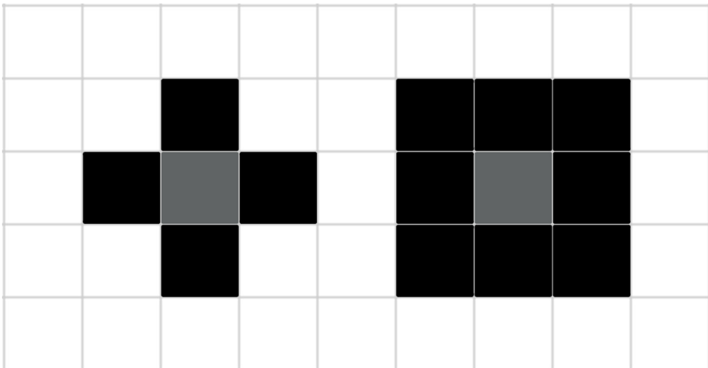

Figure 64: Von Neumann (left) and Moore neighbourhood (right) of the grey cell in the middle (Source: by author)

The objective of such models is to determine the nature and circumstances of interactions and interrelations between cells on a local scale as well as within the whole system. Simple rules can generate global structures and behaviours that are highly complex. The attractiveness to use cellular automata to study urban forms and structures stems from the relatively easy adaptability of urban elements for this model: built spatial units of cities such as buildings, lots and city-blocks can be modelled in cellular automata in a slightly different, but also discrete, form: cells. This works relatively well since cities and cellular automata models share another characteristic: properties of specific spatial units, also in the real city, are largely determined relatively to their immediate neighbours (cf. Portugali 2000). Cellular automata are mathematically rather simple, which makes them naturally predestined for simulating city dynamics (cf. Batty 2005, Benenson & Torrens 2004, Portugali 2000 in: Portugali 2009). They can basically be subdivided into implicit and explicit self-organised cellular automata cities. Implicit models aim on simulating an existing pattern as accurately as possible with the help of the simulation abilities of cellular automata (cf. Batty 2005 in: Portugali 2009) in order to explain currently or historically existing patterns or to predict a future pattern that is supposed to help planning. Since the model has some self-organising elements, these simulations can be quite realistic and sophisticated. Explicit models, on the other hand, are used to study self-organisation characteristics that are inherent in cities. They are used to investigate decision-making and behaviour on a micro scale (individuals and companies), observed on a local scale, and linked to structure and behaviour of the city on the global scale. These models are rather heuristic and the simulated cellular automata city is used as a learning device. Since they show an iterative structure, they are also suitable to create fractal structures (cf. Portugali 2000).