DISSERTATION

ORGANIZING THE CITY: MORPHOLOGY AND DYNAMICS
PHENOMENOLOGY OF A SPATIAL HIERARCHY

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PHENOMENOLOGY OF A SPATIAL HIERARCHY

for Christoph

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I. TOWARDS A HUMAN ARCHITECTURE - PROLOGUE

In general, the internal organization
of a settlement should be a hierarchy -
a branching tree - with units
that include sub-units, and so on.
Kevin Lynch, 1981

Understanding the principle of a complex urban organization with its interwoven structures and actions is the premise for sensible urban planning. Implementation of planning is a surgical intervention in the urban system. The surgeon, represented by the architect and urban planner, must know about structures, circulations, fluctuations, and the whole behaviour of the system, if he wants to appraise and prognose consequences. Batty points out that our knowledge of understanding cities is still based on a kaleidoscope of viewpoints (Batty, 1994).

The basic principles of architecture are the relationship between physical elements and between physical elements and dynamic components. These can be described as "spatial packing" (Franck, 2005). They aggregate on different scales through interactions of dense and seperated spaces created by fluctuations. Hence, two major architectural definitons emerge: buildings and movement channels.

Buildings and movement channels are the subject of the organisation of urban space determined by a geometric pattern (Hillier, 1994; Salingaros, 2003; Franck, 2006). The etymological origin of the term organisation is the Latin word *organum*, tool (Kluge 2002, 670). The most accurate interpretation of *organon* is to manage. Organon refers to a problem regarding diverse spatial manifestations: How is architectural and urban space managed?

A qualitative and quantitative description of spatial layout and relating these patterns to social activities such as movement can achieve a comprehension of spatial coherences (Parra, 2003). "How are things put together" (Hillier, 1994) has to be answered with a quantitative description. The scientific searching for traces refers consistently to the organisational principle of a hierarchy as a premise of self-organising living structures as in flora and fauna. The greek term hierarchy, Ἱεραρχία, is derived from the greek *ἱερός* - hieros, sacred and *ἄρχω* - arkho, rule (Wikipedia, 2007); and defines as the *sacred rule* a ranking system of things or people, where every element is sub-ordinated to another element exept the top element as as prior-ranked one.

Life itself is hierarchically structured: the configuration of leaves or the human vascular system, or social hierarchies of a society. Within architecture cascades exists as the antagonism of centre and periphery; from the street to the private living room; or as time cascades represented by rhythms and influencing the spatial morphology. Hence, cities are the arrangement of dense and seperated spatial spaces with a physical seperation and discriminatory accessibility rights (Franck, 2005).

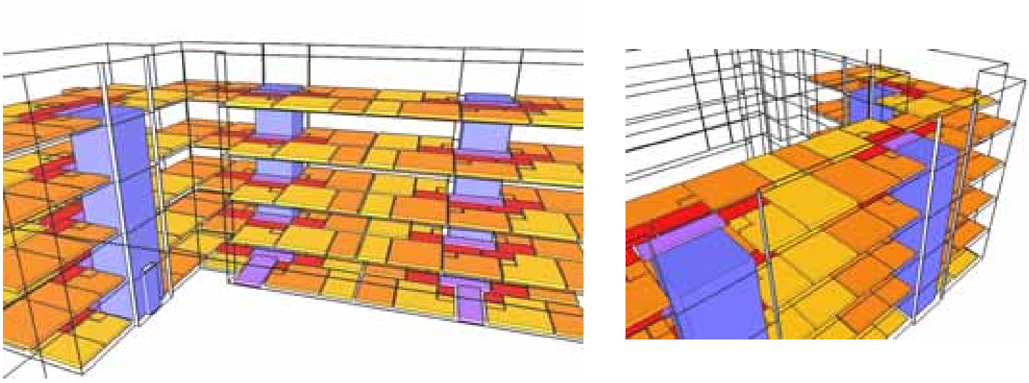


Figure I: Different zones with discriminatory accessibility rights from semi-public to privat in an apartment house.

In a general description of urban systems the phenomenon of hierarchy is constantly a subject of the literature in the field of architecture and urban planning (Hilberseimer, 1927; Lynch, 1981; Batty, Longley, 1994; Hillier, 1996; Frankhauser, 1994, 1997; Read, 2000; Pumain, 2000; Salingaros, 2000; Marshall, 2005). Hierarchies organise themselves as functions of an optimal adjustment for open and closed systems. Thermodynamics is the scientific basis (Prigogine, 1980). Dynamics aggregates as the basis of self-organizing systems (Portugali, 2000). In turn, these are again linked to the ordering principle of a hierarchy. Kritz also explains dynamic systems as complex, regenerative structures (Kritz, 1995). Additionally, the complexity of systems such as cities not only depend on the number and types of elements, but also on the number and types of links in-between the elements (Oeser, 1996). This again points to hierarchy as a structuring principle of urban systems.

Within architecture a *spatial hierarchy* manifests as the visual result of diverse hierarchies such as the social one of complex systems. Additionally, for the phenomenology different scales have to be defined for a hierarchical classification. At the same time the different scales highlight the diverse discussions in context of the built environment.

The architectural scale examines the scales of buildings and their relation in parts or as a whole to an urban environment. Therefore, an urban scale of an urban morphology investigates the relations between buildings in an urban environment and their relation to the space they create. The relations are identified in plans and maps, where the block structure is visualised, and on the basis of street sections. In contrast, the spatial scale as used in geography examines the abstract associations in a spatial and temporal sense (Mavridou, 2007). This research focuses on the urban scale as the most accurate scale for the identification of diverse hierarchical manifestations.

Its phenomenological descripion can be analysed and visualised by urban models. Modeling is based on the question "how the system is at the moment" and this is simply a description of systems (Allen, 1997). The urban model does not contain past or future; the dimension of time is missing (Franck, 2007). Therefore, the complex interdependence not only with time, but also with ecology and economy are taken into account.
Static modeling is adequate as a scientific, earmarked tool for analysis and illustration of the research in question. This heuristic working principle was intentionally used for the empirical research.
In this research the characteristics of a *spatial hierarchy* are under scrutiny. The phenomenology of diverse forms of emergence of the spatial hierarchical principle of interest is reflected in the four main hypotheses:

I. Urban space is hierarchically structured. Topological packing and nesting of space are produced by relations of development.

II. The street network is hierarchically structured by the aspects of topology and metric (geometry), political planning and route choice.

III. The more detailed a system is, the higher the level of urbanisation.

III a. An intensive use of urban space is represented by the concentration of density, population, facilities, and transport.

III b. Political and historic planning decisions have an impact on intensive use (landuse plan, masterplan) and therefore influence urban patterns. Ergo, utilisation of space and configuration influence each other.

IV. Spatial and chronological hierarchies are intrinsically linked to each other. Space and time are two aspects of the urban hierarchy. Both influence each other and cause one another.

This research is structured in four major parts (Part I to Part IV). The first part (Part I) focuses on the theoretical background. An approach to the concept of space is illustrated by different space theories in the context of abstract, philosophical, architectural, and dynamic points of view. Furthermore, this part specialises in urban space. In general, every formulation and layering of space can be found compacted like minimal space in cities: basic principles of morphology and dynamics are broached. Vienna is used as the focus for analysis, and the Viennese pattern is explained in its historical context. Consistently dynamics have been the issue up to now. Now, in this research some dynamic theories are discussed. The focal point is the question of "hierarchy and urban self-organisation". The theoretical background is the basis for the empiricism.
Both empirical parts (Part II & Part III) are structured into two sub-parts. Part II deals with the morphology whereas Part III deals with the dynamic flux of the network. Within

both the term of movement is part of the analysis - first, as a passive indicator and second as an active indicator producing urban hierarchies.

Part II is subdivided into the sections of topology and metric. For the topological, syntactic analysis Bill Hillier´s analytical theory Space Syntax was used, and for the metric coherence, Pierre Frankhauser´s fractal analysis methodology. Vienna has been never completely analysed using Space Syntax before. In the case of fractal analysis a city´s street network has never been placed under scrutiny before. Naturally, built-up surfaces are the content of a fractal analysis. In some cases, the public transport channels of high-speed railways have also been analysed (Moskow: Benguigui, 1992, 1993; Paris: Benguigui, Daoud, 1991; Stuttgart: Frankhauser, 1994; Seoul: Kim, Marinov et al., 2003). The novelty of this fractal research complicates the placement of results as no reference research exists.

The second empirical part (Part III) deals with the direct impact of active dynamic indicators. They are represented by the aspect of motorised individual traffic. As a basis the political planning decisions of Vienna and the cognitive route choice were chosen. Within political planning, geometric and speed aspects are the priority. Cognitive route choice is analysed using the methodology of segment analysis - an angle-weighted system graph.

In contrast, for political planning an original hierarchical concept was developed and visualised. The Viennese street network has never been classified with regard to content and with a conception as found for the streets of Lower Austria in the norms and regulations of Lower Austria (NÖBO). Again, it has to be highlighted that the application of the described models of active indicators to the Viennese street network is completely new and has not been implemented until now.

All described models are correlated with socio-economic data and the traffic census to link the abstract layer of the structure models to real life: a structure-function-model. Conclusion and discussion are an important part of this research. A reflective consideration of the quality and quantity of the individual urban models is seen as one of the fundamentals and tasks in this field of science.

Understanding hierarchical coherences as a basic principle for a functional and therefore social solution in urban planning and its implementation facilitates the path to a *humane architecture* - an architecture from and for people.

II. FÜR EINE HUMANE ARCHITEKTUR - PROLOG

In general, the internal organization
of a settlement should be a hierarchy -
a branching tree- with units
that include sub-units, and so on.
(Kevin Lynch, 1981)

Das Verstehen des Prinzips der komplexen Organisation einer Stadt mit ihren in sich verwirkten, komplexen Strukturen und Vorgängen ist die Prämisse für eine sinnvolle Stadtplanung. Implementation von Planung bedeutet einen chirurgischen Eingriff in das urbane System. Der Chirurg in Form des Architekten und Stadtplaners muss um die Struktur, Zirkulation, Fluktuation und das Gesamtverhalten des Systems Bescheid wissen, will er die Auswirkungen abschätzen und vorhersagen. Batty betont, dass unser Wissen im Bemühen, die Organisationsform der Stadt zu verstehen noch immer auf einem Kaleidoskop von Ansichten basiert (Batty, 1994).

Grundprinzip in der Architektur sind die Beziehungen zwischen physischen Elementen sowie zwischen physischen Elementen und dynamischen Komponenten. Diese letztere sind als „räumliche Packungen" (Franck, 2005) beschreibbar. Sie existieren auf unterschiedlichen maßstäblichen Ebenen durch die Interaktion von dichten und weniger dichten Räumen, die wiederum durch verschiedenste Fluktuationen entstehen. Einerseits beeinflussen die interaktiven Fluktuationen die Raumkonfigurationen, andererseits beeinflussen Raumkonfigurationen die Fluktuationen. Daraus ergeben sich die zwei maßgebliche architektonische Ausformulierungen einer Stadt: Gebäude und Bewegungskanäle.

Gebäude und Bewegungskanäle unterliegen der Organisation von urbanem Raum, der durch ein geometrisches Muster bestimmt ist (Hillier 1994, Salingaros 2003, Franck 2006 et al.). Etymologisch leitet sich der Terminus Organisation von dem Lateinischen *organum* ab, das Werkzeug, Instrument bedeutet (Kluge 2002, 670). Im modernen Sprachgebrauch kann im Sinne einer akkuraten Interpretation die Begrifflichkeit mit „verwalten" gleichgesetzt werden. Der Begriff Organum verweist auf eine Fragestellung hinsichtlich diverser räumlicher Manifestationen: Wie ist der urbane Raum verwaltet?

Ein Verständnis für die räumlichen Zusammenhänge kann durch eine qualitative und quantitative Beschreibung von räumlichen Mustern erreicht werden, und eine Interpretation dieser mit sozialen Aktivitäten wie Fluktuationen und Bewegungen in Zusammenhang gebracht werden (Parra, 2003). Zu beantworten ist die Frage „Wie die Dinge zusammengesetzt sind" durch eine quantitative Antwort. Die wissenschaftliche Spurensuche verweist immer wieder auf das Organisationsprinzip der Hierarchie als weit reichende Prämisse von sich selbst organisierenden lebenden Systemen wie sie in Fauna und Flora vorkommen.

Der Terminus Hierarch**i**e, Ἱεραρχία, leitet sich vom griechischen ἱερός - hieros, heilig, und ἄρχω **-** arkho, Regel**,** ab (Wikipedia, 2007) und definiert somit als „heilige Regel" ein System von Kaskaden von Dingen und Menschen. Dabei ist jedes Element einem anderen untergeordnet, außer dem Element an der Spitze des Systems.

Das Leben selbst ist hierarchisch strukturiert, was bei zahlreichen Beispielen in Erscheinung tritt, sei es im Aufbau von Blättern oder des menschlichen Gefäßsystems, oder aber auch die sozialen Hierarchien einer Gesellschaftsstruktur. In Architektur und Städtebau finden sich Kaskaden sowohl im Gegensatz von städtischen Zentren und deren Peripherien; von der öffentlichen Straße zum persönlichen, privaten Wohnzimmer, oder aber auch auf zeitlicher Ebene in Form von Rhythmen, die wiederum die Raummorphologien beeinflussen.

So sind Städte Anordnungen von dicht gepackten und getrennten Räumlichkeiten, die ihre Trennung über eine physische Abschirmung und diskriminierende Zugangsrechte erfahren. Ein hierarchisches System kennzeichnet die strukturelle Packung (Franck, 2005).

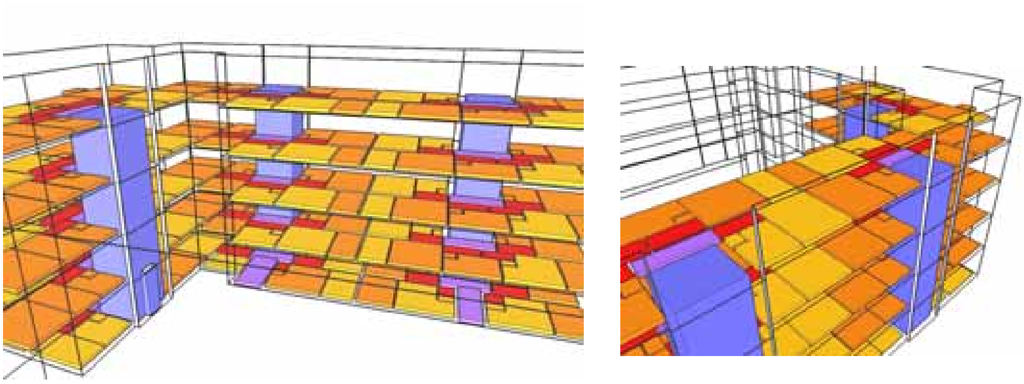


Abb. II: Verschiedene Zonen mit diskriminierenden Zugangsrechten von semi-öffentlich bis privat anhand eines Miethauses.

In allgemeinen Deskriptionen von urbanen Systemen ist das Phänomen der Hierarchie immer wieder Gegenstand der Betrachtung von städtebaulicher Planung und Architektur (Hilberseimer, 1927; Lynch, 1981; Batty, Langley, 1994; Frankhauser, 1994, 1997; Read 2000; Pumain 2000; Salingaros 2000; Marshall 2005). Kaskaden organisieren sich als Ausdruck und Funktion einer optimierten Anpassung für ein geschlossenes oder offenes System. Thermodynamik bietet hierzu die wissenschaftliche Grundlage (Prigogine, 1980). Die Dynamik aggregiert sich auf der Basis von selbst-organisierenden Systemen (Portugali, 2000). Diese wiederum sind mit dem Ordnungsprinzip Hierarchie verwoben. Dynamische Systeme sind komplexe, rückgekoppelte Systeme (Kritz, 1995). Die Komplexität von Systemen wie Städte bezieht sich nicht nur auf die Anzahl und Art der Elemente, sondern auch auf die Anzahl und Art der Verbindungen und Beziehungen der Elemente untereinander, wodurch ein System entsteht (Oeser, 1996, 221).

Hierarchie ist ein globales Prinzip, städtebauliche Systeme oder Gruppierungen zu strukturieren. Dabei greifen verschiedene Ausformulierungen der Hierarchie. Im

architektonischen Bereich manifestiert sich die räumliche Hierarchie als visuelles Ergebnis anderweitiger Hierarchieformen komplexer Systeme. Ergänzend zur Analyse von Hierarchien müssen daher die ausdifferenzierten Mechanismen, die in der gebauten Umwelt wirksam werden, klassifiziert werden. Erst dann kann eine Einordnung der Hierarchie in die verschiedenen Maßstäblichkeiten vorgenommen werden. Diese Unterteilung definiert zugleich die Themenbereiche in der Auseinandersetzung mit gebauter Umwelt:
Der architektonische Maßstab untersucht die Maßstäblichkeit von Gebäuden und ihre Beziehung zueinander im Verhältnis zum Ganzen oder untereinander. Urbaner Maßstab einer urbanen Morphologie untersucht zudem in einer städtebaulichen Umgebung die Beziehungen der Gebäude zueinander und die Beziehung zum Raum, den sie kreieren. Die Relationen im urbanen Maßstab werden zumeist anhand von Stadtplänen, in die die Blockstrukturen eingetragen sind, oder anhand von Straßenabschnitten analysiert. Im Gegensatz dazu untersucht der räumliche Maßstab, wie er in der Geographie verwendet wird, die abstrakte Vorstellung von Ausdehnung im räumlichen oder temporären Sinne (Mavridou, 2007). In dieser Arbeit liegt der Fokus auf der Untersuchung von Hierarchien auf der Ebene des urbanen Maßstabs.

Die phänomenologische Beschreibung lässt sich in mathematischen Modellen von Stadtentwicklungstheorien sichtbar machen. Das Modell beruht auf der Frage „Wie das System im Moment ist", was lediglich eine Beschreibung darstellt. Das urbane Modell enthält weder Zukunft noch Vergangenheit; die Zeitdimension fehlt (Allen, 1997; Franck, 2007). Das statische Modell hingegen eignet sich als ein wissenschaftliches, zweckgebundenes Arbeitsinstrument zur Analyse und Erläuterung der *räumlichen Hierarchie*. Den komplexen Verflechtungen der Hierarchien urbaner Systeme sowohl mit dem Faktor Zeit, als auch mit Ökonomie und Ökologie wurde Rechnung getragen. Diese heuristische Arbeitsmethodik wurde hier bewusst angewandt.

In dieser Arbeit wird das Charakteristikum der *räumlichen Hierarchie* analysiert. Die Phänomenologie verschiedener Erscheinungsformen des räumlichen, hierarchischen Prinzips von Interesse spiegeln sich in den vier Haupthypothesen wieder:

I. Der urbane Raum ist hierarchisch gegliedert. Die topologische Packung und Schachtelung der Räume wird durch die Beziehungen der Erschließungen produziert.
II. Das Straßennetzwerk wird durch die Aspekte von Topologie und Metrik (Geometrie), Planung und Routenwahl hierarchisch gegliedert.
III. Je detaillierter ein System ist, desto höher ist der Grad an Urbanität.

IIIa. Eine intensive Nutzung von urbanen Räumen wird durch Dichte von Bevölkerung, Versorgung und Transport repräsentiert.

IIIb. Eine intensive Nutzung ist durch politische und historische Planungsentscheidungen geprägt (Flächenwidmungsplan, Masterplan) und beeinflusst die urbanen Muster. Ergo, die Nutzung von Raum und die Konfiguration beeinflussen sich gegenseitig.

IV. Räumliche und chronologische Hierarchien sind untrennbar miteinander verbunden. Raum und Zeit sind zwei verschiedene Aspekte der urbanen Hierarchie. Sie beeinflussen sich gegenseitig.

Die vorliegende Arbeit gliedert sich in vier Teile (Part I-Part IV). Im ersten Teil (Part I) steht die Theorie im Vordergrund. Eine Annäherung an die Begrifflichkeit der Hierarchie erfolgt durch eine allgemeine Einleitung der verschiedenen Raumtheorien aus abstrakter, philosophischer, architektonischer und dynamischer Sicht. Im Folgenden konzentriert sich das Kapitel auf die Beschreibung städtebaulichen Raum. Thematisiert werden die Grundprinzipien der Stadt und ihre Morphologie. Da der Gegenstand der Untersuchung die Stadt Wien ist, wird die Morphologie der Stadt noch einmal speziell in ihrem historischen Kontext dargestellt und erläutert. Das Prinzip der Dynamik leitet schließlich auf die Kernthematik der Arbeit über. Diese wird nun explizit angesprochen und die Annäherung an den Nukleus der Arbeit erfolgt: Hierarchie und urbane Selbstorganisation. Diese zwei Hauptthematiken werden in den nächsten beiden Teilen der Arbeit mit Hilfe der aufgezeigten theoretischen Leitlinien empirisch untersucht.
Die beiden empirischen Teile (Part II, Part III) sind in die zwei Hauptbereiche unterteilt. Erstens, jenen der Morphologie (Part II) und zweitens, jenen des Dynamischem Flux (Part III). In beiden Terminologien ist die Begrifflichkeit Bewegung Teil des theoretischen Unterbaus - einmal als passiver Indikator, einmal als aktiver Indikator für die Produktion räumlicher Hierarchien.
Part II unterteilt sich wiederum in die Teilbereiche Topologie und Metrik. Für die empirische Untersuchung im topologischen Kontext wurde Bill Hilliers qualitative Space Syntax Theorie angewandt, für die metrische Untersuchung Pierre Frankhausers fraktale Analysenmethodologie (Programm fractalyze).

Noch nie zuvor wurde der Forschungsgegenstand Wien in seiner Gesamtheit anhand der Space Syntax - Methode im Ganzen untersucht. Selbiges gilt für das fraktale Modell. Darüber hinaus wurde noch nie zuvor im Bereich der fraktalen Analyse ein Straßennetzwerk einer Stadt analysiert. Für gewöhnlich wird diese Methode zur Analyse gebauter Strukturen herangezogen, in nur wenigen Fällen wurde sie im Bereich des öffentlichen Transports angewandt (Transportkanäle von Schnellbahnlinien - Moskow:

Benguigui 1992, 1993; Paris: Benguigui und Daoud 1991, Stuttgart: Frankhauser 1994; Seoul: Kim und Marinov et al, 2003). Insofern handelt es sich um ein Novum, was die Einordnung der Ergebnisse erschwert, da bis jetzt keine Referenzprojekte als Bezugsquellen existieren.

Die zweite empirische Teil (Part III) beschäftigt sich mit dem direkten Einfluss aktiver dynamischer Komponenten als ein Einfluss für die räumliche Hierarchie. Diese wurden in Folge unter dem Aspekt des motorisierten Individualverkehrs (MIV) eingearbeitet. Als Grundlage für die zwei Teilbereiche von Part III dienen einerseits die städtebaulichen Entscheidungen der Stadt Wien; andererseits ein kognitives Modell zur Routenwahl. Geometrische und geschwindigkeitsorientierte Aspekte sind in den öffentlichen Planungsstrategien vorrangig. Danben spiegelt das kognitive Modell den topologischen Aspekt wider, der sich hier nicht als reiner Systemgraph präsentiert, sondern eine Variante in Form eines winkelgewichteten Graphen darstellt. Es modelliert die Hierarchie aktiver Routenwahl bei individueller Fortbewegung.

Im Gegensatz dazu wurde ein hierarchisches Modell der Wiener Stadtstraßen der öffentlicher Stadtplanung entwickelt und visualisiert. Das Wiener Straßennetz unterlag bis dato keiner genauen begrifflichen und inhaltlichen Klassifizierung, so wie man es beispielsweise in der Niederösterreichischen Bauordnung (NÖBO) für das Niederösterreichische Straßensystem vorfindet.

Alle beschriebenen Modelle wurden durch die Korrelation mit sozi-ökonomischen Daten und dem Verkehrs Zensus von der abstrahierten Ebene eines Strukturmodells in einen Realitätsbezug gebracht (structure-function model).

Konklusion und Diskussion sind ein wichtiger Bestandteil dieser Arbeit. Ein reflektiertes Nachdenken über Qualität und Quantität der einzelnen Städtebautheorien schließt jeden Teilbereich ab. Im letzten Kapitel werden die Ergebnisse der Arbeit zusammengefasst, eine kritische Betrachtung der Modelle beschließt das Kapitel.

Das Verstehen von hierarchischen Zusammenhängen als grundlegendes Prinzip der städtebaulichen Planung bereitet den Weg zu einer *humanen Architektur*; einer Architektur von und für Menschen.

PART I

A THEORETICAL APPROACH TO SPATIAL SPACE

I. A GENERAL APPROACH TO SPACE

Books are beyond space;
they do not fit into the physical
or mathematical definition
of space.
Martin Goldstern, 2006

1.1 Space as an Abstract Entity

The term space is an abstract word. Time and Space are constructions that help people to arrange the world into fitting schemata. However, by being able to think about and imagine time and space, we as humans are lifted above these constructions. It is through physics and mathematics that the terms time and space find an interface to the physical world and therefore an interpretation.

Humans experience space through motion. They experience the effects of this motion within space. Whenever they move from one point to another within space they will try to connect the two points with each other, for example through the act of walking. It is also possible to move through space merely in imagination - hodologic space (Lewin, 1934) During the action of movement, physically or mentally moving persons will find themselves in different points within the space of this movement. They will then join these different points into an inner set of relations. This inner relation emblematises space and thus enables us to observe it.

Space can not be touched, it can only be conceived. One can measure the length and width of a structure and calculate its volume which can then be architectonically defined as space. This is only one possible construct of space, namely a mathematical one which uses a measurement of distances that indicates space; but it is not the space itself. The volume, therefore, is a possible set of relations for measurements. Physics and mathematics provide a basis for attaching the same units and values to measures of length in any given spatial position which can then be arranged into a logical construct. This logical construct, in turn, then represents the physically built world.

Physical space is dominated by matter. This matter enables us to perceive physical space which we feel as being absolute. However, space, time and matter are only perceivable through manifested things like constructions.

Although we think we control space when we are moving and connecting different points within space, our personal limit is always our body.

Through the imagined constructs of time and space humans can approach the hidden world which can be made visible and therefore experienced by the above mentioned constructions.

An interesting definition of time is given by the Italian philosopher Massimo Scaligero who has a very individual approach to time and space:

Die Aufeinanderfolge ist nicht die Zeit, sondern ihr Fall in die Verzauberung des Raums. Für einen Stein hat es weder das „Davor" noch das „Danach" einen Sinn: Es ist bedeutungslos, ob er jetzt oder in einem Jahr betrachtet wird. Der Rapport mit ihm betrifft allein das Wahrnehmen und Erkennen des Menschen, dessen Gegenwart in der Zeit. (Scaligero, 1963,42)

The sequence is not time but its fall into the magic of space. For a stone it is insignificant whether it is being looked at now or in a year: neither the 'before' nor the 'after' makes sense. Rapport with him applies only to the percipience and recognition of the human and its presence in time. (Scaligero, 1963, 42)

A book that is being read will only be integrated into a time frame through the act of reading. The book itself is beyond time. For the mathematician Martin Goldstern books are beyond space because they do not fit into the physical or mathematical definition of space. Space and time are only established in the process of reading and thinking (Goldstern, 2006). Constructions of space and time give ground to the making of a synthesis of pictures of the world we perceive. (According to the philosopher and theologian George Berkley all material things including space and time are an illusion.) In order to surrender to the illusion of mastering time and space, humans divide time into moments and instants.

Humans are condensed time because they merge the past and the future into the present by formation. Through the spread of technology, that has reached cyberspace, explosion and shrinkage can take place at the same time in telematic space. Cyberspace, which was created through telematics, is of paramount importance in the rapidly and constantly changing space. Like books, it is not possible for physics to incorporate cyberspace into a common definition of space, we can only approach it metaphorically. A clear answer does not exist.

Due to the various widely differing approaches towards a definition of time and space we can only look at them in terms of archaeological layers. For this, it is important to define the proper context for the terms time and space. Architects will have a different approach towards these terms than physicists. The appropriate layer will be used in order to picture a structure of thoughts – however, one could also try an interdisciplinary approach.

A history of the term space with its varying aspects which can be either very contrary or complementary and superimposing will be given on the following pages.

1.2 A Brief History of Space

Horror Vacui - fear of emptiness - best describes Aristotle's idea of space. For him, space is the adjacent margins of things. The volume of emptiness does not exist for him. This means that there is no extensive emptiness within our universe. According to his concept of space, one material starts where another one ends. Matter is everywhere and space is only the set of margins.

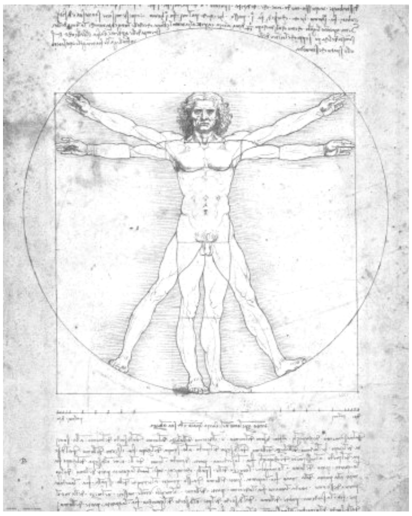
The main point of Aristotle's concept of space is the fact that for him space is a bordered and filled cavity and is therefore finite. This makes the question of whether empty space exists invalid. There is no empty space for Aristotle (Bollnow, 2004). Ergo: the universe is filled, it is not expanding. Hawking comments that him and most other Greek philosophers found little interest in the imagination of creation because it was connected to the idea of godly interventions. They thought that humans and the world surrounding them had always existed and this would never change (Hawking, 1988). Space, in Aristotle's view, had no expansion and therefore no depth; it was merely the surface of things. Only tangible material things have depth but not space itself.

Artistry can serve as a proof for this assumption. If we look at Giotto's pictures that were painted at a time where the Aristotelian world view was still valid, we will find a spatial depth of the individual elements but no overall picture of spatial depth. The linear perspective and its clear rules were not yet invented. However, the realism in Giotto's pictures marks the beginning of Renaissance painting.

In the 5th century BC Leukippos proposed a contrary hypothesis of space and criticised Aristotle heavily. He and his disciple Democrit believed in the existence of atoms which meant that the material world was made of unbreakable particles – the atoms – which were surrounded by empty space.

Furthermore, Aristotle held the view that space was not moveable which he had inferred from his other theses. This theory was criticised until the 13th century because only the idea of an existing empty space could infer to the possibility of a movement of space. Whenever space is moving it leaves empty space behind but neither emptiness, nor movement. This theory caused a fundamental clash between Christianity and Science. The church was enraged because this theory would deny God's almightiness because it would mean that not even God could move the universe. In 1277 a decree was issued by the bishop of Paris, Etienne Tempier, in which 219 suspicious philosophical and scientific text were criticised. He condemned Aristotle's theory that God could not move the sky horizontally because a vacuum would be left behind. This decree was abrogated in 1325.

The real benefit of these controversies lay in the fact that more people were actually thinking about these problems. Although people did not yet know that the universe was actually moving, medieval theology was certain about the fact that God could move the universe. It was in the 14th century that scholars contemplated the possibility of movement within empty space. A number of scholars from Paris called the Terminists and another group in Oxford calling themselves Calculators provided a basis for modern science by trying to define terms like speed and acceleration. By the 15th century the Spanish scholar Chasdai Crescas had defined the term depth, which introduced a three-dimensional thinking into the learned world. Aristotle had defined the space of a structure as its surrounding surface which means that the space of that part is bigger than that of the whole structure. This is absurd and could therefore refute Aristotle's theory. According to Crecas the physical space was not their adjacent margins but the actual volume they are captured in. He also maintained the idea of the existence of an endless emptiness behind the universe (Wertheim, 1999).



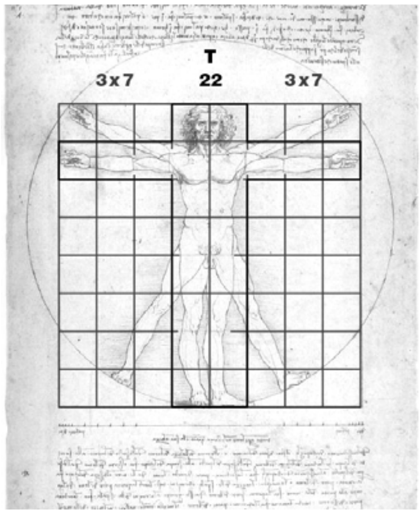


Figure 1: Vitruvian Man, Leonardo da Vinci, 1513
Figure 2: Vitruvian Man; the letter Thau embraces 22 squares, each half remains 21 or 3x7 squares. 22 and 7 are connected through the approximation of $\pi = 22/7$.

In the work of Leoardo da Vinci - for example in the Virtuvian canon of human proportions - da Vinci pictured the world of High Renaissance thinking which shifted the human into the centre of attention: the human as the measure of all things as Le Corbusier´s Modulor in the 20th century. Furthermore, in the Renaissance the new method of painting in perspective had been invented and therefore a great emphasis was put on the depiction of a spatial unity.

Another important scholar who worked on the definition of space was Galileo Galilei, who defined it as a continuous, homogenous, three - dimensional emptiness. For Galilei, space was the ontological basis of reality in which all things move. Through Galilei's definition of space for mathematical purposes, physical space turned into a synonym for the Euclidean space. Galilei's space is also known as the pre-relativist space which is defined as a large formless, three-dimensional emptiness. This made Aristotle's theories obsolete. Also, Copernicus developed the heliocentric world picture which places the earth in a focal point during the Renaissance.

Galilei's measurements were the basis for the laws of motion developed by Newton. If in Galielei's experiments a body rolls down a hill, a constant motive force is applied on it (namely its own weight) with the effect that the body's speed will raise constantly. This shows that the true power of force lies in changing the speed of a body and not only in putting it into motion, as scholars had believed before. It also means that a body will move in a straight line in constant speed if force is applied onto it. (Hawking, 1988, 28)

This idea was first developed by the Christian but heretic scientist Isaac Newton who heavily influenced the "new science" by his Principa mathematica of 1687. This work presented a picture of unification between celestial and earthly space. As its basis he laid the theory of gravity which he used as an explanation for the fact that planets move in certain orbits and that humans stand with their feet on the ground. Newton saw God as being omnipresent and if he was omnipresent the universe had to be infinite. The infinite shapeless universe with its infinite shapeless space became the basis of human thinking. For Newton time and space were absolute.

Immanuel Kant, in his 1781 work 'Critique of Pure Reason', also concerned himself with the question whether the universe had had a beginning and whether it was spatially restricted. He supported Newton's concepts of an absolute space and time - which he called a priori categories - by stating that they were necessary aspects of a scientific world picture.

It was Einstein who in 1916 formulated the idea of relativistic space. He argued that each human being had its own time and its own space instead of sharing it with all other beings. This could solve the question of different travel speeds and constant speed of light relative to two different travelling or observing people. The mathematical formula of Einstein showed how the perception of time and space in terms of a difference in speed could change between two observers. Therefore, time and space changed into dynamic concepts and the general theory of relativity was a geometric theory of space.

Newton had formulated a timeless universe in which there was no sign of a history of creation. In the general theory of relativity, however, there is a mathematical history of the creation of the universe out of nothingness. The ideas of Newton had been replaced by a dynamic, expanding universe with a possible beginning and ending.

According to the general theory of relativity two different regions of spacetime can be connected by wormholes (tunnels). This model of thinking would make it possible to travel through time into the past and the future because the existence of these wormholes would connect different spacetimes. In order to put this utopia of science-fiction into reality one would have to travel faster than light and the wormhole would have to stay constant for the whole period of travelling (NASA, 2006).

1.3 Architectural Space

Space is formed through existential connections. Through these a meaning and allocation of things, places, boundaries and qualities can be defined. Albert Einstein stated that the term space had to precede the term place so that space would be an "order of bodily objects and nothing than a kind of bodily objects". However, he did not explain how these places and orders were to be materialised (Baier, 2007, 130). In his lecture 'Bauen-Wohnen-Denken' Martin Heidegger describes space as something that is stacked in and let loose, thus being something integrated into certain boundaries. He sees the boundary - like the Greeks - as something that does not mark an end but rather the beginning of an existence. Space is by character something stacked in, something within its own borders. The stacked in parts will then be joined, thus being assembled by one place. This means that space receives its character through places and not through space. (Heidegger, 1951, 9). The place (topos, locus) is part of space. Aristotle differentiates place (topos, idios) from space (topos, koinos) (www.textlog.de, 2006). It is impossible to talk about space without mentioning the according place and vice versa. Thus, we need to see Bachelard's use of topos in two respects: as place and space, as both are defined and explained through and by each other.

For the field of architecture, the term of space is especially important but also rather totalitarian. In his trilogy on spheres the philosopher Peter Sloterdijk (Sloterdijk, 1998, 1999, 2004) assigns a metaphoric form, a morphologic symbol and a power of fate to the construct of space. Henri Lefebvre (Lefebvre, 1974) goes even further and calls for an analysis and explanation of the concept of space in order to be able to define architecture:

Unfortunately, any definition of architecture itself requires a prior analysis and exposition of the concept of space. (Lefebvre, 2002, 15)

The architectural space is defined on the basis of three-dimensionality as a uniform linguistic model of architecture. The architect Christa Illera sees architecture in itself as a three-dimensional reality. Walter Gropius defines three-dimensional thinking as a basic architectural discipline (Illera, 2003). According to the Dutch architect and Benedictine monk Dom H. van der Laan the concept of space in architecture has a superposition within natural space. By separating the architectural space from natural space a space within a space is formed. The boundary of architectural space is the wall, which confines the space from outside. He depicts it as being a frame space - with the boundary being formed by an outer frame of solid walls (Van der Laan, 2003).

The architectural space is bound by a three-dimensionality defined by height, width and length - which makes up the construction volume. The length is there for calculating distances, sizes and interspaces. Thinking in terms of areas (2 dimensions) and volumes (3

dimensions) is a manmade principle of organisation. Through these, items like walls or staircases are assigned their functional forms. This gives priority to the visible space.
The architect Franz Xaver Baier criticises this geometrization theorem to space and argues that the geometrization theorem, if projected onto humans takes the form of animal or human bodies; the theorem extracts humans out of their world like Corbusier's Modulor, that reduces all humans to a standard size of 183cm. Therefore, the creature receives the mark of being an item or thing. Within geometric space, formations are connected through the relations of a superordinate coordinate system. (Baier, 2000, 13)
The geometrization theorem to space has been followed by a technological approach to space. This approach describes space which consists of a technical and a formal layer. These two layers can be seen as a partition equal to an architectural boundary. The space of humans is formed in this abstract space: the lived and experienced space which is accessible to humans through the geometrization theorem.
According to the Neo-Marxist philosopher Henri Lefebvre the physical space exists but the organisation and experience of this space are a product of social processes of acquisition. Lefebvre criticises the fact that architecture works with an abstract concept of space which has nothing to do with the common concept of space. His primary concern is to arrange manifested space into perceived, conceived and lived space. Furthermore he classifies three related proportions of space:

1.) Spatial Practice
It embraces production and reproduction, and the particular locations and spatial sets characteristic of each social formation. Spatial practice ensures continuity and some degree cohesion. In terms of social space, and of each memeber of a given society´s relationship to that space, this cohesion implies a guaranteed level of competence and a specific level of performance (Lefebvre, 2002, 33).

2.) Representations of space
They are tied to the relations of production and to the „order" which those relations impose, and hence knowledge, to signs, to codes, and to „frontal" relations (Lefebvre, 2002, 33).

3.) Representational spaces
They are embodying complex symbolism, sometimes coded, sometimes not, linked to the clandestime or underground side of social life, as also to art - which may come eventually to be defined less as a code of space than as a code of representianol spaces (Lefebvre, 2002, 33).

Lefebvre sees a connection between the structure of power (i.e. the state) and the three concepts of spatial practice (production and reproduction and socio-specific relations to space), representation of space (e.g. architectural design) and representational spaces (which depict the social relations in the process of being occupied or lived in) which control the production of space.
The question is, whether the geometrization theorem to space is alluded solely to the architectural world or whether the perception of the lived and perceived space is connected to Lefebvre's theory of production of space. (However, it has to be noted, that Lefebvre was not concerned with the perception of space in his work.) Perceived and perceivable space as a product of social education which works with analogical mechanisms equal to the geometrization theorem on space. Living in and lived space as an social product of education, working with analogous mechanism as the geometrization of space. Nevertheless, Lefebvre stresses by his „Triple / Triade“ that space is of complex nature and that it penetrates all levels of social relations.
In his work 'Die Zukunft des Raumes' the designer Bernd Meurer expounds various problems of space. By perceiving and acquiring space, by using it as a resource, as a social space for communication and interaction, as urban and landscaped space, as private and public space, we constantly transform it. (Meurer, 1994, 13) This transformation of the space of action, communication and orientation is in a way again subject to a schema of production - namely of a reproduction in the sense of a replication of space. Through these metamorphoses of space, the relation between space, time, distance and speed change and with it the architectural formation as something visibly happening.
This suggests: Space and its perception is a product of culture.

In order to separate the mathematical, physical space from the lived space the philosopher Otto Friedrich Bollnow composed a list of characteristics of space based on the Euclidean approach towards space. To ease understanding he used an orthogonal coordinate system as an underlying basis. Homogeneity is the key characteristic of mathematical space. Geometrization theorem and homogeneity are closely related and conform to the Cartesian continuum (Bollnow, 2004).

Homogeneity means:

- No point is distinguished. The space and its coordinate system do not have a centre. However, by a simple adjustment of coordinates one can move each individual point into the centre of the system.
- No direction is distinguished. By a simple rotation one can use each direction within space as a coordinate axis.

- The space is subdivided in itself; it is completely uniform and expands equally and infinitely into all directions.

For lived space this does not apply, however:

- There is a fixed centre, which is given by the place of the experiencing person within this space.
- There is a fixed coordinate system which is levelled according to the human body and its erect position opposed to gravity.
- The areas and places of space have qualitative differences. The connections between these are a basis for a rich contextually-related structure of the experienced space. This does not find analogies in mathematical space.
- There are smooth transitions as well as sharp borders from one area to another. The experienced space shows a number of discontinuities (In his work 'Das Heilige und das Profane' the philosopher Mircea Eliade refers to cracks and breakages in sacred space; note from the author).
- Overall, the experienced space is not a domain of neutral value.
- The concrete reference towards humans is not detached of reality.
- Lived space is not a reality detached from humans in terms of a concrete reference, but rather something that available for humans and therefore it is one with the human reference to space. These two can not be separated from each other (Bollnow, 2004, 17f).

Michel Foucault (Foucault, 2002) agrees with Bollnow by stating that we are not living in a homogenous and empty space, but in one, load onto with qualities. Foucault speaks of the space of our first cognition, the space of our dreams and the space of our passion:

'Sie enthalten gleichsam innere Qualitäten; es ist ein leichter, ätherischer, durchsichtiger Raum, oder es ist ein dunkler, steiniger, versprerrter Raum; es ist ein Raum der Höhe, ein Raum der Gipfel, oder es ist im Gegenteil ein Raum der Niederung, ein Raum des Schlammes; es ist ein Raum, der fließt wie das Wasser; es ist ein Raum, der fest und gefroren ist wie der Stein oder der Kristall.' (Foucault, 2002, 38)

'They possess inner qualities; this might be a light, ethereal, transparent space, or a dark, stony, locked space; it is a space of height, a space of peaks, or conversely a space of lowland, a space of mud; it is a space that flows like water, it is a solid or frozen space like stone or crystal' (Foucault, 2002, 38).

This is the inner quality of space, to which the outer quality is joined. Our reality and our history are taking place in the outer space. Like Bollnow, Foucault sees this outer (lived/ perceived) space as a homogenous space because it extracts itself out of humans and therefore it diffuses from the inner to the outer space, where it solidifies.

Humans constantly break lived space physically; the area and level on which we move sways upwards and downwards in certain places. Places of living have windows, in which the 'rest of the world' is depicted. Certain margin areas, margins, centres, connections, channels, bunkers, areas, compressions, springs, funnels, gateways, black holes and elevators are formed (Baier, 2006, 132). Because space is divided into inner space (we ourselves) and outward space (our environment) lived space constantly passes through material. It seems as if lived space constantly trenches material.

1.4 Spatial Space and the Human Body

The human body and architectural structures have a number of similarities. One can observe, analyse, dissect, deconstruct and measure it, one can assign proportions to it, calculate its area and volume, which has been shown by the geometrization theorem of space. Although criticism towards the geometrization theorem is appropriate (Baier, 2006), the body and architecture are mutually dependant on each other in that they have a geometric analogy in order to be able to communicate with each other. Despite the extraction of humans from their surrounding by geometry, this extraction can also cause a connection to the constructed world in the form of architectural gestures.
The French philosopher Maurice Merleau-Ponty (Merleau-Ponty, 1966) describes how the body on the one hand and architecture on the other are mutually dependant on each other within a cultural world:

Der Leib ist unser Mittelpunkt überhaupt, eine Welt zu haben. Bald beschränkt er sich auf die zur Erhaltung des Lebens erforderlichen Gesten und setzt korrelativ um uns herum eine biologische Welt; bald spielt er auf diesen Gesten und geht von ihrem unmittelbaren zu deren übertragenem Sinne über, durch sie hindurch einen neuen Bedeutungskern bekundend; so im Falle eines motorischen Habitus wie etwa des Tanzes. Bald endlich ist die vermeinte Bedeutung solcher Art, dass die natürlichen Mittel des Leibes sie nicht zu erreichen vermögen; er muß alsdann ein Werkzeug schaffen und entwirft um sich herum eine Kulturwelt. (Merleau-Ponty, 1966, 176)

The body is our dead centre to posess space at all. Sometimes it focuses on the gestures that are vital fort he preservation of life and therefore build a correlative biological world around us; sometimes the body plays with these gestures and uses their metaphoric meaning instead of the natural one and therefore manifests a new denotation; this can be seen, for example, in kinetic habits such as dancing. Sometimes the natural abilities of the body do not suffice for something; the human then has to produce a tool and therefore creates a cultural world around himself' (Merleau-Ponty, 1966, 176)

This cultural world communicates with the human body. Through walking, turning, etc. the human can understand space and the gestures of architecture become readable. The connection between architecture and the body is shown in the architectural disposition that acts on and is adjusted to the body and therefore assigns the disposition of the body in architecture.

This bodily communication extends from feeling the architectural charge to the architectural terminology and the recognition and definition of architectural styles. Each construction has an effect on the human body.

The code of communication between the human body and architecture can be limited to a few typologies (Meisenheimer, 2004, 25):

- A gesture of erection (to erect a vertical)
- The gestures here! and there! (to affix places)
- The separation of inside and outside (to set boundaries)
- Gestures for constriction and extent (to create tension)

The gesture of erection is an analogous form for the body and architecture. The human body is constantly occupied with vertical adjustment and readjustment of the body towards an axis, whereas constructions can have a fixed and highly geometric verticality. Humans regularly experience this verticality in urban context (e.g. in skyscrapers).

Deviations from this strict geometry occur via optical adjustments. These adjustments can, for example, avert a sensation of protuberance in structures or they cause tension by using a chamfer, which is internally seen proportionally to the (theoretical but invisible) vertical axis which produces the tension. We can experience the idea of building into great heights in church construction, where humans are elevated (and at the same time humbled) through this height. Therefore, in a vertical arrangement of structure, there is to be found not only a functional context in the sense of load transfer but also an ontological need of humans. This shows a connection between the construction of churches and skyscrapers in terms of a political and ideological potential of power dependant on the individual cultural surrounding.

At the same time, vertically erected structures mark a place within the living space of humans. If the vertical is clearly formulated and therefore made visible with the help of building material, it becomes a boundary which defines the place and the inner and outer space at the same time. The geometrical place is an imagined construct of thoughts. Geometry is mainly important for planning; in order to experience the living space within a construction, the place which accommodates the space is vital. As mentioned above, for Martin Heidegger (Heidegger, 1951) space is something stacked in and let loose, something integrated into a boundary. The space with its according qualities (Foucault, 2002) is integrated into a time-space-schema because it connects humans to the past, present and future, which they will find in the individual architectural space. Therefore, architectural places that assemble these spaces are staged scenes serving as paths for past, present and future events. It is precisely this dependence between the human body and architecture, which receives its communication through reflexion, which in turn opens up the living space of humans.

Places and spaces filled with qualities spread throughout urban context like islands that lie next to each other. These architectural islands confine each other. Each architectural structure possesses a casing (the façade), which houses the interior. It encases humans like a uterus and the outer skin of the architectural structure offers a functional boundary to the outer world. The interior is the architectural stage of experienced space. This shows an analogy to the human body, where the skin is the protective boundary to the environment, within which humans can experience themselves.

For the sociologist Angelika Kampfl (Kampfl, 2003) human eyesight is an overcoming of the boundaries – which are usually limited to the skin – of the body:

Mit dem Sehen werden die Grenzen des eigenen Körpers überschritten. Es überbrückt die Entfernung zu den Dingen und lässt sie doch an ihrem Ort, so bleibt auch eine Distanz bestehen. Das bloße Sehen bildet Dinge nicht nur einfach ab, im Gehirn wird das geistige Bild des Gegenstandes erzeugt. (Klampfl, 2003, 91)

Through eyesight the boundaries of the body are crossed. It bridges the distance to things and at the same time leaves them at the same place and therefore a distance still exists. Mere seeing does not only picture things but also the brain produces a mental picture of the item. (Klampfl, 2003, 91)

Although the 'interior' of architectural structures is confined like a space capsule, every structure also possesses openings and closings which are a connection to the outer world. Windows and doors are like a gate into the distance. Therefore, each interior possesses breakages out of the 'space capsule' where the casing of each architectural structure is penetrated. Thus, optical (windows) and functional (doors) channels accrue, that channel people in and out like a pulsating river. The schemata of interior/ exterior between humans and architectural buildings are therefore simultaneous and similar .

These streams of humans that move to and fro are especially intense in the entrances and exits of structures; here they concentrate and then separate again inside or outside the building. The entrance acts like a funnel that sucks in, concentrates and releases again. Constriction and width are therefore further constants which continuously communicate with each other and which are able to produce positive and negative tensions in an architectural as well as in a social formulation. The ratio of architectural tension is made of a modular system of constriction and expansion. The transitions trigger a change in the perception of humans. Because we are used to our own organic functions of constriction and expansion we find ourselves in this architectural staging.

Cultural differences that can cause different sensations and therefore produce small deviations from the communicative code have to be taken into account. This might cause interest and barriers which will have to be understood and might again ask for new learning.

1.5. Possesed Space: Locomotion and Geometric Bodies

The act of walking manifests the being of humans within its environment and is also the most archaic form of accessing paths (Humpert, 1997). The human body and the bodily act of walking are essential prerequisites for being human, for interaction and localisation within space. It is only by moving through space that humans can produce a subjective spatial reality. The act of walking is an anthropological constant that is inextricably associated to locomotion, survival, social action and social interaction.

The importance and diversity of walking is manifested in its linguistic coding. Words like striding, loping, jaunting, ambling, tramping, scuffling, bumbling, promenading, loafing, and strolling are only some of the possible linguistic variations of the basic word 'walking'. The word 'walk' or 'gehen' in German derives from the Middle High German word *gan* or 'gen' , 8th century, which again derives from the Old High German word *gæ*. The Greek basis for the German words is the word 'kichano' which means 'I reach, attain, encounter' (Kluge, 2002, 339). Words connected to the word ‚walking' have a versatile etymology. One of the many synonyms of the German word 'gehen' is 'spazieren' which derives from the Latin word *spatium* This word describes space, distance or width.

During the act of walking the whole body is in action: the vertical position, the downcast and loose shoulders, the soft swinging of the arms and the steady interplay of heels, soles and toes. Walking is done in sequences; there are also times for stopping and sitting down. Moving humans make contact to their environment by this motion. They meander through crowds, pass by different buildings like cinemas or supermarkets or they walk alone along the bank of a river within urban space. The way of walking is a means of communication within itself, which can convey linguistic quality (body language of individual humans) as well as linguistic quantity (the body of mass). The historian J.A. Amato describes this communicative expression of walking by 'walking is talking' (Amato, 2004, 4).

The moving crowd is to be equated in its visual formulation with the individual human body, which shows cultural differences in appearance, speed and flexibility. This shows us that there might be differences in the appearance and effect of crowds and therefore also differences in various cities like Paris or New York. Adolf Loos comments on the different ways of walking in different cities:

> Kommt man nach New York, so hat man immer das Gefühl, als ob es irgendein Unglück gegeben hätte. Auch der Wiener aus dem vorigen Jahrhundert würde heute in der Kärntnerstraße den Eindruck erhalten, dass etwas passiert sei. (Loos, 1898, 115ff)

> If you come to New York you will always have the feeling that some disaster has just happened. Also, Viennese people living in the last century would have the same feeling walking down the Kärntnerstraße today. (Loos, 1898, 115ff)

Loos tried to connect the different speeds of walking to lower and higher cultures. The speed of walking, however, is not connected to a cultural difference in standards but rather it is formulated by an adaptation of humans to the environment and the individual needs, which again articulate cultural differences.

There are a variety of different linguistic levels. The act of walking can be seen as the expression of non-verbal communication and as a connection towards the communicative interaction between humans. Non-verbal communication is connected to the vocal and physical behaviours that can transport messages symbolically and can use things, actions and gestures as a means of communication. (Paschen, 1978, 48) Verbal communication always has to be seen in context with non-verbal communication. Both layers include informal characteristics and are the basis of interpersonal communication. The architect Bernard Rudolfsky (Rudofsky, 1995) illustrates the connection between communication and the act of walking by using a city – namely the city of Milan – as an expanded living-room for exchange of communication.

Mailand sperrte im Sommer 1967 jeden Abend nach neun Uhr die Hauptverkehrsadern der Stadt, seinen Corso Vittorio Emanuele, für Fahrzeuge und überließ so dem Volk einen […] salotto, einen kleinen Salon. […] Tatsächlich bemühte sich damals fast jede Stadt, das hohe Ziel bürgerlicher Freiheiten vor Augen, um pedonalizzazione, die Rückgabe gewisser Straßen an Fußgänger. Stadtbewohner […] verlangten nach freien Fußgängerzonen; ein durch historisches Präjudiz beglaubigtes Privileg, das jedoch irgendwann in den Trümmern des modernen Fortschritts verloren gegangen war. Sie ersuchten die Stadtverwaltung ein gemeinsames Wohnzimmer zur Verfügung zu stellen; keine verzierten Lücken zwischen den Häusern oder ein ödes Bürgerzentrum, sondern ein lebendiges, volkstümliches und historisches Ambiente. Und dieses nicht gedacht für Paraden und Versammlungen, sondern für die tägliche Demonstration der Zusammengehörigkeit durch ihren rituellen Spaziergang. (Rudofsky, 1995, 109)

In the summer of 1967 the city of Milan closed its main road, the Corso Vittoria Emanuele, after nine o'clock in the evening for all vehicles and provided the population with a […] salotto, a small parlour. […] At that time, almost every town strived to achieve pedonalizzazione, which means to give back the streets to pedestrians in order to increase the amount of civic liberties. Urbanites […] demanded pedestrian areas; it was a privilege certified by historical precedent that had at one time been lost in the debris of modernisation. They asked the municipality to provide a common living room; no adorned breaches between houses, however, nor a bleak community centre, but a lively, popular and historical ambiance. This should not provide for parades or gatherings but it should constantly demonstrate unity through its ritual walk. (Rudofsky, 1995, 109)

In an article in the New York Times from 1968 the philosopher Hanna Arendt points out that the quality of living within a city depends on the people that are on the streets.

Thus, the act of walking is a property that society constitutes via communication and also it forms the identity of a community or a social system. This social interaction is an essential precondition for the formation of identity.

Within the process of communication of beings with rationality the social acting should activate a similar reaction in the participating individuals. The attitude that is activated in these individuals should control the message and affect further developments. Rudofsky stages that this process is of is of vital importance for the formation of an identity as the symbols that should trigger similar reactions are a necessary requirement for the development of an identity. In other words, humans can only develop identity once they can communicate with other people on the basis of certain symbols that represent a widely accepted meaning. (Rudofksy, 1995, 64)

Also, the act of walking gives powers to human beings that are not possessed by their environment. In a historical context, power represents the fact that people had the privilege to sit on, ride on horseback to or be carried to certain religious or secular occasions, ceremonies or rituals.

Speed allows humans to approach their environment at different rates. Therefore, it is an important factor and a source of potential of power. The fact that certain means of transport have a higher speed of motion than others results in power and the possibility to spread power.

The Vitruvian Canon of human proportions by Leonardo da Vinci is one of the most important graphic illustrations of the transition of natural bodies in natural movement into a phase of geometric and mechanical movement. The established interpretation of this integration of anatomy (of the human body) into geometry (of circle and square) does not only see harmonic proportions but also a symbol for the unity of earth and sky within humans in this work. The circle is the symbol of the solid em quad of the earth and of the four elements. However, our interpretation of this work as a study of motion seems to be more legitimate. This is because, at the same time da Vinci also produced his work 'Trattato della pintura', which shows and explains a hand in movement. Here, he explains the disruption and the divisibility of movement as working according to the cinematographic principle. Each constant value can be divided infinitely. The eye that watches the hand's movement, moves from point A to point B and therefore measures a space a – b. This space is a constant value and can therefore be divided infinitely. The square with its closed legs can now easily be seen as a symbol of standing, static or peacefulness, whereas the circle with the spread legs can be seen as a symbol of walking and movement. The circle stands for a wheel, where the legs are the spokes. Squares and cubes are immobile and instable whereas circles and balls roll. Therefore, Leonardo's picture is concerned with steadiness and motion at the same time. To this binary system he assigns anatomic as well as two geometric forms. The visible geometric approach towards the body should not suppress the source of this geometry, namely mechanic movement and transport. The importance of Leonardo's picture lies in the fact that it shows us a geometric approach towards the body which is can be further developed into a geometric approach towards nature and finally towards society (Weibel, 1987, 27f).

The French philosopher Paul Virilio speaks of a correlation between speed and power in connection to mounds. These are superior to the metabolic human vehicle in terms of endurance and speed and therefore enhance superiority and power. Furthermore, Virilio sees the pregnant woman as being the first means of transportation. (Virilio, 1989) Humans and their need for technology continuously increase the speed of their means of transport and therefore enhance their power. Virilio's terminology (metabolic human vehicle; the woman as the first means of transport) is a continuation of Leonardo's illustrations, which have been based on the theses of Marcus Vitruvius Pollio. The geometric approach in linguistic terms refers to machines, who themselves refer to speed and the enhancement of power.

The ratio of speed to power is growing complex because of different means of transport and their further technological development. Through the ratio of power and speed the structure of time and space of different technologies change and interfere with each other. The measure of perception is modified by speed. Speed distinguishes a social system in terms of prestige because the materialised bubble (Garbrecht, 1981) leaves its traces. A parked car, an airport, train station or a bike stand are such indicators for absence or presence in an urban agglomeration. Once a walking person is absent he is not detectable for his environment.

2. CITY SPACE: MORPHOLOGY

Je besser eine Großstadt ihren Zweck erfüllt,
je größeres behagen ihrer Bewohner sie hervorruft...
Otto Wagner, 1911

The better a city serves a purpose,
the greater it evokes the residents´ pleasure…
Otto Wagner, 1911

2.1 The City

A city consists of an interplay between occupied areas, i.e. places, and their connecting paths. Places represent the manifestation of "identity", for example, or a house, a shop, within a mass including the necessary boundaries. The lane network is the "intervention highway" in between these. Obviously the generative processes of urban systems is never finished, because they will always act in a loop. The individual choice of routes, between source and destination, and amplification of those routes through regular use produces a hierarchical structure. In order words, a city exists of buildings (city blocks) and streets - creating its hierarchical morphology. It can also be defined as an emergent phenomenon. According to Rob Krier, the city block is the original cell. It defines the network of routes around its edges (Krier, 2003).
Spiro Kostof summarizes the prerequisites of about cities, regardless of their origin, their birthplace, their form and their makers, in a fundamental way. These prerequisites are effective for any urban system and are at the same time a generalization of existing hypotheses (Spiro Kostof, 1991, 37ff).

- Cities are places where a certain energized crowding of people takes place. This has nothing to do with absolute size or with absolute numbers: it has to do with settlement density.
- Cities come in clusters. A town never exists unaccompanied by other towns. It is therefore inevitably locked in an urban system, an urban hierarchy. Even the lowest of townlets has its dependent vallages.
- Cities are places that have some physical circumscriptum (i.e. a city without a wall is not a city); whether material or symbolic, to seperate those who belong in the urban order from those who do not.
- Cities are places where there is a specialized differentiation of work - where people are priests or craftsmen, or soldiers - and wealth is not equally disributed among the citizens. These distinctions create social hierarchies: the rich are more powerful thant the poor; the priest is more important than the artisan.

- Cities are places favored by a source of income - trade, intensive agriculture and the possibility of surplus food, a physical resource like a mine or a spring (bath), a geomorphic resource like a natural harbour, or a human resource like a king.
- Cities are places that must rely on written records. It is through writing that they will tally their goods, put down the laws that will govern the community, and establish title to property – which is extremely important, because in the final analysis a city rests on a construct of ownership.
- Cities are places that are intimately engaged with their countryside, that have a territory that feeds them and which they protect and provide services for. The separation of town and country does not exist apart from the centruriated land roundabout.
- Cities are places distinguished by some kind of monumental definition., that is, where the fabric is more than a blanket of residence. This means a set of public buildings that give the city, and the citizenry landmarks of common identity. Technological monuments are also important in the people´s city; the princely palace disappears, or is translated into a palace of the people, and the temple is "secularized" - for example theRathaus, European city hall, or a civic cathedral.

So far, we have defined the fabric and prerequisites of a city. In addition, cities emerged with different typologies and different "urban attitudes" in history. Kevin Lynch sets up three normative models. He points out that a normative theory is a set of ideas about proper city form and its reason. He also comments that there are a number of such theories and each group of theory focuses on some comprehensive metaphor of what a city is and how it works (Lynch, 1981, 73).

The *cosmic model* is the idea of a cristalline city. It is stable and hierarchical, a microcosm in which each part is fused into a perfectly ordered role. In history, the first cities arose as ceremonial, magical places embodying rituals to controll the forces of nature. The growth of these cities was controlled by the power and material resources of a leading class. To stabilize the universe, religious rituals and the extension of the city were common physical tools. This theory underlines the magical model of the universe in a manifestation of an urban settlement to stabilize universal order and harmony. The city shape of the cosmic model uses, for example, cardinal directions, divisions and sub-divisions of streets and paths to represent religious and civils hierarchies, building materials, colours, etc.

Physical splints of the cosmic model can still be found in the "modern" city. We are still affected by rite and form. Nowadays, power is expressed by boundaries and gates, parade routes, boulevards, dominant landmarks, the evaluation of size, and bilateral symmetry. Also in Vienna, a historic capital city, monumental axes and dominant landmarks are an important part of the city form.

The normative theory of the *machine model* contrasts with the cosmic model, and it is an utterly different conception. In general, a machine exists of different parts, that move to fullfil a certain demand. The parts are linked to each other and also move each other. A machine can be changed partly or as a whole. Its parts are definite. A machine is assembled through the system of addition, a mathematical sum of parts. Functionality is the major premise. In terms of urban settlements, this model has been very useful for a temporary demand including a fast set-up. In practical terms, it is the typology for many colonial foundations such as Roman military camps - a rectangular square where streets crosses between four gates. It could be temporary or the layout of the centres for a permanent city like Vienna.

Later, in the eighteenth and nineteenth century, with the notion of biology the idea of an organic city occurred. The concept of an *organic model* focuses on the city as an autonomous individual with a definite boundary and size. Size does not change through the addition of parts as with a machine, but the city reorganizes its form within the process of changing size. The perception of the outside and inside is not heterogeneous – the outside is limited by definite borders while the inside is more undifferentiated. Parts are linked to each other and influence each other. Form and function is not linked in a linear way, but in a complex mode. Another interesting thought is that the organism is permanently dynamic. This dynamic is responsible for keeping up the internal balanced state of the whole system. The functions are rhythmic. Extended growth can prceed in the form of colonies.

Lynch comments that certain physical forms are linked to these ideas such as radial patterns, bounded units, greenbelts, focused centers, romantic, antigeometrical layouts, irregular curving, "organic" shapes (Lynch, 1981, 94). For Vienna, Camillo Sitte invented the idea of buckled curves as a design revolution at the end of the nineteenth century.

A very well known interpretation of the organic model of the 20th century is Le Corbusier´s *cités idéale,* which stands totally in contrast to the traditional European city. In Le Corbusier´s thinking the city as a social and architectural organism is of important significance. His ideas are influenced by functionality, an effect of the industrial hype. The ocean liner is the prototype of a skyscraper - proportionateness, a functional organism and the cabine as the prototype of a cell. He expresses his belief in functionalism as working by calculation, using geometrical forms, which satisfy our eyes by their geometry and our understanding by their mathematics (Le Corbusier, 1923).

One of the main characteristics of *cité idéale* is the substitution of a flat, but dense development with a spacious, but high one. Urbanity shall emerge by light, air, sun, width, height, etc. Density is of no interest to Corbusier. In his sense the free, green space is continuous. In a historical city, as can be seen in Vienna, the buildings appear to be continuous. Michael Graves (Graves, 2003) points out that within those two different ideologies we have two different analogous, forces at work - one that is additive - Le Corbusier - and one that is substractive - the historical city. "A sculptor working in steel, for example, assembles the artwork piece by piece, whereas a sculptor working in stone carves away the mass." (Graves, 2003, 6). Through this ideological opposition the traditional European city is easier to understand in its generic process of appearance. Hence, we used the organic model of Le Corbusier to make the difference clear between the two strategies in order to sketch a better image of historical cities in their traditional appearance.

2.2 Urban Patterns

The carved away mass emerges as streets; a bunch of intersected streets emerge as a network; the street networks emerge as patterns. Again, Kevin Lynch (Lynch, 1961) outlines the three fundamental indicators of a spatial pattern. They can be summarized as location of fixed activites, pattern of circulation, and physical structure. The physical structure is characterized by structural density (the ratio ground floor to space) and the structural condition (the state of obsolescence or repair). Density and condition, a very common analysis in geography, represent an magnificant index in urban region processes. The second factor is the pattern of circulation - roads, transit systems, and pathways of all sorts. Circulation is linked to intercommunication and through this constitutional state it is one of the essential functions of a city. Finally, the third factor is the location of fixed activities and this makes up the spatial pattern of a city. Buildings represent the locations of fixed activites.
All three indicators are responsible for the "image of the city" , to speak in Lynch´s words. In the next step, the various types of urban patterns will be under scrutiny. We will explore the nature of patterns; the way, in which they are characterized. Qualification and quantification is not the focus here.

Within this discussion we must first of all distinguish between regular and irregular patterns. Planned and unplanned patterns also include hybrids. They are permutations of simpler forms and basic typologies. Also, different scales are important for describing and analyzing an urban agglomeration. The diverse combination of different structures at various scales (the hierarchical impact) is very useful and a natural effect in traditional cities for the functionallity of a city. In this research we will divide the different scales of pattern into macro- and micro-level; at the same we have to be aware of the complexity of defining pattern in the context of graduation of scale.

The *Mosborough Master Plan* by Clifford Culpin and Partners, 1969, is a systematic study of patterns that offers patterns at a micro- and macro - structure (an internal hierarchy). The problem within this sophisticated analysis lies in the absence of a rectangular grid, considered at the micro level, as well as of "tree like" forms (see also Marshall, 2005). In general, most patterns do not look like optimal geometric forms in nature as presented in the plan. Also, the initial structures (radial, mesh, linear) cuts out two-thirds of possible combinations. Permutations and combinations depend on their initial structures and generator rules. We will have an in-depth explanation of this effect within the field of fractal analysis.

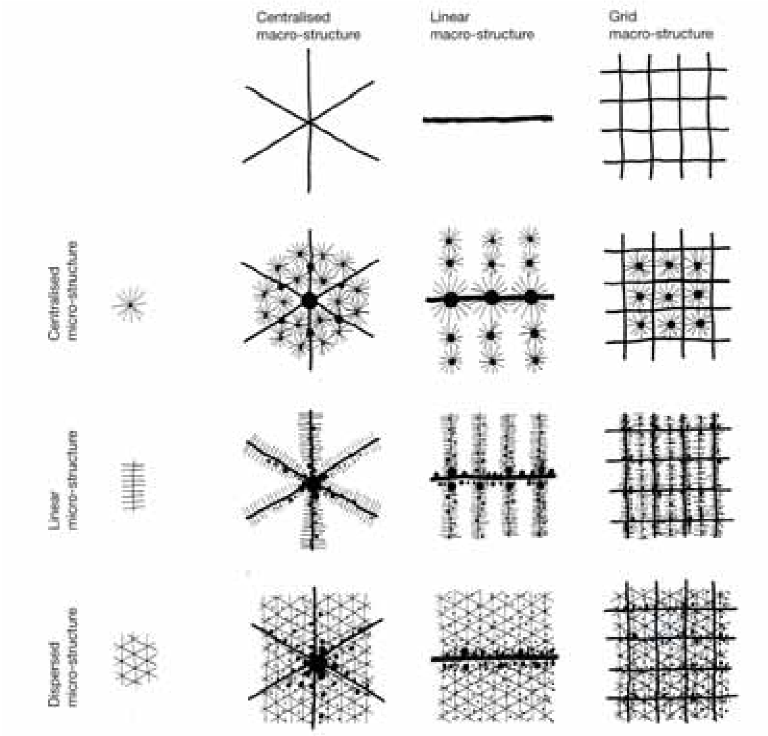


Figure 3: Hybrids and combinations of the Mosborough Masterplan

The geographers Haggett and Chorley (Haggett, Chorley, 1969) present a more useful categorization of types. They created a dendrogram, based on non mutated types. The benefit of a dendrogram lies in the visulisation of a hierarchical cluster analysis, from micro- to macro-level. This effective systematic distinguishes three basic types: path, tree, and circuit. The typological categories are set up. We have to consider that circuits and cells may be geometrically identical. Still, we have to deal with them as with any other descriptor, as already described above. Therfore interpretation rests on their context of use.

Compared to the Mosborough Masterplan the advantage of Haggetts and Chorley´s hierarchical systematic is that in their dendrogram, there is no singlular typology set of basic types. Every element is a singular basic type and can be combinied in any variation with every other element.

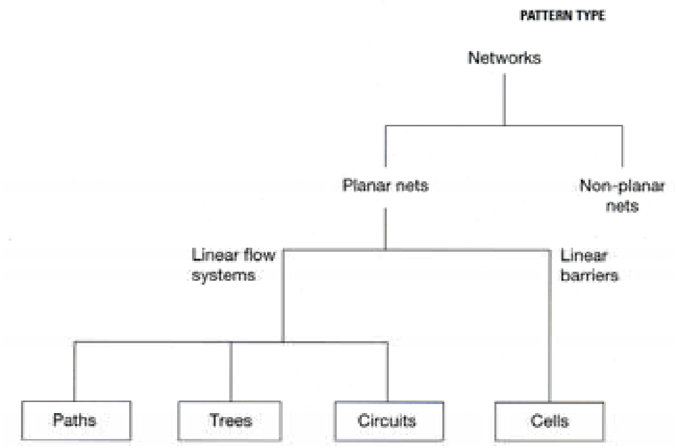


Figure 4: Haggett and Chorley´s dendrogram of pattern types, 1969

Next, we will introduce the ABCD typology according to Stephen Marshall. Marshall comments that this typology has been developed with the intention of reflecting typical street patterns that are encountered in different kinds of urban analysis (Marshall, 2005, 84). The four types feature different stages of the growth of town and cities - from the historic nucleus to the suburbs of an urban agglomeration.

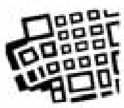
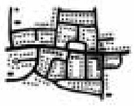
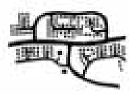
Type	Example pattern	Typical location	Frontages	Transport era
A-type *Altstadt*		Historic core	Built frontages	Era of pedestrian and horseback
B-type Bilateral		Gridiron (central, or extension, or citywide)	Built frontages	Era of horse and carriage
C-type Characteristic/ Conjoint		Anywhere; including individual villages or suburban extensions: often astride arterial routes	Built frontages or buildings set back in space ('pavilions')	Any Era of public transport; car
D-type Distributory		Peripheral development: off-line pods or superblock infill	Buildings set back in space, access only to minor roads	Era of the car

Figure 5: ABCD types

A-type: The nucleus of old cities; especially walled cities – the Altstadt; angularity in combination with a variety of directions, generates a rudimentary radiality.

B-type: A typical newly-founded settlement; the four-way perpendicular junctions give rise to bilateral directionality.

C-type: Describing arterial routes, whether constituting the centre of a village, a whole settlement, or suburban extensions along a route.

D-type: Modern hierarchical layout; it can be compared with the analogy of distribution

The ABCD types can emerge singularly or in a mixed mode, or also arranged according to the order of centrality in urban systems. In particular, this phenomenon exists in traditional European towns such as Vienna.

Up to now the composition of street patterns has been described. In this research the terminus of configuration will also be important for the empirical analysis of the hierarchical impact of topology. In general, compositions deal with physical geometry, where as configuration refers to topology.

geometry = topology + metric (Franck, 2006)

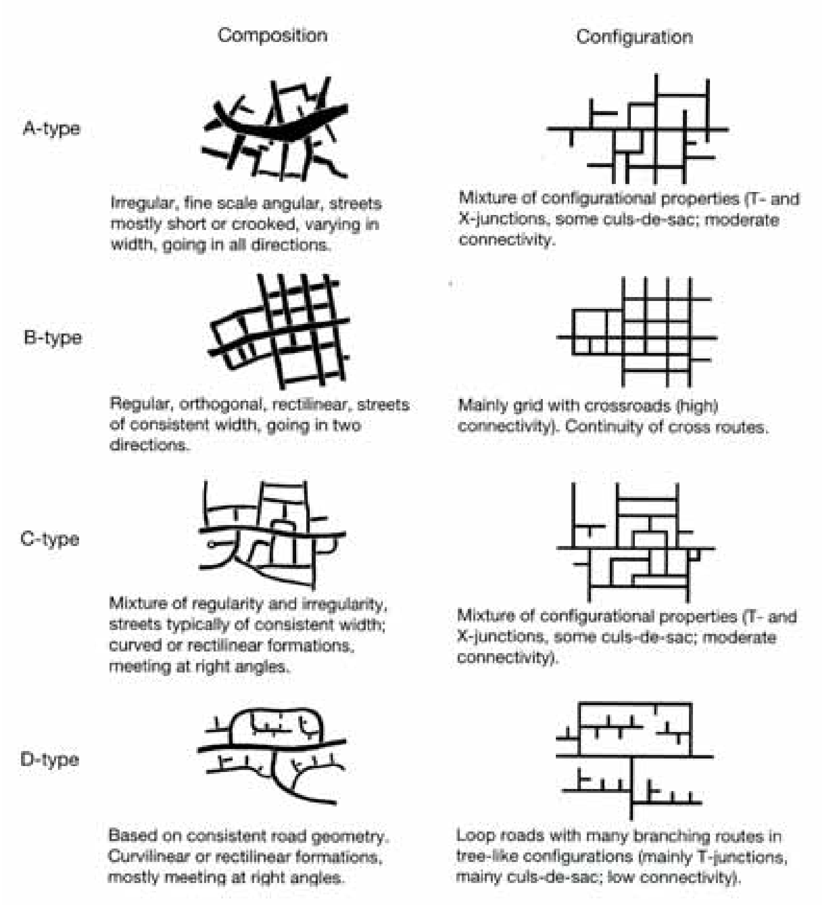


Figure 6: ABCD types in compositional and comfigurational terms

The composition represents a geographical map of urban layout and configuration represents a diagram. Configuration links to graph-theory. Graph-theory is a mathematical foundation for the uniform display and description of different networks. Therefore, a graph focuses on the modeling of relations of elements. It is most useful for describing connectivity. Connectivity is a topological attribute. Independently, whether a street is a highway or a path, connectivity can be the same in both cases. Also, the ABCD types can be interpreted in configurational terms.

In the field of modeling it is necessary to use the distinction between composition and configuration to explore different urban system and structures.

Altogether four different modes of theoretically generating street patterns including Lynch´s three indicators as the essential coherence for urban patterns, have been presented in this chapter. The idea was to present completely different modes to give an introduction to the very wide and complex field of urban patterns and graph-theory. Still, the emergence and structure of urban patterns are always linked to history; just as any city is connected to its historical development, and we can only understand street patterns, if we understand the history of a city.

2.1 Vienna´s Street Patterns

History is the main transport medium for understanding urban settlements and their street patterns. In general, the Viennese settlement has a long tradition. The first appearance of humans in the area of today´s Vienna was in 10 000 B.C. Vienna is, like most central-European cities historically, a radial-concentric city. It has an almost circular shape influenced by topographic circumstances.

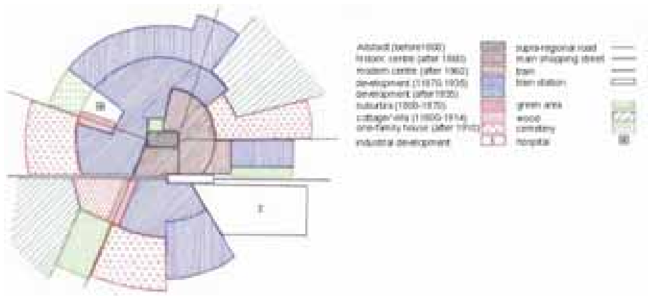


Figure 7: Model of a central-European city

Different ancient events influence the structure of settlements and streets, for example, war, fire, epidemic plague, the changeover of monarchs, population growth, immigrants, or the necessecity of supply and services for the population. Viennese street patterns were also influenced by these indicators. Marshall´s ABCD-typology partly reflects the Viennese street patterns systematic.

For the analysis of the Viennese street patterns the town will be split according to its radial and historic contex into four parts of urban development: inside the city wall, the former outskirts, industrial zones, and Transdanubia.

Inside the city wall - "die Altstadt"

The beginning of Vienna´s settlements can be found in the roman ancient world. In the first century A.D. the roman military camp Vindobona was founded. It was one among many along the limes-border of the Roman empire. The historian Ferdinand Oppl points out, that this camp was in the centre of todays city, and its brickwork is still reflected in the prominent morphology of streets (Oppl, 1999). Determinant of the urban development is this camp of a Roman legion, of which the western part has been populated since the 11th century A.D. In the second half of the 12th century a dynamic densification of population began through the appearance of new building zones, so called "Lucken". Of course, this phenomenon has to be noted in contrast to the unspoilt areas (vineyards). Around 1200 this development was completed by the erection of the city wall, which stood in place until the 19th century. In the early 13th century the quartering of the city was carried out as parts of the city´s defense organisation. Major reconfigurations were conducted by the new sovereigns, the Habsburger, from 1278 on. Furthermore, the cityscape became gothic. The last big building impulse took place in the time of Rudolf IV. He founded the Viennese university in 1365. Another recreation of the "Altstadt" was the effect of the banishment of Viennese jews in 1421 (the end of the ghetto). After the first turkish siege in 1529 a moving in inside the city wall started, encouraged by the desire for security. The change of the city wall was the conclusion. In 1530 Vienna became a new "bastion belt" (Basteingürtel) after Italian paradigm.

Figure 8: Vienna in 1547, Bonifaciüs Wolmuet

Figure 9: City centre, 2006

In the 17th century, the gothic visual appearance of houses transformed into the optic of Renaissance and early Baroque. Also, an interesting fact is the density of high houses in the city centre at that time. Approximately 292 houses had two floors and 48 houses had three floors (Oppl, 1983). During the second turkish siege in 1683 not only were the outskirts demolished, but the fortified city also suffered heavy losses. The rebuilding established the opportunitiy to transform Vienna to a absolutistic capital city. Many middle-class houses were substituted by the nobility´s palaces. The biggest "building mass" was the winter residence of the emperor.

Later, in 1805 and 1809, under the emperor Napoléon Bonaparte (1769-1821) french troops were in Vienna twice. With the the demonstrative, part-detonation of the city´s fortifications the french troops strongly interfered in the cityscape in November 1809. Oppl comments that in May of the same year, facing the approach of the french troops, the city wall was sedulously repaired. The uselessness of the old fortification was exposed through its destruction by the modern ordnance of the french troops in late autumn. With this act, Napoléon highlighted the opinion that was the right one in his time: namely, the absurdity of the continued existence of the Viennese bastion belt (Oppl, 1983).

In 1857 the city wall, city gates and the glacis were broken down and the whole area became a boulevard with monumental buildings and parks. Nowadays the *Ringstraße* contains the parliament, city hall, theatre, etc. as well as big public spaces and parks. At the end of the 19th century, the process of transformation from the "Altstadt" to a modern city also involved changes of the street network for the first time. Whole building blocks were demolished for a better infrastructure or wider streets in the centre. In some cases this modification took around thirty years.

Between city wall and second wall - the former outskirts

In the epoch around 1200 the first references of settlements were found in the hinterlands of the city. During the 12th and 13th century the urban centre radiates into its environment and in the 14th century new settlements developed in the periphery. The development had a major role during the first turkish siege in 1529. The suburbs were razed by the defenders, and after the siege everything lay wasted. The fortified inner city was less involved in the battles.

Between the first and second turkish siege rapid settlement in the periphery was stopped by the creation of the glacis around the city wall. A resettlement under pressure was the consequence. Another razing during the second turkish siege in 1683 took place. The successful relief of Vienna against the Ottomans induced a building boom. It can still be noticed in the city today. Huge summer palais including parks for the aristocracy were built in the suburbs.

Around 1700 in an nothern Viennese area, called Lichtental, very small allotments were developed, *Ratzenstadl* (rat stalls), with three-sided houses, having very small rooms. Other parts of the suburbs were built up with a grid-perimeter-block-development, *Raster-Baublockstruktur*. These allotments were quadratic and wide enough for small craftman´s houses or little factories. In 1704 the second wall was errected for the safety of the population.

Figure 10: Vienna in 1706 including city wall and second wall, Augustissimo Roman

Through a simple process whole areas were developed in the 19th century. Therefore, different specific systems were developed and implemented in different parts of the suburbs. They are responsible for the visual appearance of todays Vienna.

Within one methodology the centre of a composition is a rectangular square. In its middle two streets cross othogonally. The streets were part of a street network that could have four to twelve blocks around this square in the middle. This system is additive, see figure 11.

Another pattern is the composition of opening streets, so called *Durchbruchsgassen* of former parks and longitudinal allotments. With this schema moderate shallow allotments were created, see figure 12.

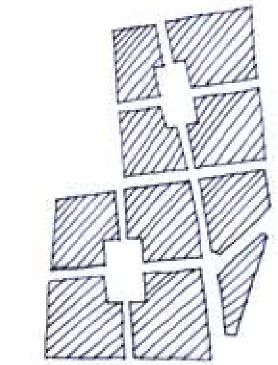


Figure 11: Bennoplatz, Vienna

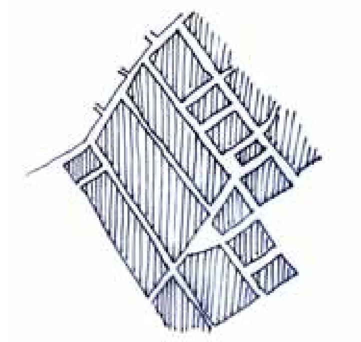


Figure 12: Große Neugasse & Kleine Neugasse, Vienna

After the revolution in 1848 the formation of municipalities replaced the system of *Grundherrschaft*; a lordship over lands and subjects. This new formation totally changed the

organisation of urban development. The responsibility devolved from the landlord to the municipality. It was in their area of responsibility to prepare plans for building lines, and so on. As they didn´t know what the future uses and who the future owners would be, a simple checker-board pattern was decided upon. Hence, another Viennese street pattern is the checker-board pattern, a flexible urban fabric for all developments. The building blocks touch as many street fronts as possible, therefore the allotments are small in size, see figure 13. This raises the profitability of the individual buildings. Also, the functional separation between living and working can be noticed within this type.
In this period, with regard to a global context, the suburbs of Vienna were incorporated in Vienna and the Danube river was regulated between 1870 and 1875.

Another pattern typology is the *Währinger Cottage*, a schema based on one-family houses as an overlay of the checker-board pattern. Originally, this project was originated for the lower society, but changed into a project for upper and high society because of their financial strength. The *Blockrandverbauung* (perimeter block development) was substituted by free standing villas. The "Währinger Cottage" became a template for the areas of former traditional villages such as Hütteldorf, Hetzendorf, Unter St. Veit and Meidling.

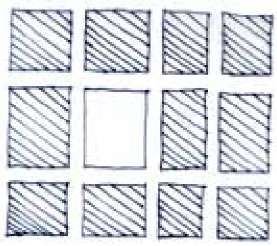


Figure 13: Laubeplatz, Vienna

Figure 14: Weimarer Straße, Vienna

The design revolution of Camillo Sitte, beginning with his book "Der Städtebau nach seinen künstlerischen Grundsätzen" in 1889, made it possible to implement bended and buckled streets as a design concept. Still, the perimeter block development is the most prevalent scheme in Vienna.
At the same time a land use plan and a model for the heights of the built up surfaces was set up contolling the private decisions of investors. The balance between privat and public urban development was disturbed by World War I. Between World War I and World War II, garden plots were rededicated and sheeted with super building blocks. After World War II, the social democratic party carried out buildings in its most efficient and economic form - the *Lückenverbauung*, a refill of urban gaps.
Nowadays, urban development focuses more on the preservation and refinement of urban structures.

Outside the wall

Traditional villages at the edge of the city mostly feature a *Blockrandbebauung*, a typical feature of European cities. With this kind of building structure the boundary of a building block, delimited by a street or a path, is almost built over. In contrary to more centered urban agglomerations this typology has a bigger affinity to agricultural use. Typical indicators are a developed structure, small partitions, and uniform enclosed building fronts on low buildings. These suburbanized traditional villages are part of the Viennese identity. Within the empirical anylsis of "route choice", these villages will reflect the sub-centres of today´s city, like Hütteldorf, Hadersdorf, Atzgersdorf, and so on. Hence, they are both autonomous and integrated into the urban context at the same time.

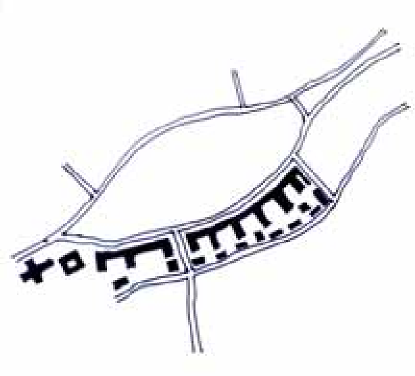


Figure 15: Traditional centre of a former Viennese village

In the interwar years of the twentieth century another type emergered: *superblocks*. One of the most famous examples of this building structure is the Karl-Marx-Hof (1927-1930, architect: Karl Ehn - a student of Otto Wagner), an archetype of social housing. It combines the systematic attributes of a "Blockrandverbauung" with a high percentage of green space and enough sunlight for the individual living units. Only twenty per cent of the whole area is built-up surfaces. This superblock is 1100m long. In 1934 this residental building was a centre of conflicts during the Austrian Civil war.

Other superblocks are the Hugo-Breitner-Hof, Friedrich-Engels-Hof, and the George-Washington-Hof.

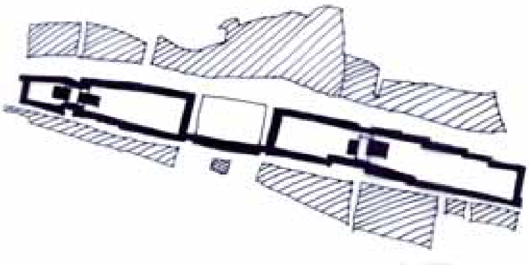


Figure 16: Karl-Marx-Hof, 1927-1930

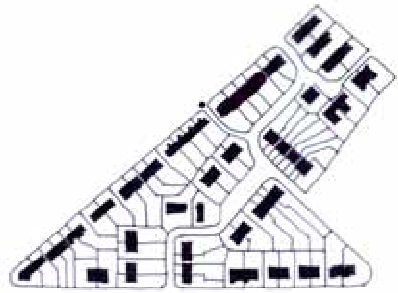


Figure 17: Werkbundsiedlung, 1930-1932

Within the same period the concept of the *garden city* was selective implemented in the urban pattern. This archetype was intended to support a good-quality, economical, and healthy living opportunity. In Vienna this kind of accomodation is achieved in the examples of Freihofsiedlung, Siedlung Hermeswiese, and so on, and also in the experimental housing development of *Werkbundsiedlung* (1930-1932), as a continuation of Stuttgart´s Weißenhofsiedlung in 1927, Germany. This archetype is a critical take on Vienna´s monumental residential building program. Werkbundsiedlung is a protoype of the era of modernity in Austria. 70 buildings were built by 32 architects such as Josef Frank, Adolf Loos, Josef Hoffmann, Richard Neutra, Grete Schütte-Lichotzky, Hugo Häring, Gerrit T. Rietveld and others, who designed a human residential culture within the smallest spatial space and using the simplest methods (Wikipedia, 2007).

Industrial zones always make up an important part of the urban functional structure. In the first half of the nineteenth century, the economic boom was reflected in the urban development in Vienna. Industrialization started around 1830. Spatially, it influenced the construction and building of the first railway line. From this time the production line was a north-south axis, attracting factories which demanded a lot of space. Today we can still find the industrial zones in the south of Vienna. Because of their need of space, the train stations were built outside the wall. For industrial zones no specific pattern can be detected. Areas of industrial zones are dedicated to functional issues.
In the mid nineteenth century, residential buildings for workers were linked to the industrial production areas, for example Hernals, and Ottakring - both areas outside the wall. The most spectacular case with regard to urban enlargement is the area of "Schmelz", a former military parade ground. The huge area of nearly 100ha was subdivided into allotments in 1910. In the middle of the area garden plots were left and to the south and east the terrain was subdivided into 62 building blocks with 14 to 18 allotments per block. Ergo, an average of approximately 1000 allotments for the whole area were created.

Across the Danube - Transdanubia

Through the first bridge construction in 1439 Vienna was directly connected with Transdanubia. Originally, Transdanubia was an agricultural area and flood plain, for example containing the winter flood of 1830. The agricultural basis still exists today. As a whole the area was adopted very late as two regular Viennese districts: Donaustadt and Floridsdorf. Donaustadt is compiled of the villages Aspern, Eßling, Lobau and Kagran. Only from the 1970s on, due to diverse initatives, can an intensive population settlement be recorded.

Floridsdorf, the second big part of Transdanubia, developed quickly by way of a better infrastructure - a railroad line in existence from 1837. Floridsdorf consists of the three municipalities of Jedlsee, Donaufeld and Neu-Jedlersdorf. The railway line was the cause of the progress of the industrialisation. Floridsdorf was incorporated as a Viennese district in 1904. During World War II Floridsdorf was heavily damaged by the impact of bombing raids.

2.5 Vienna´s Supra Regional Roads and Boulevards

Supra regional roads as superior structure are mostly linked to the global street pattern. They are an essential factor for trade, and the supply and service of a city. Without these supra-regional ateries an urban system cannot exist efficiently. The geographer Elisabeth Lichtenberger gives a significant in-depth view of the Viennese supra regional streets in her research work.

Vienna´s supra regional roads result from their location at the spur in the north east of the alps in the Viennese basin (part of the green belt around Vienna). Parts of the medieval arterial roads fall into line with the old roman roads. The most important one was the limes road, following the course of the river at the higher terraces of the south shore from north west to south east. During the Roman Empire two roads lead to the south. One still exists as the Triesterstraße (see figure 18) nowadays, whereas the other one might have its succession in the medieval Liesinger path (though this is not archaeologically proven).

Across the Danube river roman transport systems were missing. The first bridge construction was in 1439 and initiated the continuation of the north east road into the region of Floridsdorf, Transdanubia. Before the river was bridged, the passage across the Danube was located close to Klosterneuburg and Korneuburg, above the city, in the north; and in the area of Erdberg, below the city, in the south.

The actual routes of the Prager- and Brünner road (forking at the Floridsdorfer Spitz in the north, see figure 18) were set up in the eighteenth century. During this period the medieval supra regional road net was developed and extended as the basis for today´s street network. Younger in date is the arterial road to the Marchfeld, crossing a bridge called Reichsbrücke. This road has no independent objective, but it is a modern variation of the old roads leading to Silesia and Poland.

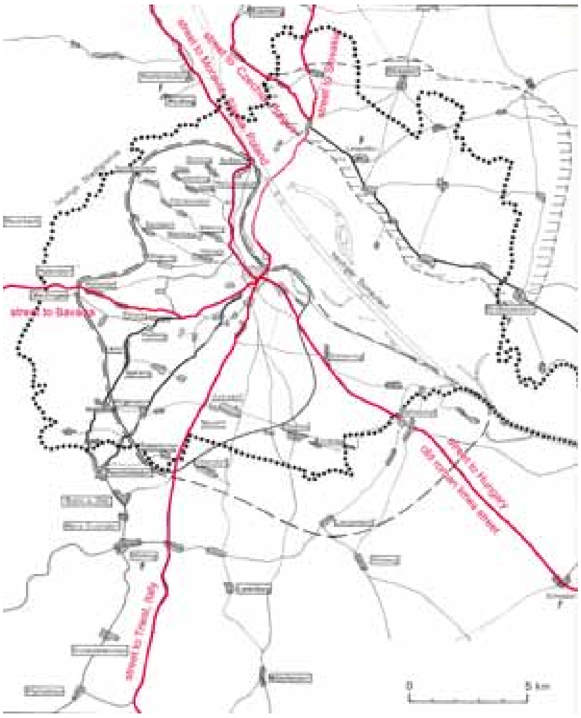


Figure 18: The six historic supra regional roads, Vienna

Vienna´s medieval supra regional roads had their beginning at the five main city gates. The arterial road to Poland and Moravia started from the main entrance, *Schottentor*; the one to to Bavaria started from the main city gate, *Burgtor*; the road to Italy from the *Kärntnertor*; the one to Hungary from the *Stubentor*; and the two roads (fork in the north) to Czechia (Prague) and Slovakia both started at the *Rotenturmtor,* incorporating the bridge across the Danube canal.

The above-mentioned roads connect Vienna with many hinterlands. This effect can be noticed with the road to Hungary, the Landstraße, where not just hungarian influences came to Vienna, but also the Byzantine-turkish oriental influences flowed in to Vienna from the high medieval period. Greek and oriental trader colonies settled down in the medieval city and also gave the Rennweg (the side arm of the Landstraße) its significant visual imprint. The Landstraße was the main transport route for supplies from the Middle Ages. Until the end of the eighteenth century, herds of bullocks were droved along this road. By contrast the arterial roads were suply routes for vegetables. During the nineteenth century, Bulgarian gardners also came to Vienna, settling down in Simmering and Kaisers-Ebdersorf.

Vienna had influences from the West through the arterial road to Bavaria. New religious and spiritual ideologies, and economic ideas came from there. One of the most significant characteristics of Vienna was mail transport and person transfer. It always had a larger significance than the carriage of goods.

The arterial road *Triesterstraße* brought the influence of Italian master builders and brick layers to Vienna from when the Renaissance started. Many artists, working for the baroque courtly society, came from the south. Also, the retail of silk and southern fruits was in Italian hands.

The north-western supra regional road to Moravia and Poland had an impact as the „wine road“. Today this area is still famous for wine in Vienna and its popular tourist attraction is Grinzing, an attractive area with old traditional winemaker families. Its biggest competitor was the Danube River, where all types of goods, persons, and also wine and grain were transported upriver.

The arterial road in the north-east, forking into the *Brünnerstraße* and *Pragerstraße*, also led to an agricultural hinterland at first. Later, it transformed to an important transport connection between the Waldviertel (a region in the north of Austria), Bohemia and the Viennese basin. This road brought immigrants from Bohemia and Moravia to Vienna. Because of the closer alliance with these crown lands under the Austrian sovereign Maria Theresia (1717-1780), the number of immigrants increased continously.

The last supra regional road in a historical context emerged after the beginning of industrialisation. It led to the east. This aterial road connects the historical nucleus of Vienna with Transdanubia, the former shire, where it is interspersed with water and therefore marks an important location for recreation of Vienna (Lichtenberger, 1978).

In contrast, the Viennese historic boulevards follow a different functional. They were mainly built to facilitate the journey between the urban residences and summer palaces of the Viennese aristocracy.

Beginning in the first half of the eighteenth century, extremely straight boulevards and alleys were built between the summer palaces and the urban centre. Of course, correlations between the popular summer palace of the each emperor and the date of origin exists. The *Laxenburger Allee*, a boulevard, is the best connection between the pleasure palace Favorita and the palace of Laxenburg. The date of origin is in the period of Emperor Karl VI, because he used the pleasure palace of *Favorita* as his summer residence, more than the famous palace of Schönbrunn. Under his daughter, Maria Theresia, the time of Schönbrunn´s popularity began and therefore, all the new connecting streets came to the fore. Today a part of of the connecting boulevards to the historic centre has the name “Schönbrunner Allee” (Oppl, 1983).

In general, the described street patterns, main roads, and urban interventions underlie a dynamic aspect – movement. This dynamic feature influences the order of street networks and implies on a meta-level the aspect of a self-organising system.

3. CITY SPACE: DYNAMICS

Oft erschien das Verhalten, einzeln betrachtet,
chaotisch; aber wenn Sie die richtige
Aggregationsebene der Daten fanden, sahen Sie
wunderbare statistische Gesetze aufscheinen
– eine im Lärm versteckte Melodie.
Ioannis Antoniou, 2007

Often, individual behaviour seemed to be chaotic;
but if you found the right level of aggregation for the data
you saw emerging delightful statistical law -
a hidden music within noise.
Ioannis Antoniou, 2007

3.1 Urban Hierarchy and Self-Organisation

Hierarchical and spatial structures emerge as a feature of evolutionary settlement. Settlements are organised as a continously differentiated hierarchy of sizes and levels of complexity (Pumain et al., 2000). Hierarchy emerges within an urban system or in a grouping of urban systems all around the world. It is the visual manifestation of dynamic flux. Without movement, a hierarchical system would not originate. Hierarchy is a sub-division of the term self-organisation, because in self-organising systems the order by fluctuation of all kinds of locomotion and regrouping occurs.

The principle of self-organising systems in physics and chemistry can lead to an understanding of the self-organising principle of human settlements. Of course, molecules in interaction have none of the human intelligence and complex behaviour. They are capeable of creating structures of functionality and form at large scales – bigger than their single condition and emergence. In fact, to detect a certain pattern and behaviour we need a bunch of singular elements. This phenomenon results from the behaviour of coherence. In physics, the behaviour of systems is influenced by time, pressure and temperature. Isolation of the molecular events from the outside world has the effect that the system moves towards a thermodynamic equilibrium, a molecular disorder. This means that an existing spatial structure can erode. Allen comments, that what is of great importance is that a system that is open to exchanges of energy and matter with the external world can, under certain conditions, exhibit a quite different evolution, one corresponding to a decrease of its entropy, to a “self-organisation” (Allen, 1997, 10).

Self-organisation can be described as an entropy of order that transforms into a chaotic or non-organized phase that then again finally moves towards a new stage of complex order. This new order is the best temporary fit. Following the observations of Prigogine (Prigogine, 1980), the sudden emergance of order from chaos is more the rule than the exception. Chaos is a highly complex condition, where no order is identifiable, and also cannot be described in a simple, generalized way for a whole system. Therefore, the term *deterministic chaos* describes the fact that even simple operations under certain conditions in the field of mathematics can lead to incalculable results.

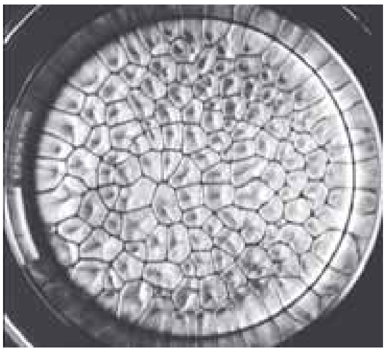


Figure 19: Bénard, convection cells

A typical example of self-organising systems are the Bénard cells. A thin oil-layer is so highly heated that heat transmission for the evacuation of heat from the bottom to the top is no longer sufficient. The system changes. Hot packages of oil climb up and, once cooled, sink down. A new structure of convection cells emerges. For particles, climbing up at the rim of the cells, fluctuations are the decision-makers, determining to which cells the particles move. The emergence of the first convection cells through the rise in temperature is also decided by fluctuations. Many different patterns of organization can appear in the state of instability. Franck describes it as "the islands of order inbetween chaos" (Franck, 2006).

The conclusion is that open systems, within the exchange of matter and energy, including a non-linear interaction between the micro-elements, can influence the state of the macro-elements, ergo the global organisation of a system. The behaviour can undergo a bifurcation. It describes a system where for identical external conditions a variety of possible structures exist. Each of the emerging structures are compatible with the interactions on a micro-scale. The bifurcation of a "tree" happens faster and faster progressing to an *infinitely fast state*. Like fractals, the "bifurcation tree" is part of chaos theory.

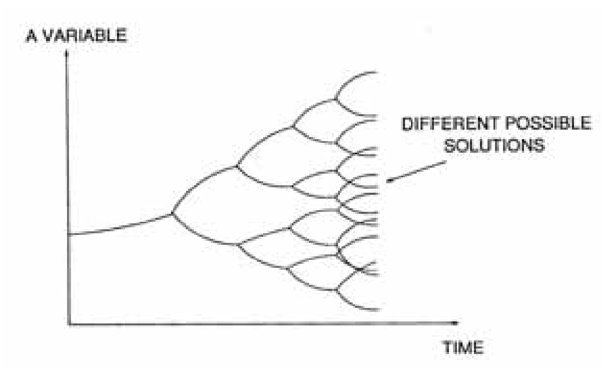


Figure 20: Bifurcation tree with different possible solutions

Allen summarizes that self organising-systems are collective structures which emerge from the interplay between average behaviour, and deviations around this which drive the system through successive instabilities. While a structure is stable, then it can certainly be described by the churning of its connected parts. But, when instability occurs, it can change its structure spontaneously, and afterwards will be described by the churning of a new set of parts (Allen, 1997, 18).

Prigogine outlined self-organisation for urban settlements in his conception of dissipative structures, as the structure of a city can only be understood with regard to its economic exchange with its hinterland (Prigogine, 1980, 12). Not only is the exchange with its hinterland of importance, but also the activities of each actor within the system. Each actor may take simple decisions, but from a global view the dynamic flux - all decision criteria of all actors - unfold a complex, dynamic system of the self-organisational principle. Hierarchical street patterns, centres and sub-centres - the general hierarchy of a city - is the result of all actors´ individual decision criterias of movement.

3.2. Hierarchical Concept of Street Patterns

As arleady mentioned, hierarchy is an abstract concept influencing the functionality of human settlements. Hierarchy emerges thtrough a dynamic flux. It deals with the quality and quantity of urban areas. Yet, Leornardo da Vinci proposed a system of traffic separation including different street types. In the 20th century Le Corbusier set up a hierarchy of routes: *la régle des 7v* - where traffic is channeled from highways down to pedestrian circulation paths around buildings.

The basic principle for hierarchical street patterns is a system from major roads to minor roads. In general, major roads access strategic routes in a global context; where as minor roads are associated with access to neighbourhoods in a local context. For the definition of a street hierarchy Marshall set up three general indicators (Marshall, 2005, 47):

A. Roads designated as "streets" - implying built frontages and public space - are normally found at the lower end of the spectrum.
B. There tends to be greater segregation of transport modes implied at either extreme of these hierarchies: segregated vehicular traffic at one end and segregated pedestrians at the other; with all-purpose roads in-between.
C. Most route types appear to be designated according to transport or traffic function, although some at the lower end also imply relationships with buildings.

The fact of the matter is, the division and prioritization of different traffic distribution has to do with the needs of movement. Also, different characteristics influence hierarchy: form, use, relation, and designation. The political public space of streets and roads creates different spatial spaces of priority. Hence, a hierarchy of public space emerges. This hierarchical network is intra-connected and linked through a complex system of junctions. In this conception we find the difficulty of mixed function the higher the level of hierarchy. Another problem we find within the political urban planning of street networks is the difficulty of a conventional hierarchy. This does not always work, because hierarchy is more an adapted topology to the functional demands of actors than a conventional hierarchy implemented only through functional aspects. Lynch argues that passing up and down the branching lines of a hierarchy is laborious (Lynch, 1981, 96). Therefore, hierarchy has to be linked to actor´s movement and their needs of slight shifts and variations of the network for an optimal comfort of movement - the influence if cognitive aspects.

A hierarchical network bundles all kinds of urban spaces. Different structural elements find their manifestation in superior and subordinated splits in the whole street network. We have already referred to this issue as the local and global context of a hierarchy.

Finally, we can outline the structural conditions for a hierarchy:

A. Elements: each element is singular and individual. Through normalization the elements can appear in the same systematic, structural, and functional way.
B. Rank size of elements: as the Rank Size Rule notes the relationship bewteen the ranks of cities and their population we can adapt this system for the rank size logic of elements within a hierarchy of street networks.
C. Junctions: As the bifurcation tree junctions are necessary for a linked network, a hierarchy can only emerge as part of the whole formation of a system. Hierarchy can be defined by at least a pair of elements.
D. Cascade of junctions: an element can only connect one level higher or lower to its neighbourly element.
E. Pyramid effect: as with a pyramid, the number and distribution of elements decreases the higher the hierarchical level in the system. Hence, there is an inverse relationship between number of elements and level of hierarchy.
F. Configuration of elements: this gives structural information about the questioned hierarchy or non-existing hierarchy. There is no need for a hierarchical impact within a configuration of elements.

3.3 Christaller´s Central Place Theory

In general, groupings of urban systems display a hierarchical order. This order requires the factors of hierarchical organisation of political, administrative systems; distribution of agglomeration through growth - the choice of location of private companies; and the positioning of the urban settlement within the hierarchical order - advantage of time. Therefore, we have to note that the order of urban systems does not only depend on the size of city, but is in addition regulated by the centrality of goods and the localisation of service functions (Lichtenberger, 1998).

Christaller´s Central Place Theory (1933) is evolved from the concept of centralization as an ordering principle. The Central Place Theory tries to explain the size and spacing of human settlements. It is the relation between the average separation of centres and their size. In Christaller´s model centralization is a natural principle of order linked with the notion of hierarchy. Christaller applied to urban agglomerations the idea of centralization of mass around a nucleus as an elementary form of order. His theory illustrates metrical centrality. The spatial economic theory has its fullest application at an inter-mediate and macroscopic scale. Mercantile is the essential issue - towns which serve as centres for regional communities by supplying them with goods and services. Christaller argues that the various appearances of settlements should shall not be spoken about; only the location of the function shall be the centrepoint - the geometric location of the settlement (Christaller, 1968, 24). In Central Place Theory supply is the main principle and structures the primarily law of distribution. Christaller´s model plays with economic forces which reflect the spatial and hierarchical interplay between urban centres. This also influences the spatial layout of towns and cities. The bigger a centre the more it accomodates economic functions, and the higher population it has. Central Place Theory consists of the concepts of centrality, threshold, and range. Threshold defines the minimum market that is needed to bring a new service into existence and range is the minimum distance that people will travel to buy these services. The model conceptualizes hexagonal arrangements as the hexagon best equates a circle for maximum coverage and overlapping problems within circular arrangements are removed through the hexagons.

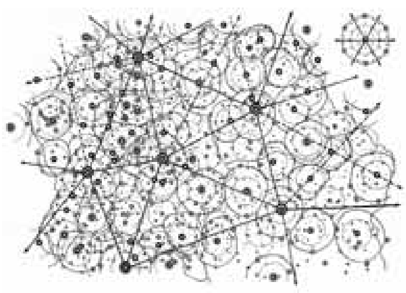


Figure 21: Christaller´s original map

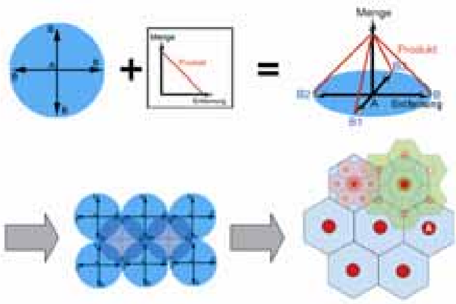


Figure 22: Christaller´s theoretical scheme

In the conception of dynamic systems Christaller´s model is in state of "equilibrium", a stable state, when the areas are "filled" and from there it is of course impossible to know how the system will react to new interventions such as growth of population, decrease of population, or new transportation corridors. Christaller´s ideas are taken from the assumption of an "equilibrium" like a crystalline structure in physics. The inherent problem with taking on these ideas and implementing them into social science is that systems could arrive at a spatial organisation of global optimization without asking for the mechanism or the time scale of the process involved. Every individual action leads to an equilibrium, characterized through global optimization - which is not the case. The theory cannot deal with change (Allen, 1997).
Another critical aspect within Christaller´s model is the fact, that the theory only relates to the service sector. Factors such as location of natural resources is constant assumed by an even plain and a uniform distribution of natural resources. It also assumes an uniform distribution of population. In real life, settlements depend on the factors of climate, agricultural circumstances, and so on. Hence, Central Place Theory cannot provide an general theory and is of a very abstract nature, developed from idealized estimations.
Still, despite of the innapplicatibility of Christaller´s model in real life, it is a break-through in the hierarchical development of human settlements and towns. It has been applied in the regional and urban economical strategies of cities. Central Place Theory also seeks to show that each urban agglomeration is set within a system of towns and cities and any changes are effected through the position of a location within the system (Heilbrun, 1987).
Christaller´s model is important in understanding the influence of centrality, ergo hierarchy, on urban patterns. His model is applied at a regional scale; nevertheless, Christaller´s theory also operates within an urban system. City centres and sub-centres, among other things, underlie the influence of distribution.

Contrary to Christaller´s rigid agglomeration structure Lösch developed (Lösch, 1940) in his *Theorie der Marktnetze* a more flexible system. Different locations offer different products with diverse centrality levels. In addition, not every centrality level offers the same products like with Christaller´s theory. Giffinger points out that Lösch´ theory focuses the development of more differentiated agglomeration structures; range of articles varies for different centres; and centres of the same hierarchical level are offering different products (Giffinger, 2007).

3.4 Rank Size Rule

In general, fractal organisation follows a well-defined, rather simple repartition law: hyperbolic distribution. This law is well known in economics and urban geography as Pareto-distribution. Also, the central place theory deals with the type of rank-size distribution as a type of hierarchy. Dynamic systems linked to urban patterns like transportation networks are also organized in a hierarchical way (Batty, Longley, 1994, Frankhauser 1994, 1997). Rank-Size-Rule is an approximation to Zipf´s law and Pareto-distribution.

It describes the regularity in many phenomena including the distribution of city sizes around the world. The importance of a city can be measured by the population and the rank within a global urban city stystem. If we rank a country´s cities by the population, the relation of the population of each city is in inverse proportion of its rank. Therefore, the second ranked city has half the population of the first one and the third ranked city only on third of the population of the primary city, etc.

Following, this distribution implicates the values of a city´s population in rank *r*, the population of the biggest city, and the rank of the city.

$$Pr = P1/r$$

Pr… a city´s population in rank r
P1… population of the biggest city
r… rank of the city

It is significant that the Rank-Size-Rule does not consider the spatial distribution of systems; only the distribution of size is taken into account for the evaluation. In a logarithmic description we get a linear equation.

$$\log Pr = \log P1 - \log r$$

Statistically the Rank-Size-Rule is valid, if the slope does not strongly deviate from the factor 1. This limitation highlights the problem with it. First, a regulation is needed for the calculation of the accurate population of an urban settlement. It raises the question, of whether suburbs are factors or not. Also, political borders can be problematic. Another difficulty is the unequial distribution of city sizes through history. In Austria we have an unproportionally large capital city compared to the remaining cities and towns of the country. This evolved from the historical growth and collapse of the Austrian Empire.

3.5 Minimal Systems

Minimal systems play an important role in nature, art, science and industry. The reasons are on the one hand ecological and economical; on the other hand nature evolves minimal systems through minimal input for maximum effort. Another explanation comes from the field of neurobiology. The limited capacity and limited use of the human brain demands for a concept of small descriptions, limited elements and operations. Miller suggests seven plus or minus two elements for processing information for the human brain (Miller, 1956). Schwill (Schwill, 2007) describes *orthogonalization* as a fundamental idea for minimal systems. Orthogonalization in linear algebra means that we start with a linearly indipendent set of vectors {v1,…, vk} in an inner product space (mostly, Euclidean space), and we want to find pairwise othogonal vectors {u1,…, uk}that generate the same subspace as the vectors v1,…,vk. Every vector in the new set is orthogonal to every other vector in the new set; and the new and the old set have the same linear span (Wikipedia, 2007).

By orthogonalization of a field Δ he denotes the definiton of a number of basic elements Δe of the field along with ΔeK of operations, K = K1,…Kn, on the basis, each as small and simple as possible; such that every other object of the field may be generated by finitely many applications of operations on the basis elements. Schwill demonstrates that the result of *orthogonalization* is a minimal generating system: B= (Δe, K); a pair consisting of the basis and operations. It can be considered as a construction kit for the field (Schwill, 2007).

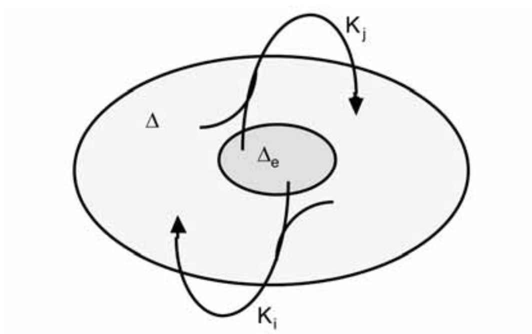


Figure 23: Construction kit scheme

Orthogonalization can be found for example in arts as the concept of the movement of minimal arts, a style that emerged in the 1960s. Reduction to a number of stylistic elements for a maximum production of different creative variations is the main idea. Another example in arts is music. Minimal music denotes a style with highly simplified tones, rhythms, etc. and compositon. The major operation is the repitition of musical patterns in a high variety of combinations through overlaying, shifting, and so on. A popular example for minimal music is Techno.

This idea leads to mathematics. Fractals are an example of minimal systems. Simple construction kits generate highly complex systems related to chaos theory, like julia sets The starting point´s copies of itself result in a non-linear transformation (see chapter 6.2).

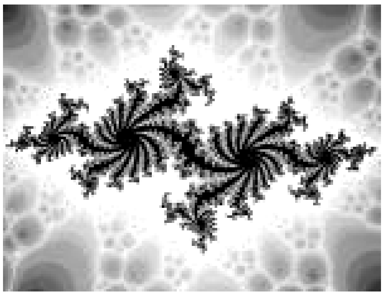


Figure 24: Julia set

PART I I

EMPRICISM - HIERARCHY OF THE STREET NETWORK BY TOPOLOGY AND METRIC

4. SPACE SYNTAX: HIERARCHICAL ORGANISATION BY TOPOLOGICAL ACCESSIBILITY

History does
more for the city than leaves us buildings.
It creates relation between the form of the
city and the wax it functions.
Bill Hillier, 2003

4.1 A Theoretical Statement

Space syntax works with the comprehensive concept of "space", either as built form or as "open space", which occurs inside and between built structures. The space syntax methodology addresses the relationship between physical elements of a city and its social activity and the pattern of utilization. Marcus defines the space syntax theory in a very understandable way when he explains that the main variable of urban form that is analysed within space syntax is accessibility and how the accessibility between spaces varies according to the changes in the configuration of urban form (Marcus, 2007). Space Syntax theory represents urban settlements as a continuous whole.
It focuses on creating a platform for society and space, to give a spatial nature to society as well as a social dimension to space (Karimi, 1997). This methodology considers space and the spatial structure as the fundamental concept of urbanism. Each spatial manifestation unit of urban agglomerations develops an interface with itself. There is a direct link between the urban structure and the pattern of activity, as the organisation of a city and its network of "open spaces" is created by the urban agglomeration of socio-spatial units. One of the major attributes is the relationship between movement - represented by connectivity and accessibility - and the spatial network, known as configuration.
Lucas Figueiredo argues that "one key characteristic of recent urban studies on urban morphology is the use of networks to describe the built environment. From this perspective, the city is not seen as a collection of building blocks that may have geometrical regularities, […] but as a network of interconnected open spaces - the urban grid" (Figueiredo 2007, 1). So, he points out that such studies unfold cities in terms of their underlying spatial organisation, tracing a connection between space and society.

As a basic tool, space syntax applies the axial line as the minimal set of longest straight lines of sight that interconnects all open spaces. Stephen Marshall argues that the axial line reflects the geometry of bounded space (Marshall, 2005). The axial line intersection of an axial map becomes the edge and the retrieved graph structure of the axial map is the "axial graph". An axial map is a geometric model of an urban grid that transfers into a topological graph. This topological graph has the street network structure as its"underlying" property. As Hillier describes the city as a set of lines (Hillier, 2003) we can postulate the axial line logic as an abstraction of the urban network. He draws attention to the importance of connectivity and its topological arrangement into a network by the geometry of a system. What can be derived from this point is that the abstract connectivity (configuration) is more important than the position of space (composition) (Marshall, 2005). What space syntax represents is a topological network to link urban structures with social activity through the idea of connectivity and accessibility.

Like every theory, the space syntax methodology also has its limitations. In the context of the space syntax theory some questions araise, such as "what are the non-spatial characteristics of the city? How does it deal with the problem of geometry? How is the third dimension taken into account?" (Karimi, 1997). The standard approach is that the space syntax methodology has its abilities to support architects, urban planners and designers. Hillier argues that space syntax offers no more than a powerful aid to a designer´s intuition and intensions and it helps them to understand what they are doing (Hillier, 1993).

Space syntax is an on-going framework of research at University of London (UCL) and continuously being adapted or newly developed (e.g. the introduction of local measures, radius radius measures, angular analysis) - and this, in the field of science, is the most important point.

4.2 Centrality as an Indicator for a Topological Hierarchy

Centrality has been revealed as a very important factor for understanding the structural characteristics of a complex relational network. It is also relevant to various spatial factors affecting social activity in cities. Centrality, or better to say the cascade of centre and periphery, represents the topological hierarchical scale of accessibility within a system. The higher the connectivity of the street pattern, ergo the accessibility, the more central a place is.

The etymological origin of the word centre is the Latin *centrum* or Greek *kentron*, which means thorn. It also means the peak of a compass, and at the same the middle point of a drawn circle (Kluge, 2002, 1008). In other words, embedded in the context of urban settlements, the peak of a city is the highest connected agglomeration of socio-spatial units.

Different kinds of centrality are at work within urban agglomerations. Spatial and social concepts have to be distinguished. Spatial centrality supports social centrality. *Metric centrality*, like Christaller´s *Central Place Theory* and Lösch *Theorie der Marktnetze*, implies the metric centre as the middle of an area where services, goods, and supply are located.

Therefore, *topological centrality* as applied in space syntax theory implies the spatial integration of an area. It can be described as the configurational structure of the street network. Finally, a *cultural centrality*, defines the concentration of historical and cultural artefacts in an area (Van Nes, 2007).

Hillier argues that the centre of an urban agglomeration usually means a concentration and mix of land uses and activities in a prominent location. A concentration and mix of activities in a certain spatial position is carried out in relation to the whole settlement (Hillier, 1999). Hence, where there is a centre, there is centrality. Topological centrality is linked to the urban fabric and its accessibility. Space syntax offers a tool, called integration, to analyse centrality in cities. With regard to space syntax, centrality is defined through appropriate accessibility with the least possible changes in direction within the local or global urban environment. Hence, the integration of central places has a very high rank with respect to the whole system. The exclusion of other urban places as central places and the definition of one or more centres classifies a cascade. Every city has its own topological hierarchy.

Centrality is also represented by a high movement flow of pedestrians. For example, historic centres in most towns have a good *movement economy*. The movement economy is a component of "live centrality", that itself is a key component of centrality. It refers to the socio-spatial impact. Live centrality means the element of centrality which is led by retail, markets, catering and entertainment, and other activities which benefit unusually from movement. Live centres governing live centrality appear to invoke spatial requirements over and above those related to other central functions such as administration, office employment or religion. The key proposal is that a distinctive spatial component is influenced by the *movement economy* process. The movement economy theory builds on the analysis of movement flows of a street network, influenced by the spatial configuration of the network itself.

We have to consider that two kinds of movement are at work. The first is linear movement from specific origins to specific destinations. In contrast to this, the second kind of movement is 'moving around' movement within a local area, and relates to all origins and all destinations within that area. This process has the effect of optimizing "metric distance", that is, minimizing mean trip lengths from all points to all others within that area (Space Syntax Ltd., 2006).

The organisation of settlements generates movement patterns, influencing land use choices and, furthermore, political planning decisions. These land use choices in turn influence local grids and so movement representing intensive use and density can be read of from the street fabric. Moreover, centres have the highest intensity of movement in an urban system. Through movement a cascade of higher and lower intensive movement emerges and therefore reflects a hierarchy.

In general, different centres can accommodate different functions. For example, the historic centre can be more a shopping and office centre, while in the periphery there is more of a residential function. The Wall Street in New York is a financial centre and in London there is a historic centre, a centre of administration and a religious one close to Westminster. When we think of well known centres as in London or New York it is quite clear that, historically, centres grow and shrink as cities change through time. But do they also shift and diversify?

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

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

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

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

Stephen Read claims that configurtionally cities consist of different scales of hierarchy. These scales are layered, distinguished by the scales of mobility, and are designed to convey different scales of movement. He points out, that by the hierarchical configuration of the network there are different levels of carrying traffic over medium, longer and local distance. (Read, 2000). A historic centre supports pedestrian movement; an outlet centre or a shopping mall supports individual transport by car. Hence, there are different types of centres for the diverse mobility scales that exists. Read and van Nes point out, that those who complain that the centre has become specialised for parts of the lives we live have failed to understand that this cannot in reality be otherwise, given the fact that the city as it is lived in now is bigger and includes more, and more diverse networks and territory. (Read et al., 2007).

In general the image of the compact European city has changed and transformed over the last few decades. If centrality is a place, where the action takes place, not only does periphery becomes a site of "new centres", but also entertainment centres are the new attractors. This new centrality has, in the opinion of Read (Read, 2000, 2007), a different quality compared to the "old" centres. They are based on highly dynamic flux and appear without the centering and locating power that is recognized and used form historic towns. This placenessless becomes part of the network grid and mobility strategy. The hierarchical split in the context of movement has to be recognized. These centres are appendixes to the network and not a geometrical, pattern-based centrality. A very important issue is that these centres are autarkic. They provide total autonomy from the urban functional structure. In Vienna these new types of centres are examples of Millenium City, Twin Towers, Gasometer City, Donau City, Shopping City North.

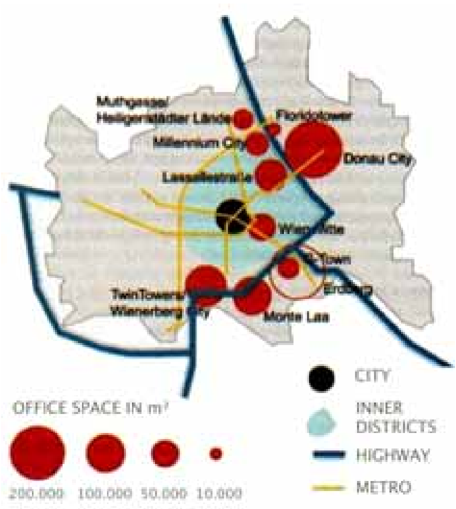


Figure 25: New urban centres of Vienna in 2002

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

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

4.3 Theory and Methodology

Space has a certain value. Buildings are located in and on space and create new spaces. Space has the possibility to attract people or put them off; include or exclude them. These attributes depend on how space is planned and designed. In general, urban space exists of buildings and movement channels. Space is defined by buildings and movement channels that surround them and in turn it gives definition to streets and buildings. The buildings imply more than just a functional aspect of "shelter". Of course, this function is essential and one of the major functions besides the social impact of buildings or their arrangement in a whole system.

Hillier points out, that buildings are normally multifunctional. They provide shelter from the elements, they provide some kind of spatial scheme for ordering social relations and activities, they provide a framework for arrangement of objects, they provide a diversity of internal and external opportunities for aesthetic and cultural expression, and so on. At the most elementary level, a building is a construction of physical elements or materials into a more or less stable form, as a result of which space is created which is distinct from the ambient space. (Hillier, 1996, 21f). The social interaction of buildings and streets will be more discussed in detail in chapter 4.6.

Boundaries are implemented by the physical appearance of buildings. A fundamental point is that a building divides the outside space from the space inside. The outside space in urban settlements is used for movements to access and connect buildings and their inside space. Ergo, the outside space is transforming by their utilisation, mostly into movement channels. By the location of those two elements - buildings and movement channels – they are linked by a spatial arrangement that manifests a spatial relation.

Spaces are linked together. Their linkage consists of different attributes such as adjancency, permeability, seperation, and segregation. Therefore in Hillier´s theory configuration deals with interdependent relationship of the simultaneous co-presence of at least a third element or as many as possible in a complex system (Hillier, 1996). To visualise the relation or configuration between spatial elements, drawing a graph is a method used as a basic element in space syntax theory.

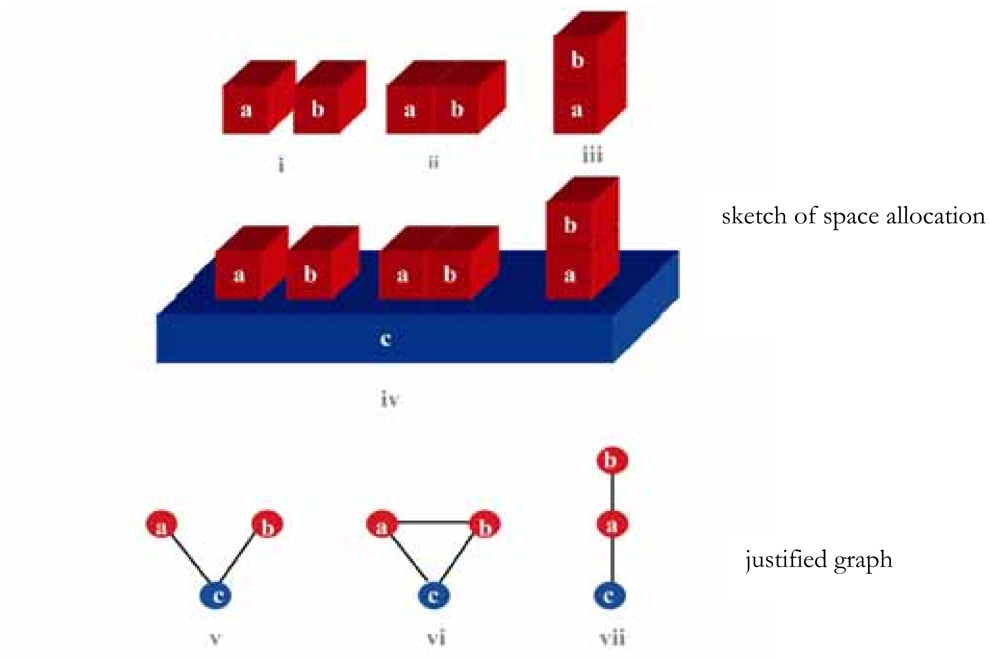


Figure 26: Relations between elements and corresponding graph

This figure demonstrates the concept of permeability and adjacency graphs. To clarify the configuration of spatial elements a justified graph or j-graph is used. Individual elements are represented by small circles or nodes and the relation between the elements as lines, joining the nodes. The configuration shows that a bottom node or "earth"is used which is called the "root node" (blue; c) and is in topological steps defined as zero. Between the root node and the elements a,b one (v, vi) or two (vii) topological steps exist. A measure of *Depth* can be retrieved from the justified graph by starting at a root node (blue in the figure above). For example, one syntactic step has the value of one, two steps the value of two and so on. For a practical understanding of the theoretical background the next figure will use a ground plan of a traditional Viennese flat.

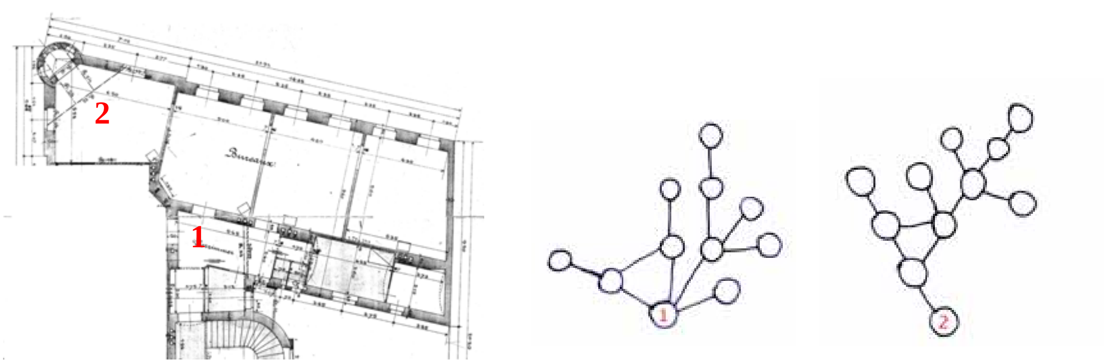


Figure 27: Gründerzeit-flat, Vienna 1897, and its j-graphs, from starting points 1 and 2; j-graph [1] has a total depth of 288 , j-graph [2] has a total depth of 297.

The value ***Total Depth*** is defined through the number of spaces that must be passed through from a chosen or given starting point in a system. The Total Depth of a system is calculated by the sum of all possible steps from a given starting point. The depth value when combined with the actual shape of the system itself provides important information for the interpretation and analysis of architectural and urban space.

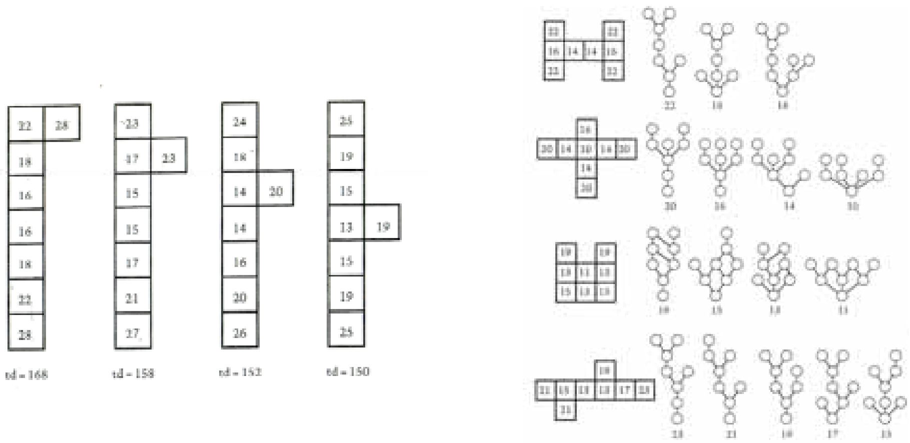


Figure 28: Square cells - coherence of shape and total depth

What has been seen in the ground plan is that depending on the chosen root node the shape of the graph differs. That indicates that shape has an major impact on integration or depth of a system. The square cells illustrate this coherence very clearly. All figures have the same number of cells, but the location of one cell, ergo node, shifts within each figure.

That the influence of shape has an impact on distribution is fundamental in the studies of architectural and urban systems. In general, the distribution of depth underlies architectural and geometrical effects. The problem of Total Depth being influenced by the shape of the system makes it impossible to compare different spatial systems. Therefore, the value of Depth is normalized and so it is possible to express the numerical value of Total Depth independently of the size of an urban system. As the j-graph represents the structure of graphs it leads to the demand for a standardised format for comparative analysis.

From the idea of the value Total Depth a value called ***Mean Depth*** can be differentiated. Instead of the node changing place in a graph a value is attributed to each individual space. Mean Depth is the average depth of a certain space within each possible j-graph drawn for the urban system in question. For the visualisation of this topological calculation different colours in the analogous to a thermography are implemented. Hence, architectural plans and city maps can be coloured with regard to their graphical attributes.

The Line Logic - Axial Map

The black and white illustration below shows the public space of the first district of Vienna - the historic center, founded in the roman antiquity. The Romans established the garrison camp Vindobona in the 1st century A.D. The figure 29 is taken from a map of 2006. It is very interesting that the plan looks on one hand very "labyrinthian" but on the other hand a structural pattern can be conjecturated. For people moving in the streets it is not at all labyrinthian. Cognitive orientation is quite clear. The spatial pattern in figure 30 is "highly connected" for pedestrian movement.

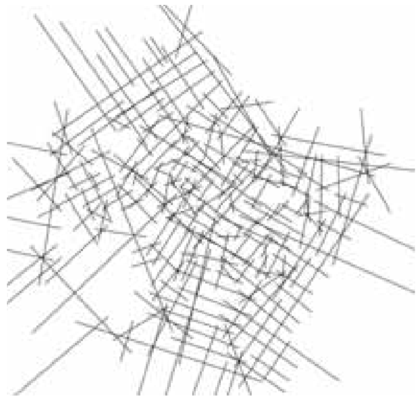


Figure 29: Historic centre of Vienna - black and white model of street network; open public space, 2006
Figure 30: Historic centre of Vienna - axial map of movement street network; open public space, 2006

As people move along lines (streets) in urban settlements they usually orient themselves visually by landmarks (Lynch, 1960) or intersections. Hence, from a certain distance pedestrians can see the next point of aim. Even the main grid on the plan looks labyrinthian, but by moving through and around the street grid it isn´t labyrinthian at all. It can be explained by the existance of two different scales. The pedestrian absorbs the city on a micro level and therefore the labyrinthian character disappears.
"Interfaces" are the effects of the surrounding apparent rules. Movement of people can be seen on two different scales - movement inside buildings and movement outside buildings. Both scales are linked together and exist as a co-presence. The outside movement through spatial space has a "line" structure. Also, its logic is based upon this structural impact. (Note: movement inside buildings will not be discussed in this chapter).

But how can an axial map be extracted from the spatial space?
On a larger scale the "axial map" is the basis for many topological measures - such as integration. A city can be seen as a set of straight lines that people pass through and move around. As a single person moves in lines, the spatial space between buildings can also be identified in lines of movement. An axial map represents this set of straight lines. We have to make a functional difference between longer and shorter lines.

The longer the line, the more likely it is to strike a building at the right angle. This is exactly the ideological opposite of the current rather pompous urban fashion to end major axes at the right angles on major building facades. Historically this usually occurs where urban space is taken over by the symbolic expression of power, whereas the city´s urban structure is about the movement required to create a dense encounter field. The right-angle relationship of facade to line is used in the city too, as it were, to illuminate the smaller-scale and spatially more complex areas, and to make them visible from the large scale grid. Thus it begins to emerge that not only there is an interior logic to the city´s apparently disorderly grid, but that this inner logic is fundamentally about movement, and the potential that movement gives for creating co-presence like economic processes. Many of the properties of urban space that humankind values aesthetically are a product of this functional shaping of space (Hillier, 1996, 159).
It turns out that a city is not just a set of lines, but a pattern of lines. If someone goes along a destination line (street) it is clear that a number of intevening lines intersect this destination line. Every line has a depth from another. Ergo, in an urban system every line has a depth value to all other lines in the same system. The less deep a line is to allies the more shallow the system is and the more movement exists. The integration value can be calculated that reflects the mean "linear" depth of every line in the system. Integration values in line maps are of great importance for the understanding of cities, because they reflect the potential movement or how much movement passes through. Also the position in relation to all other lines is made quite clear by integration values.

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

Practical Appliance of the Axial Map

An axial map is drawn on a separate layer as an overlay from a chosen base map. This map consists of the longest and fewest lines possible. For the manual drawing procedure there a few rules to consider:

- start with the longest line and finish with the shortest
- avoid "overmodelling" that can influence the results
- the fewest possible lines should be drawn
- for time lines the same drawing rules should be set up and documented by the researcher. Decisions on how to deal with the presentation of parks should be clear – e.g. no axial lines, just the major paths or a set of lines representing the individual movement possibilities. This way another person also can work on the same base map and follow the same modelling assumptions. The end product will be similar.
- always check against reality

It is also has to be remembered that lines have to stop, if they reach an obstacle or impermeable object like a facade or wall. If a line cuts through, for example, a building or interferes with another axial line on the neck of an object it is simply wrong and will influence the analytical result. Figure 31 shows the different maps modelling a space. The quantum of the information influences the drawing and analytical result of the axial map.

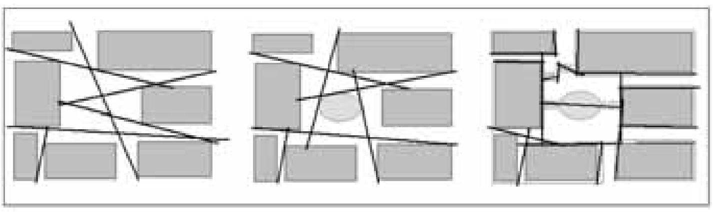


Figure 31: Different resolution of an axial map; left to right: low, medium, and high resolution.

An axial map can be of different resolutions: low, medium and high. A low resolution model includes just the major relationships between aspects of the built environments. A medium resolution mode extends by more pragmatic relations of built and non-built environment being added. A fine or high resolution mode involves the study of the precise path of pedestrian movement. The major difference in the high resolution mode to all others is that the sidewalk will be the focal point for drawing an axial map.

Another very important tool is known as "unlink". In reality urban space often cosists of complex overlapping lines of movement that may not connect each other, even though they look like they would in the plan. Overpasses, underpasses, tunnels and stairways are good examples. If an axial map links overlapping lines that do not in reality connect, the integration value would be artificially inflated and the analysis would be skewed and inaccurate. To deal with these conditions, it is possible to "unlink" overlapping lines that do not share links in reality.

Buffer zones try to handle the size of the contextual area. Different research approaches encounter different answers to this issue. As a rule of thumb the Angora Technology Platform suggests applying the "30 minutes test":

Draw a circle around the area of interest, then take a radius of 30 minutes travel from the edge. If the map is going to examine pedestrian movement only, then this would correspond to a 30 minutes walk, or approximately 2 kilometres in distance. Similarly, a vehicular map would select an area encompassing a 30 minutes drive from the area of interest. It should be noted, however, that vehicular maps are usually quite large and are often close to the whole city in size. (Agora 2004, 58ff)

For this case study, the following rules have been set up for drawing an axial map of Vienna:

- no parks are modelled
- all movement channels are modelled (pedestrian and vehicular)
- ramps for connectivity are simplified (motor highway)
- highways are only modelled by connectivity
- no driving directions (lanes) are modelled
- unlinks are set, e.g. between highway and sidestreet

Further, space syntax analysis is processed in 3 steps: drawing, analysing and visualisation. Researchers work as following:

a.) drawing an axial map
b.) analysing and processing the map (software: Map Info, Confeego, Depth Map)
c.) displaying and interpretation of the results

4.4 Configurational and Radius Measures

The space syntax analysis uses three main categories of measure: numeric measures, metric measures and configurational measures.

Numeric measures are metric measures such as length and width, and also numbers of axial lines. Configurational measures are describing the relationship of spaces to each other. Configurational measures can be divided into *local* and *global* measures. Local measures quantify the relationships of nodes closely connected, for example in 3 or 5 syntactic steps. The characteristics of spatial neigbourhoods appear. In contrast, global measures evaluate the overall characteristics of a graph as a whole. Greene points out that the importance of configurational measures is that they strongly correlate with pedestrian and vehicular movement (Greene et al., 2000). As already described before with regard to movement economy, the configuration of a street network shows the distribution of different movement volumes.

Following we will describe and explain the development from the configurational measures of *Total Depth* and *Mean Depth* to *Integration* that is used for the empirical analyses of this research.

Mean Depth (MD)

The notion of Depth has already been introduced with regard to "Total Depth", where starting from a particular axial line in the axial map the sum of syntactic steps from this particular line to everywhere else will be calculated. Mean Depth is calculated by drawing the j-graph from the node in question and after this the Mean Depth is calculated from all the remaining nodes. The root node of the graph has the value 0 with regard to the idea of syntactic steps. Mean depth is equivalent to the Total Depth relativized to the number of axial lines or nodes of the system and represents the average steps needed to reach any of the axial lines of the system.

The following visualisation shows the configurational measure of Mean Depth reciproc for a better understanding. Normally, shallow areas are visualised in the low value range. Therefore, within the visualisation, the colour would proceed from green to blue as depth decreased. In Mean Depth, shallow areas represent good accessibility, and thus they can be linked to intensive movement. For this reasonan inverse visualisation supports a better image.

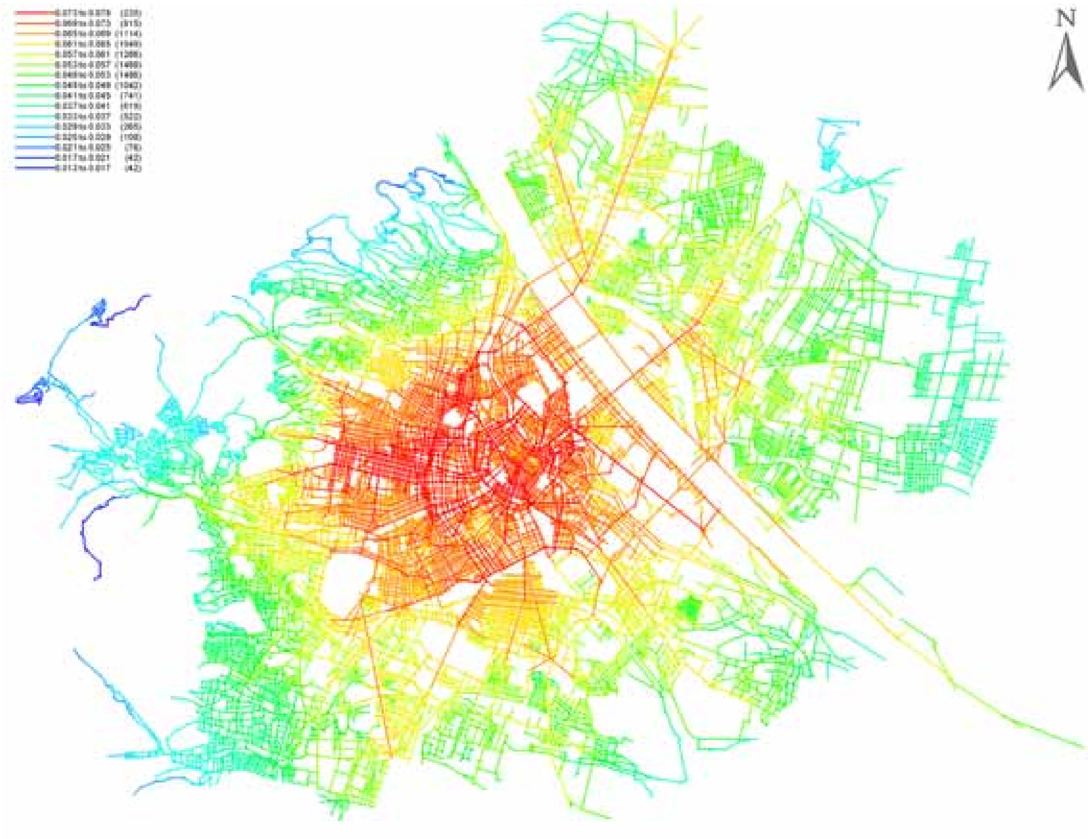


Figure 32: Visualisation of Mean Depth, Vienna 2006. For this visualisation the reciproc representation for a better understanding is used. The historic centre, the former second wall and the nearly rectangular street grid of and around the 16th Viennese district are the most shallow areas in the system.

Relative Asymmetry (RA)

Relations of depth necessarily involve the notion of asymmetry, since space can only be deep from other spaces if it is necessary to pass through intervening spaces to arrive there. Mean Depth provides the basis for RA, which provides a normalisation of the mean depth measure between the deepest a node could possibly be (at the end of a sequence) and the shallowest it could be (when all other nodes are directly connected to it). This will give a value between 0 and 1, with low values indicating a space from which the system is shallow, that is a space which tends to integrate the system, and high values indicating a space which tends to be segregated from the system. The formula for calculating RA is as follows, where MD represents Mean Depth and k represents the number of spaces in the system (Karimi, 2004, 35). This normalisation of the system enables the comparison of different systems like e.g New York and Tokyo.

$$RA = 2\,(MD-1) / k - 2$$

Real Relative Asymmetry (RRA)

RA has the effect of the size of the system. Therefore RRA provides a relativisation that allows comparison of "depth" between different sized spatial systems. D represents the distribution and k the size of the system – it follows, that Dk is a value representing a value-based number of spaces in the system.

RRA = RA/ Dk

Integration

High RRA values mean greater depth, that implies less activity and segregation. So, the reciprocal of RRA – represented by the Integration value – is used for a syntactic analysis. Integration enables measurement of the relative accessibility of a space within a system. Hillier and Hanson describe integration as a global measure of depth, relativised in such a way that differently sized systems can be compared to one another directly (Hillier, Hanson, 1984).

Integration = 1/RRA

Radius Measures

Integration can be calculated as a global or local measure. Global measures calculates integration for the whole system whereas a local measure is restricted to finite syntactic steps and therefore a specific spatial neighbourhood. Radius Measures enable compartmentalization of the global character of depth at any pre-selected depth-status. General they are systematized in local and global measures. Radius measures are strongly used in correspondance with the integration analysis.

The local measure e.g. Radius 3 is, as a shallow one, very useful. It is the root node and two topological steps in any direction. That means, Radius 3 brings up the analysis of space in terms that it is reachable within two additional topological steps. In Radius 3 or "local" integration analysis important streets for a certain area on a local scale are extracted. In addition, experiments with Radius 4,5 and onwards should be done to test the best-fit behaviour, because the size and configuration of the system always has an impact on the analysis.

Opposite to the "local" integration exists the "global" integration or Radius Infinity (N). It reveals the relationship of spatial pattern to the focus of the whole spatial system. Radius N examines the whole spatial system - instead of focusing on local areas, defined through for example Radius 3 or two topological steps, - it describes the relationship of all points to all points, regardless of their distance or the number of topological steps to each other. Radius N helps to analyse the whole, "global" system and gives a very good dimension of the spatial pattern or fabric of a city. Global measures correlate with long distance journeys and are strongly linked to vehicular movement. In other words, Radius N represents the urban system on a macro scale and highlights centrality in an urban agglomeration.

In the analysis of Radius N the "edge effect" is exists. Configurational measures have an adequate buffer of nodes around them in order to produce correct and clean results. The edge effect results from those areas, that have no accurate buffer zone around them. This produces artificially low results which are not precise or accurate. Following local measures such as Radius 3 minimizes the edge effect, but still does not eliminate it. To minimize the edge effect for a whole spatial system a measure called Radius-radius (RadR) or Super Grid (Rose, 2006) has been set up. This analysis tool works on the level of mean depth in the sense that the topological steps of Mean Depth are taken and calculated as Integration from the highest integrated axial line of a system. Radius-radius is different for every system - e.g. for Vienna 2006 Radius-radius is 13 - and represents the "real-life-character" of a pattern of utilisation.

4.5 Empirical Analysis: Calculation and Visualisation of Vienna

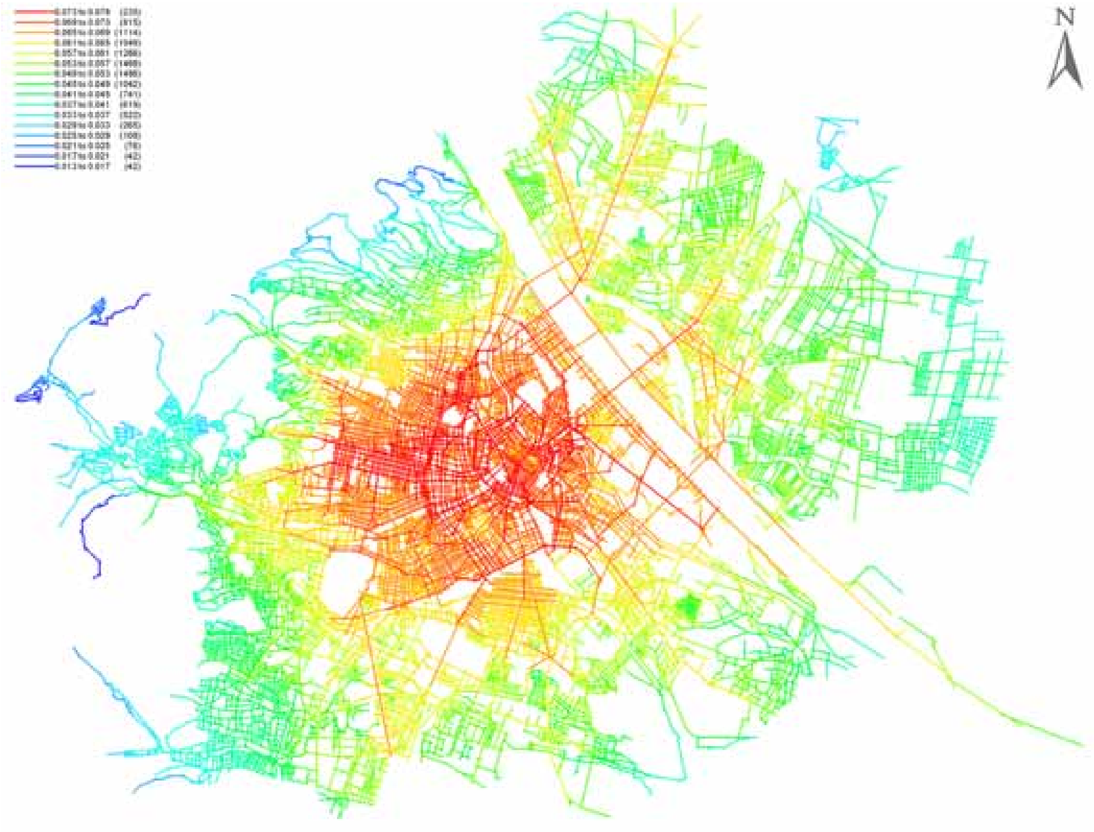


Figure 33: Integration RN, Vienna 2006: the red colour in this visualisation shows high accessibility; therefore it highlights centrality in the complex system. Typical historic structures emerge as most central in Vienna: traditional supra regional roads as the Triesterstraße to Italy, the former city wall including the former second wall; and also the almost rectangular grid of the 16th Viennese district, etc.

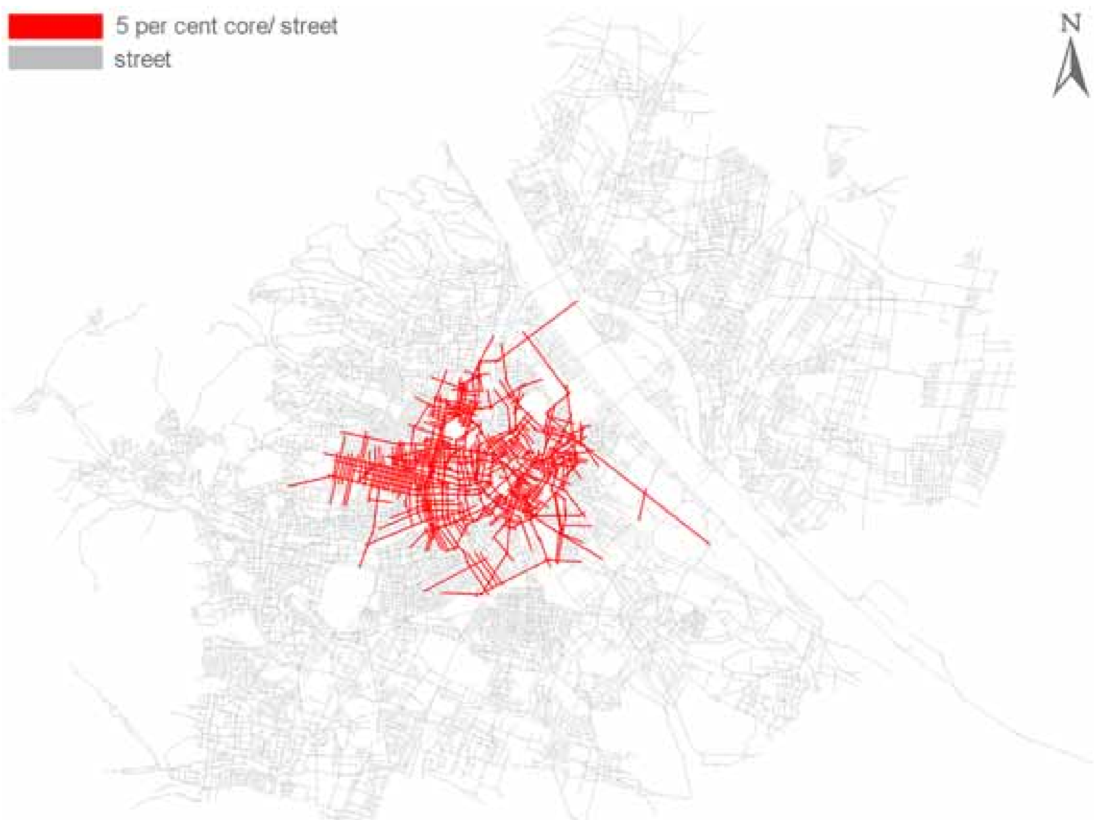


Figure 34: Integration RN, 5 per cent core, Vienna 2006: the top of the topological centrality-hierarchy is highlighted. Centrality is on the one hand linked to traditional grids and also to very strong grids close to a Manhattan grid.

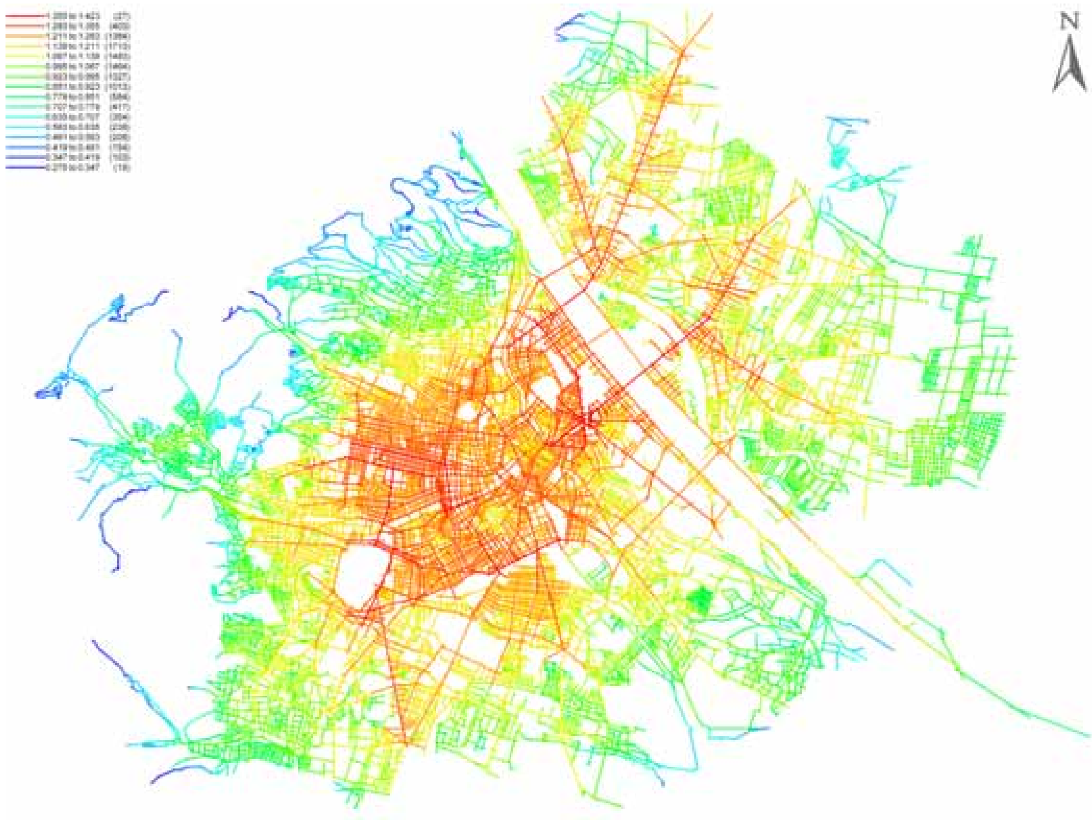


Figure 35: Integration Rrad 13 - Super Grid, Vienna 2006: local and global accessibility are linked. Major routes for long distance travel and movement in neigbourhoods are highlighted.

Figure 36: Integration Rrad 13, 5 per cent core, Vienna 2006: the top of the hierarchy is visualised

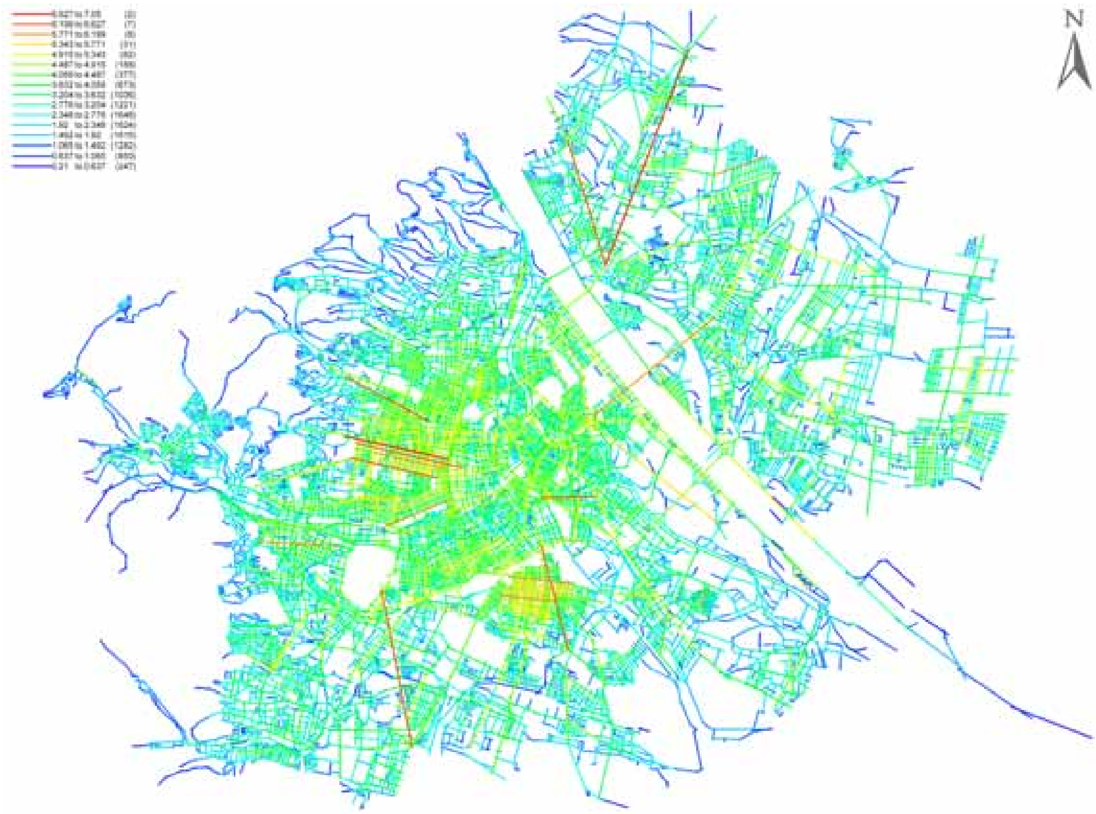


Figure 37: Integration R3, Vienna 2006: accessibility on a local scale. The visualisation highlights popular local shopping streets and communication roads such as Favoriten street, Hietzinger Hauptstraße (Hietzing - a former village), Altmannsdorfer street (an important conductor for this area), Thalia street (famous for a multi-cultural mix).

Figure 38: Integration R3, 5 per cent core, Vienna 2006: a far-scattered distribution of the hierarchical peak. Still, the historic centre is highlighted.

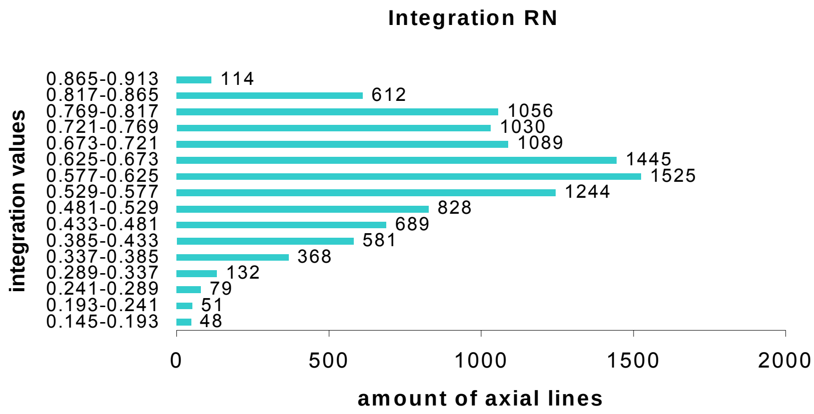


Figure 39: Integration RN, distribution of axial lines, Vienna 2006

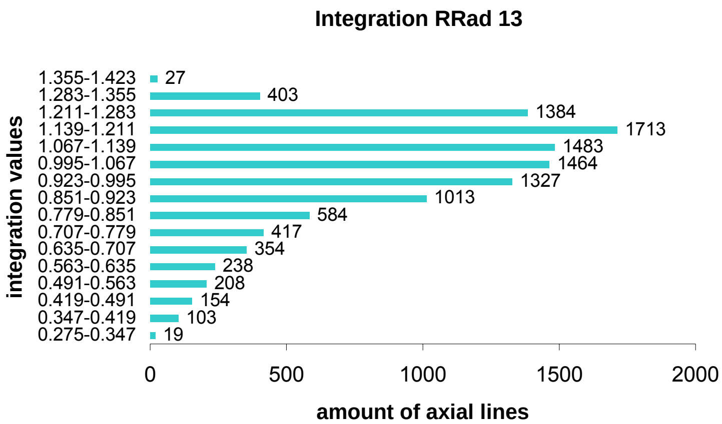


Figure 40: Integration RRad 13, distribution of axial lines, Vienna 2006

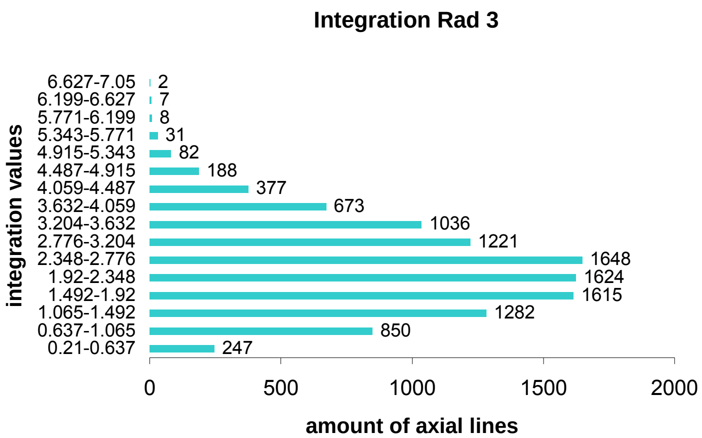


Figure 41: Integration Rad 3, distribution of axial lines, Vienna 2006

4.6. Structure-Function-Model: Correlation with Real Life Data

How can the configurational theory of space syntax be incorporated into real life based on urban morphology by also checking functionality? One way to deal with such a structure function model is to combine structural modules with phenomenological modules of urban systems.

With regard to this, Marcus suggests two variables: density and diversity. Density is a variable well-used in geographical analysis where as diversity can be found as an important quality for urban systems. Both form the "spatial capital" (Bordieu, 1986) influencing the value of properties (Marcus 2007). The structure function model will measure the socio-spatial effect. In the following, we will have a look which have the capability of measuring the effect of urban form as well as social performativity. This will give an in-depth understanding of the actual condition and, at the same time, it will test at the same time the correlation of the space syntax theory with real life.

Radius Measure Integration: We have already analysed the urban morphology of Vienna using spatial integration analysis. This measures the accessibility of each axial line from and to each other axial line in the system. Integration RN as a global measure for centrality is chosen for the correlation. It fits best to analyse the most central streets.

Density - movement and retail: It is also not surprising to find that well-integrated streets in the system collect a lot of movement in form of, for example, pedestrians. Where we find a lot of movement the location also becomes prominent for retail; also see Hillier´s live centrality discussed above.

Diversity - actors: So far, the axial line has been very successful in capturing movement. Marcus suggests shifting our focus from "experientally defined space" to "legally defined space". He argues that a plot represents the presence of an actor in urban space and furthermore the precise location of the influence of that actor (Marcus 2007). Ergo, an actor develops strategies for their domain. So, an an area with a lot of plots carries the potential of many strategies. Marcus concludes that the more strategies there are, the more diversity is carried out among these strategies.

We have to note that we still have to deal very carefully with the idea of diversity and actors. Of course, the correlation exists, but the number of actors does not exclusively influence with urban morphology. Social housing in France (HML) is one of the best examples where the number of actors is contrary to the urban form, ergo the integration of the streets.

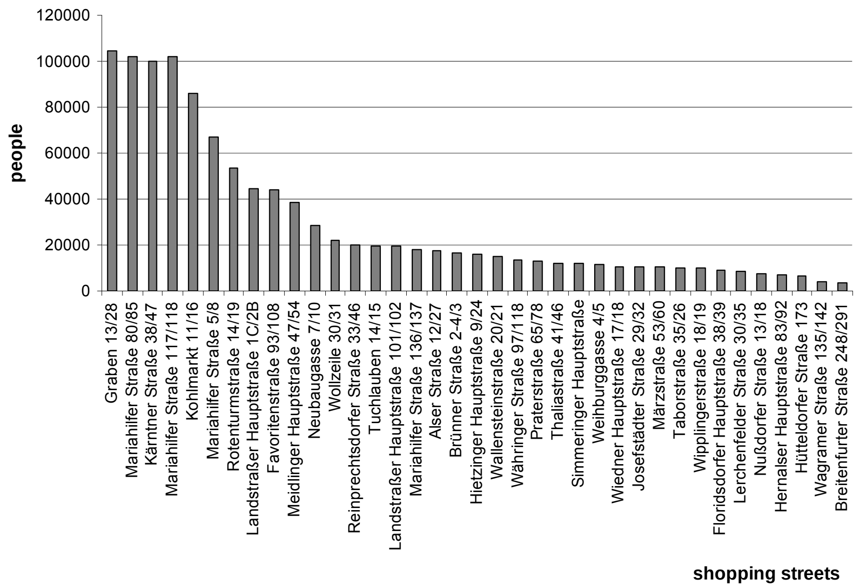


Figure 42: Pedestrian survey in shopping streets, Vienna 2006

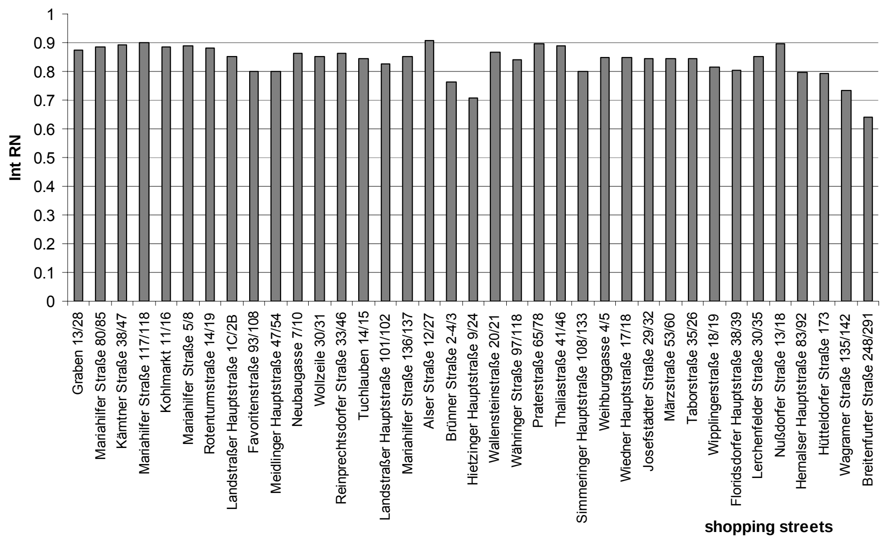
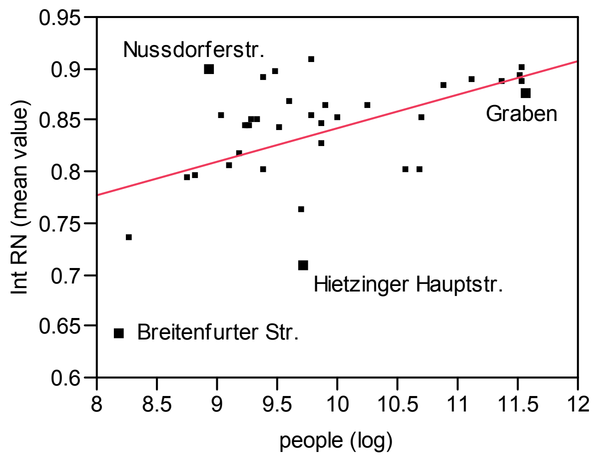


Figure 43: Int RN, shopping streets, Vienna 2006



shopping street	people (high) 12.&14.10.2006	Int RN
Graben 13/28	104584	0,874414
Mariahilfer Straße 80/85	101940	0,8852
Kärntner Straße 38/47	100137	0,892267
Mariahilfer Straße 117/118	101822	0,899503
Alser Straße 12/27	17663	0,907702
Praterstraße 65/78	13096	0,895472
Thaliastraße 41/46	11974	0,889158
Nußdorfer Straße 13/18	7482	0,897005

Figure 44: left - scattergram & linear fit; right - shopping streets with highest and medium to low pedestrian volume and Int RN

The shopping streets with the highest number of pedestrians are also in the highest range of Int RN. The correlation value is 0.434. This value indicates a medium correlation between movement and Int RN. Independently from the information given by the correlation value there are four streets which have a medium to low number of pedestrians, but their Int RN values are very high. We find the reason for this in the length of the street, represented as one straight line in the axial map such as Thaliastraße and Praterstraße. The lengths of a street influences and pushes the value in the space syntax theory. Alserstraße represents a medium length, linking the historic centre and medium number of intersections. Nußdorferstraße is also assembled of medium length and medium intersections. It is not as popular as a shopping area, because its location is a morphological tail of the inner districts. These circumstances influence the Int RN value as being one of the highest in the shown examples.

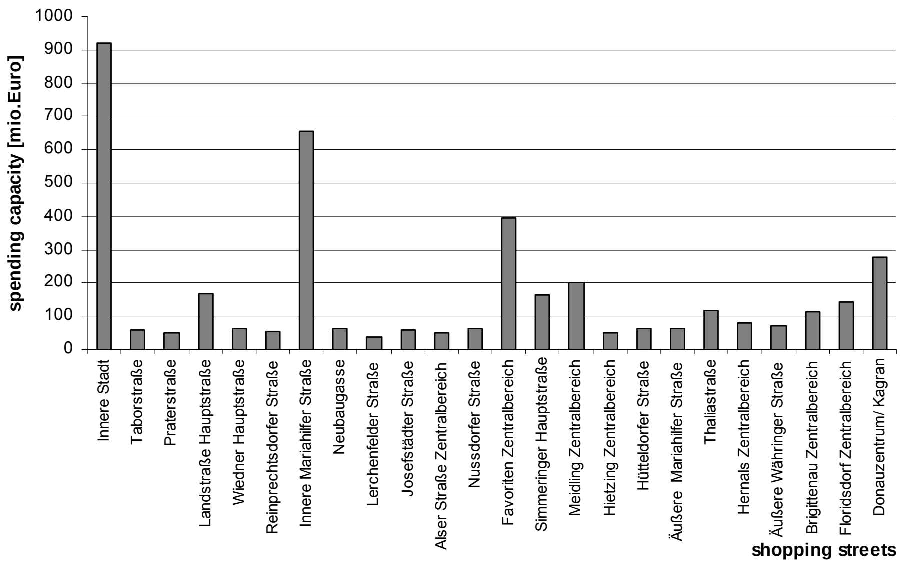


Figure 45: Spending capacity

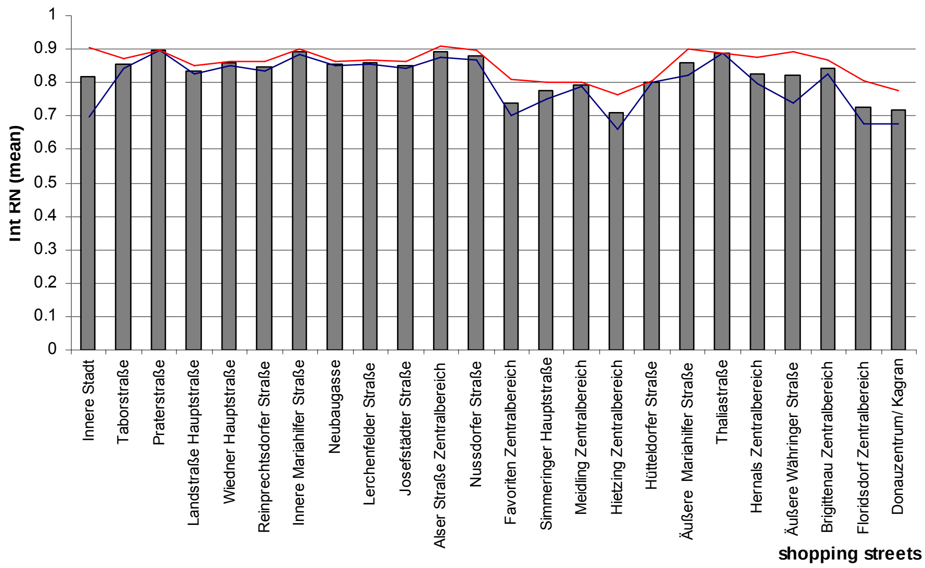


Figure 46: The blue curve represents Int RNmin, the red curve Int RNmax

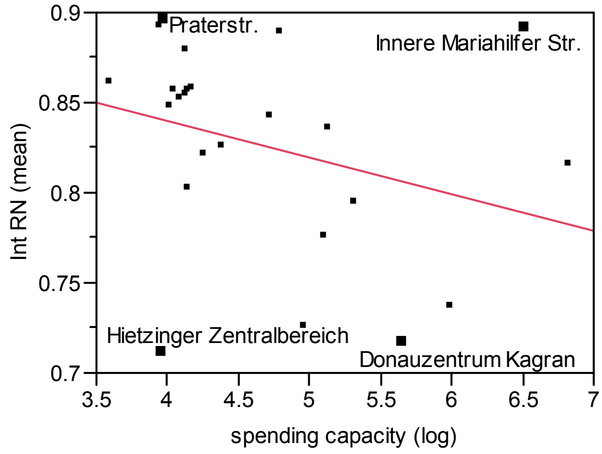


Figure 46a: Scattergram Int RN versus spending capacity

shopping street	Mio Euro	Int RN min (green)	Int RN max (green)	Int RN mean (blue)	axial lines
Innere Stadt	919,1	0,698201	0,906571	0,815496	146
Innere Mariahilfer Straße	657,5	0,8852	0,899503	0,890903	3
Favoriten central area	395,8	0,700153	0,80777	0,736586	36
Donauzentrum/ Kagran	278	0,676039	0,775052	0,716996	10
Lerchenfelder Straße	36,1	0,853217	0,867109	0,8600943	3
Hietzinger Zentralbereich	51,1	0,661145	0,764404	0,71109	7
Alser Straße Zentralbereich	51,1	0,875902	0,907702	0,891802	2
Praterstraße	51,7	0,895472	0,895472	0,895472	1

Figure 47: Highest and lowest spending capacities

At first glance it can be seen in the histogram of Int RN that all the samples of the most important shopping streets and areas in Vienna are located in the upper range of the values. In general this verifies the theory of a prominent place being linked to retail. If we look at the streets with the highest spending capacity, we notice that the inner city and Innere Mariahilfer Straße have one of the highest values, but Favoriten central area and Kagran one of the lowest Int Rn range. Why? As shall see in the fractal analysis, Favoriten is situated like an island. This urban island has one major street linking the island to the central city in an morphological sense. This street is also a pedestrian zone, which supports shopping. In the case of Kagran there are three important factors: First, Kagran is located in Transdanubia. The Int Rn values in Transdanubia are low in general. The reason for this lies in its histoical context. Still, Kagran has a direct connection to the inner city through a bridge crossing the Danube River. It also has to be noted that Kagran is not just an urban shopping area, but also incorporates a shopping mall (Donauzentrum). Correlation between spending capacity and Int RN is -0.138. The result shows a negative correlation. It means that if one component raises, the other falls, which is contrary to the theory of the prominent location. In general, is shopping a very local activity and due to the fact that shopping areas extremely varies (product ranges, etc.) they can be better correlated with local values.

For the evaluation of diversity following stratgegy was used: The number of residents (actors) in plots along the chosen street on both street sides was calculated. This absolute value for a whole street was then divided by the length of the individual street (m) to get a density value of actors/meter. Standardisation was necessary for comparison.

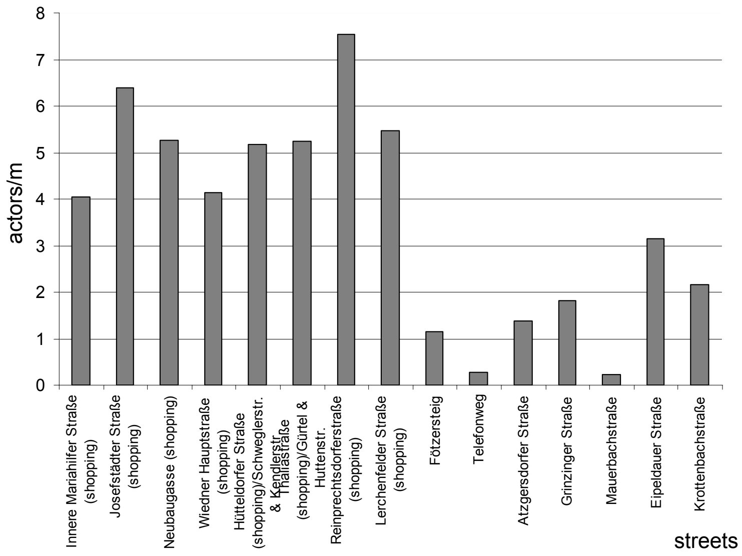


Figure 48: Diversity as density value (actors/m) of street samples - shopping and none shopping

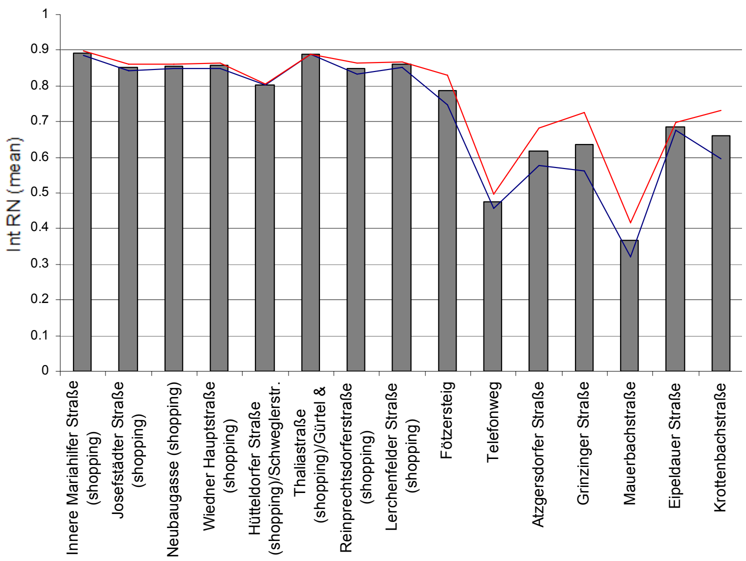


Figure 49: Int RN for samples of the diversity correlation and coherence: blue curve represents Int RNmin, red curve Int RNmax.

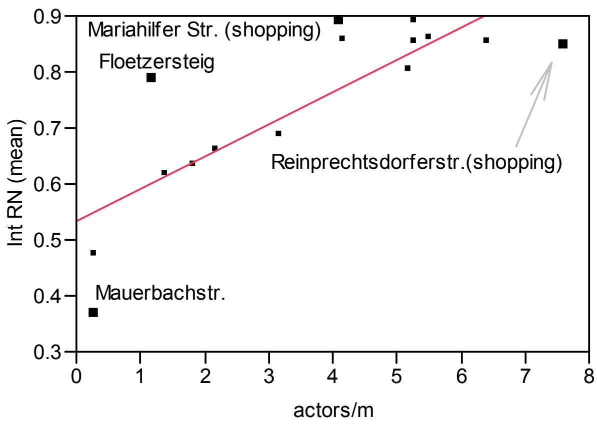


Figure 49a: Scattergram, Int RN versus actors/m

street samples	actors 2001 per street	length [m]	density [actors/m]	Int RN min	Int RN max	Int RN mean	axial line count
Innere Mariahilfer Straße (shopping)	7258	1792,5	4,05	0,8852	0,899503	0,890903	3
Josefstädter Straße (shopping)	7588	1183,8	6,4	0,843802	0,861471	0,852273	3
Neubaugasse (shopping)	4743	900	5,27	0,849064	0,862498	0,854745	3
Wiedner Hauptstraße (shopping), 4th district	5844	1410,6	4,14	0,849051	0,864794	0,856923	2
Hütteldorfer Straße (shopping), betw. Schweglerstr. & Kendlerstr.	8024	1549,8	5,18	0,801015	0,804036	0,802526	2
Thaliastraße (shopping), betw. Gürtel & Huttenstr.	10795	2055,9	5,25	0,889158	0,889158	0,889158	1
Reinprechtsdorferstraße (shopping)	7996	1059,3	7,55	0,832124	0,862712	0,847418	2
Lerchenfelder Straße (shopping)	7091	1294,2	5,48	0,853217	0,867109	0,860943	3
Fötzersteig	3464	3021,3	1,15	0,746134	0,830167	0,78815	2
Telefonweg	1572	5730	0,27	0,457437	0,49718	0,474182	4
Atzgersdorfer Straße	3176	2322,6	1,37	0,575824	0,682889	0,616291	7
Grinzinger Straße	3322	1829,1	1,82	0,560642	0,723796	0,63484	6
Mauerbachstraße	807	3445,5	0,23	0,321821	0,418107	0,366873	9
Eipeldauer Straße	4389	1387,5	3,16	0,674588	0,697024	0,685806	2
Krottenbachstraße	7323	3383,7	2,16	0,596175	0,732684	0,661397	5

Figure 50: Data representation

The correlation between actors and the Int RN value of the streets is 0.82065. It is surprisingly high. The value of 1 is the absolute optimum for a correlation as we find in nature a correlation of approximately 0.7; the value of 0 indicates no correlation (Fricker, 2007). Prominent places, ergo shopping streets, carry out a high diversity-density of actors/m.

4.7 Conclusion and Discussion

Read argues as one weakness of space syntax methodology the equal handling of all spaces when it is quite clear that different classes of of physical space in the urban patterns of the city perform at different levels of speed and form (Read, 2007). Read´s argument is correct in the sense that all axial lines are treated equally when using the Axman software as an instrument for urban analysis. Hence, different scales of urban grids with different functions cannot be differenciated with regard to their role within the transportation network in urban systems. What is important is that space syntax doens´t show the differences of scales in urban systems. It is a morphological, topological tool for centrality. It is true that different scales of movement channels aggregate different speeds, and geometry influence the *production of space* (Lefebvre, 1974). Space Syntax does not support this determination. Therefore, in this research, fractal analysis and political planning anlysis is used to bring the factors of scale, speed, geometry, and traffic volume into play. Space Syntax is a morphological analysis based on movement as an passive indicator, but not an analysis with movement as an active indicator.

The focus on the third dimension within modelisation is of more interest. With his question, "How is the third dimension taken into account?", Karimi verbalized a general problem of modelisation (Karimi, 1997). Research refers to the study of urban phenomenology mostly in two dimensions. This condition leads to the question of how the third dimension affects the route choice and orientation of people in urban environments. In other words, how does the third dimension support the intelligibility of the built space? Intelligibility is an attribute for understanding the architectural environment. Furthermore, we have to consider that height is a term of proportion. Proportion is linked to study of one dimension, two dimensions, three dimensions, and four dimensions. Furthermore, this philosophical issue poses more questions than just the question of the impact of height as an factor of intelligibility. The scrutiny of proportion, hence scale, has a long tradition - Pythagoras, Plato, Le Corbusier´s Modulor, Da Vinci´s illustration of Marcus Vitruvius Pollio´s thesis of the human body, Mandelbrot´s fractals, and so on.

As urban modelisation analysis of urban morphology, however, this discussion will focus the impact of the third dimension on movement and leads to two-dimensional modelisation of the built environment. Mavridou´s experiment (Mavridou, 2007) with virtual environments tries to go into this matter. Her result was that virtual environments with different heights were more confusing up to a height limitation of 6m (smale scale world). The same heights made the participants feel that the visual field was wider. In contrast, within large scale environments, different heights had no influence. The reason lies in the fact that the different building heights were not in the close visual field of the participant. Therefore, they were not perceived. Mavridou argues that large scale worlds in her experiment are an exception to the fact that buildings of the same height have a better correlation of integration to pedestrian count (Mavridou, 2007, 10).

This experiment is an important approach for finding a way to take the third dimension and further more general scale and proportion into account. On the basis of Mavridou´s experiment the following heuristic conclusions can be derived:

A. The perception of distance along streets depends on forms (length, width) along the street. Building heights are major indicators for route choice and cognition.
B. Building which are the same height are an ordering principle for cognitive perception, therefore influencing navigation within an urban system.
C. Environments with the same configuration, but different properties are percieved as being different.

It is quite ovious that the third dimension influences the individual choice of actors in urban systems; further, it influences movement, and in turn the adaption of the urban grid. Perception is a major factor for navigation. Also, the cognitive knowledge of the urban system has to be considered. To understand complex urban systems we have to deal with the third dimension. On basis of Mavridou´s experiment we have to agree that the analysis of urban system in two dimensions has its limitations. By omitting the third dimension, modelisation can only resemble reality, but does not actually deal with the real life condition. Therefore, every two-dimensional modelisation is an abstraction of reality.

5. FRACTALS: HIERARCHICAL ORGANISATION BY URBAN METRIC

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

5.1 Introduction

We have already described the social-spatial interaction of urban systems in the previous chapter. The urban dynamic flux is the result of complex socio-economic interaction processes including different, diverse levels of organisation. The formation of urban patterns and networks by dynamic influences is often referred to as amorphous. An in-depth knowledge of an *urban metric* seems crucial to understanding urban patterns and to verifying them with socio-economic dynamic models. Fractal geometry is a very useful and powerful tool for describing urban complex systems and forms.
It represents an inherent hierarchical feature which becomes obvious by the fact that the same type of geometric elements exist in a large range of scales. For example, Hausmann´s intervention in Paris can be explained by fractal scaling. The growth of mediaeval Paris could no longer support the traffic. It became necessary to add a new structure on a larger scale to the street network. Some urban fabric on a lower scale was destroyed in order to acquire space to implement longer and wider streets. This modification to the transport system leads to changes in the whole urban system (Salingaros, 2003).
In general, fractal organisation follows a well-defined, rather simple repartition law, the hyperbolic distribution. This law is well known in economics and urban geography as Pareto-distribution. Christaller´s Central Place Theory tackles the type of rank-size distribution as a type of hierarchy. Dynamic systems linked to urban patterns like transportation networks are also organized in a hierarchical way (Batty, Longley, 1994, Frankhauser 1994, 1997). Fractal methods of measurement, e.g the program *fractalyze*, allow to what kind of extend the real urban fabrics and networks are hierarchical structures and at which scale of organisation changes and ruptures appear. The localisation of ruptures allows the segmentation of zones within the organisation of urban patterns; and a strong and conclusive hierarchy in the context of a cluster distribution refers to a high concentration of mass. Frankhauser stresses, that the fractal parameters characterize the degree of concentration and of non-homogeneity (Frankhauser, 1997, 129).

In summary, fractal analysis combines several aspects in the field of research and investigation of urban systems (Frankhauser, 1998, 220f):

- *A method of spatial analysis.* In particular, it can be used to examine the law of distribution when moving across scales. The reference model is a Pareto distribution which is characteristic of a hierarchical organisation.
- *A geometrical approach.* Geometric structures can be generated which respect a defined law of distribution. This makes it possible to create a model urban pattern with which to illustrate certain types of spatial organisation.
- *An instrument of research.* It is possible to compare empirical structures, even when these appear irregular, with constructed structures that follow the same law of distribution. These constructed patterns can then be used as reference models by town planners and allow the calculation of spatial measures of value for planning purposes. Such a paradigmatic transcription remains difficult to realise at present.

The possibility of studying urban phenomena as settlements and networks across different scales offers the possibility of identifying the thresholds in the spatial layout.
Only a few analyses of urban networks have been carried out up to now. The fractal dimension of several studies on urban networks has been reported by Benguigui (Moskow - Benguigui 1992, 1993), Benguigui and Daoud (Paris - Benguigui, Daoud 1991), Frankhauser (Stuttgart - 1994) and Kim, Marinov et al. (Seoul - Kim, Marinov et al., 2003). The focal points of these analyses were the public transport network. Therefore, in analysis of the Viennese street network, there is an underlying difficulty of comparison with other references as no other research exists at the moment. The correlation of fractal analysis and the functionality of the Viennese network is a totally new aproach in the field of fractal analysis, and therefore interpretation of the results will not follow strict theoretical rules and can raise discussions between researchers.

In the conclusion of this chapter the difficulties of applying the fractal analysis to networks will be discussed. Alternative ideas will be under scrutiny.

5.2 Fractal Geometry

The term *fractal* was derived from the Latin fractus meaning "broken" or "fractured". Fractal geometry is capable of describing the cascade of detail observed in forms of living systems.

Fractals were introduced for the first time by Benoit Mandelbrot in 1977 with regard to the question of the length of the coastline of Britain. Mandelbrot is very often characterized as the "father" of fractal geometry, and yet it is noted that many of the descriptions of fractals go back to famous mathematicians as Georg Cantor (1890), David Hilbert (1891), Waclaw Sierpinski (1916), Gaston Julia (1918), etc. Of course, they played a key role, but they did not see their creations as a concept towards a new geometry of nature. The creations had more been seen as shapes to demonstrate the deviation from the familiar, rather than typifying the normal. With Mandelbrot's book *The fractal geometry of Nature* in 1977 new mathematical interpretation to these shapes was given. Mandelbrot´s achievement was to develop a mathematical, systematic language with words and grammar into which the characters of these shapes could be embedded (Peitgen, Jürgen et al., 2003). In general a fractal can be defined as rugged, self-similar and multi-scale. In other words, a fractal is nowhere smooth; different particles appear in their body structure as a whole and their transformation is iterative, depending on their starting conditions. Any part of a fractal can be repeatedly magnified, with each magnification resembling all or part of the original fractal. On the one hand a fractal is a complex structure, but it is also interwoven with a hierarchical order that can be described and applied by an algorithm. The following is a characterization of the fractal's keywords:

Rugged

The word *rugged* introduces landscapes as the best explanation model to define one of the fractal's characteristics. A rugged area is a very well known term, and links to Mandelbrot´s original question of how long the coast-line of Britain is. To measure a coast-line, or the border of a city there are different scale-opportunities. Depending on the scale of the map used for this scrutiny, the result will be different. The smaller the scale of the map is, the longer the outline of the analysed object will be. The reason is that the more details appear the smaller the scale of a map. The change in length-measurement and the depth of details can be understood as the function of a zoom, that leads to the most increased length that is possible regarding certain circumstances, for example a physical border.

Self-similar

The essential characteristic of fractal geometry is that the same types of geometrical elements are found at an infinite number of scales. Fractal objects do not belong to any particular scale. The presence of the same element across many scales is reflected in the existence of a hierarchical structure within the fractal object, a property of recurrence which is often referred to as self-similarity (Frankhauser, 1998, 208).

To take the example of Mandelbrot we will find that a certain coast line looks like larger parts of the whole. The irregular characteristics of this natural form remain from scale to scale.

Another example is the cauliflower. The clusters of the cauliflower can be decomposed into smaller clusters or parts. Those sections look very similar to the whole or the generation before. In the third or fourth generation the pieces or clusters will be too small for a further subdivision. From a mathematical perspective there is an idealization to the property of self-similarity of fractals: self -similarity can be continued to infinitely many stages. The example of the cauliflower head leads to following consideration: some natural structures do not have this "infinite detail".

Multi-Scale

Multi-Scale is the direct result of the procedure used to construct a theoretical fractal. This procedure is based on repeating the same operation, defined by a generator, on smaller and smaller scales (Frankhauser, 2004, 4). Generating the Sierpinski carpet is a good example of multi-scale. Starting with a square of length L, this initial square is then replaced in the first step by a cross-figure, where every square has 1/3rd of the length of the initial square. This figure consists of five squares. In the next step the same procedure is repeated. The result in the last figure is the Sierpinski carpet, where there are now twenty-five squares with 1/3rd of the length of the cross-figure before. This iteration generates a hierarchical structure, where the emerging clusters get smaller and smaller. The figure becomes more and more complex.

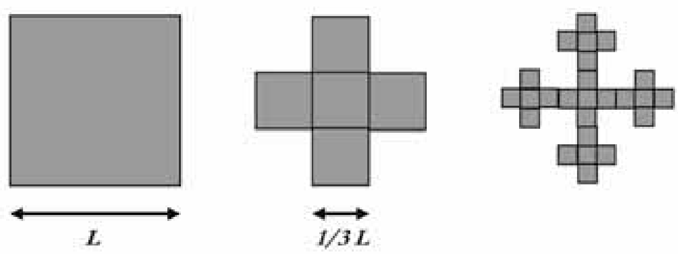


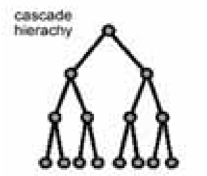
Figure 51: Generating a Sierpinski carpet: In each step each square is replaced by N=5 with the base length multiplied by the factor 1/3rd.

Prototype of Fractals

The Cantor´s Set or Cantor Dust

The Cantor Set was published in 1883 by the German mathematician Georg Cantor (1848-1914). The most common construction is the Cantor ternary set. It is produced by starting with an infinit set of points in a unit interval [0,1]. To visualize this in an easy way a little trick can be used: a single straight line of a certain length replaces the infinit set of points. From the initial line [0,1] the centre open interval [1/3, 2/3] is taken out, meaning that means that the middle third of [0,1] is taken away, but not the numbers 1/3 and 2/3. This process leaves two closed intervals [0, 1/3] and [2/3, 1]. The same procedure is repeated an infinitive number of times. The result is an infinit number of cluster points. The Cantor Set is a feedback process in which a sequence of closed intervals is generated.

$$\sum_{n=0}^{\infty} \frac{2^n}{3^{n+1}} = \frac{1}{3} + \frac{2}{9} + \frac{4}{27} + \frac{8}{81} + \cdots = \frac{1}{3}\left(\frac{1}{1-\frac{2}{3}}\right) = 1.$$



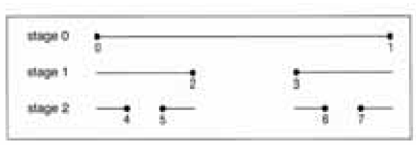


Figure 52: Cantor Set
Figure 53: Visualisation of the hierarchical impact of the generative process
Figure 54: Cantor Set, end points of intervals from stage 0 to stage 2

The Cantor Set demonstrates self-similarity as an important feature of fractals. It can be seen as an exact scaled-down copy of the previous line. It also demonstrates the feature of clustering of points. Natural systems display a clustering in their layout rather than an even or strictly random distribution of figures.

The Sierpinski Gasket and Sierpinski Carpet

This fractal was introduced by the Polish mathematician Waclaw Sierpinski (1882-1969) in 1916. Sierpinski´s most important work was in the field of set theory, point set topology, and number theory. The basic idea of the Sierpinski Carpet has already been introduced as an example of multi-scaling above. For the sake of completeness the geometric construction will be briefly reviewed.

To produce a Sierpinski gasket the iteration process starts with a solid triangle. The midpoint of its three sides is picked. This is now divided into four smaller equilateral triangles using the midpoints of the three sides of the original triangle as the new vertices. In the next step the interior of the middle triangle is removed, not the boundary. This completes the basic construction steps of a Sierpinski gasket. After this there are now three congruent triangles whose sides have exactly half of the new size of the original triangle. The same procedure is continued.

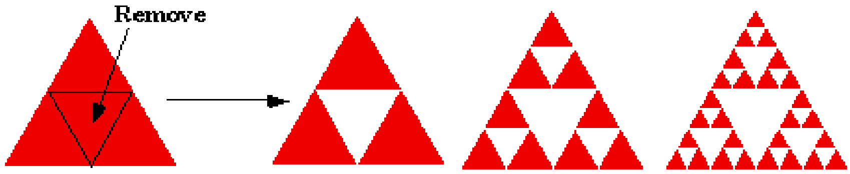
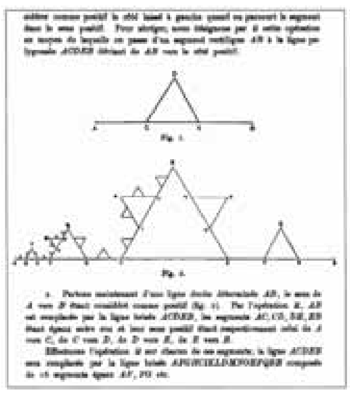


Figure 55: Sierpinski gasket, construction steps

This set also can be obtained by scaling. Three copies of the original triangle are scaled by the factor ½ and then arranged. The Sierpinski gasket also represents the unique invariant set for iteration function systems (IFS). Two of the three copies scaled by the factor ½ are rotated by +120 degrees and -120 degrees.

The Koch Curve (Snowflake Curve)

The Koch curve was introduced by the Swedish mathematician Helge von Koch. His geometric construction was introduced in his paper "Sue une courbe continue san tangente, obenue par une construction géométrique élémentaire" in 1904.



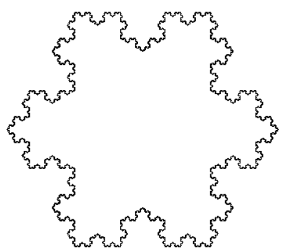
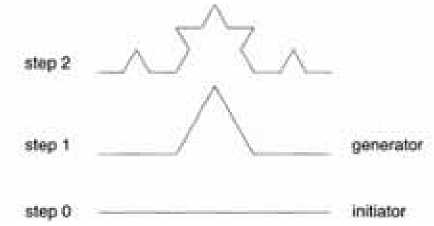


Figure 56: Original construction of Helge von Koch, excerpt, 1906
Figure 57: Snowflake curve, existing of three Koch curves.

The Koch curve contains no straight lines or segments which are smooth, in the sense that it could be seen as a bent line. This curve is a complexity which is seen in, for example, natural coast lines- and snowflakes.

The construction is as follows: the initiator is a straight line. In the next step it is partitioned into three equal parts. The middle third is now going to be replaced by an equilateral triangle with length $1/3^{rd}$ of the initiator. As a further step the base of this triangle has to be taken away. Next, the procedure is repeated with the four new lines. This process can be carried out ad infinitum. The Koch curve has an infinite length, because each time the steps above are performed on each line segment of the figure, there are four times as many line segments. It must be considered that the characteristic of infinite length is true for the "real Koch curve", because in practice the end of generating process is when the longest line segment in the graph is below the resolution of the graphic device.



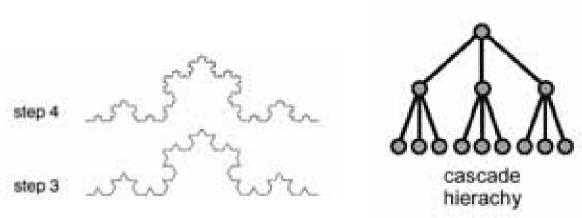


Figure 58: Generating the Koch curve
Figure 59: Koch curve - Hierarchical impact of the generative process

The length of the original Koch curve grows by the factor of 4/3. This can be explained quite briefly. It has to be noted that each construction step is considered as a curve. After the first construction stage, a curve exists made up of four line segments of the same length; in the second iteration there are 4x4, in the third iteration 4x4x4, etc.
If the original line had the length L, then after the first step a line segment has length L x 1/3, after a second step there is then L x $1/3^2$, then L x $1/3^3$, and so on. Since each step produces a curve of line segments, there is no problem in measuring their respective length. After the first step it is 4 x L x 1/3, then 4^2 x L x 1/3, and so on. After the k step, it is L x 4 ^k / 3 ^k . It can be observed that the length of the curve is growing by a factor of 4/3 (Peitgen, Jürgen, and Saupe, 2003).

The Peano Curve

In 1890 the Italian mathematician Giuseppe Peano (1858-1932) proposed a space-filling curve. One year later, in 1891, the German mathematician David Hilbert presented a curve that "fills" a plane and is also self-avoiding.
These curves are elemental to the organisation of living systems like organs or blood distribution through arteries in the human body. An organ must be supplied with essential substrates that will be transported through the vessel system. The vessel system has to reach every point of the three dimensional form of the organ. Space-filling fractals solve the problem of how to organize complex structures of living systems for distribution.

The construction of the Peano curve starts with an initiator, a straight line. In the next step the single line is substituted by a generator curve that has nine lines. The scaled down generator has a scaling factor of 3. The generator is used recursively to replace the straight line segments up to an infinite number of steps. A general rule for the length of the curve it can be derived as follows:

Step 0: initial line with the factor 1

Step 1: 9 x 1/3 = 3

Step 2: 9 x 9 x $1/3^2$ = 9

Step k: 3^k

or: Ln = (L x (9/3) ^n = (L x (9/3)^n)

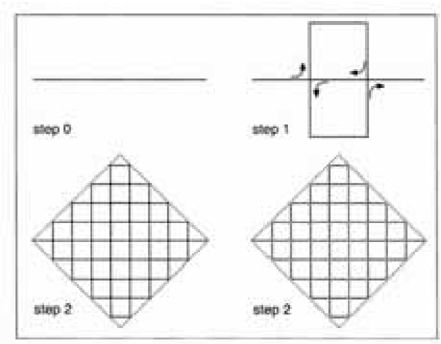


Figure 60: Peano curve, construction

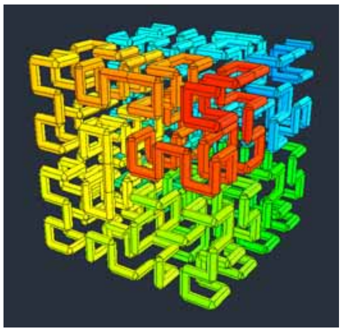
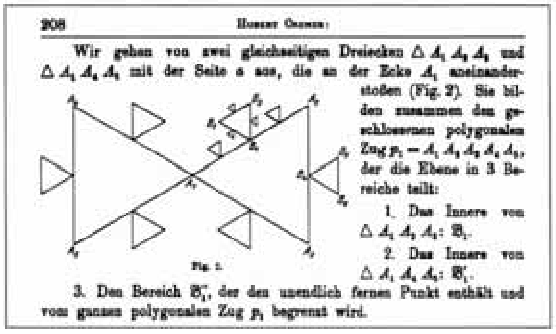


Figure 61: 3-dimensional Hilbert curve

Within the Peano curve two interesting facts appear: first, the curve offers an interesting view of how self-similarity can be represented, because even though each construction step is self-similar to the previous one, the whole curve is like a “filled” out square. This square does not look self-similar to the construction steps in detail. And yet, the Peano curve is a perfect example of self-similarity. The problem lies in its graphical representation and how to see the final object as a curve. Second, it offers a paradox. After infinite steps of iteration the Peano curve is a one-dimensional line and at the same time a two-dimensional unit, represented as a plane.

The Julia Set

Gaston Julia (1893-1973) was one of the pathfinders of modern dynamical systems theory. He was a world famous mathematician in the 1920´s. Julian published his ideas in 199-pages masterpiece in the Journal de Mathematic, *Mémoire sur líteration des functions rationelles*, in 1918. At that time he was only 25. The German mathematician Hubert Cremer visualised the Julia Set in 1925. It was nearly forgotten until Benoit Mandelbrot brought it back to light when generating images with the aid of computers.



208 Hubert Cremer:

Wir gehen von zwei gleichseitigen Dreiecken $\triangle A_1 A_2 A_3$ und $\triangle A_1 A_4 A_5$ mit der Seite a aus, die an der Ecke A_1 aneinanderstoßen (Fig. 2). Sie bilden zusammen den geschlossenen polygonalen Zug $p_1 = A_1 A_2 A_3 A_4 A_5$, der die Ebene in 3 Bereiche teilt:

1. Das Innere von $\triangle A_1 A_2 A_3$: $\mathfrak{B}_1$.

2. Das Innere von $\triangle A_1 A_4 A_5$: $\mathfrak{B}_1'$.

3. Den Bereich $\mathfrak{B}_1''$, der den unendlich fernen Punkt enthält und vom ganzen polygonalen Zug p_1 begrenzt wird.

Fig. 2.

Figure 62: Hubert Cremer´s visualisation of the Julia Set in 1925.

The Julia set belongs to chaotic, non-linear fractals. It is linked with chaos theory. Chaos theory describes the behaviour of non-linear dynamical systems that are sensitive to initial conditions. As a result of this sensitivity, the behaviour of chaotic systems appears to be random, because of an exponential growth of errors in the initial conditions (Wikipedia, 2007). A well known example is the weather forecast. Precise prognoses for a longer term are impossible. In the complex, dynamical system of "climate" the least details of the initial conditions can lead to enormous variations within a period.

The Julia set is a numerical set of numbers. They are crucial for the understanding of the iterations of polynomials like x^2+c. To explain the iteration of a Julia set let us assume x^2+c as an example. In the iteration c is constant and a value is chosen for x and obtain $x^2 + c$. In the next step this value is substituted for x and evaluates $x^2 + c$ again. When the process is repeated following term is derived:

$$x \rightarrow x^2+c \rightarrow (x^2+c)^2 + c \rightarrow (((x^2+c)^2 + c)^2 + c)^2 \rightarrow \ldots$$

It has to be noted that the Mandelbrot fractal uses the same formula as the Julia set. The difference is that the x is mostly fixed at the zero point and c is chosen differently.

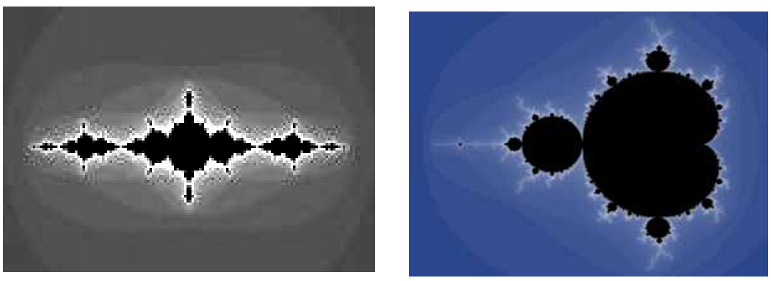


Figure 63: left - Julia Set; right - Mandelbrot Set

5.3 Branched Structures - Fractals and Urban Networks

Branched structures exist in biological systems, the vascular system of the human body, and also in networks like transportation routes and urban agglomeration. Fractal geometry is linked to their hierarchical configuration.

In a distribution system sub-structures take over superior functions. The next subordinated hierarchical order performs again a superior function for the next subordinated order and so on. From the point of view of the highest organisation the system ramifies farther and farther downwards; as, being seen from the view of the smallest element the hierarchical system bundles more and more to the top. A characteristic parameter is that the structures have the same systematic in all hierarchical levels. Batty and Longley argue that urban space can be seen as both a hierarchy and a network which in fact represents different sides of the same coin. Hierarchy might be considered an inverted tree, and the network the same tree in plane form. Such hierarchies provide models of trees. Hierarchies are very helpful in describing and measuring the importance of functions across many scales, from local to global and vice versa (Batty and Longley, 1994, 45f).

In the analysis of such systems, the fractal dimension [D] is a dimension for the non-homogeneous distribution of the individual elements in space (3D) or on a plane (2D).

The self-similarity dimension [D] expresses the degree of roughness, which means how much texture an object has (Bovill, 1996). The fractal dimension measures "how many points" lie in a given set; also how "complicated" a self-similar figure is (for further explanation see chapter 6.4). Within distribution and network systems the fractal dimension represents a dimension for the coverage of the whole area. Also, it is possible to compare different systems of different research fields, e.g. street networks and biological transport systems. As an example of a biological transport system in the human body, we have already introduced the Peano curve.

Within the distribution of individual elements on a plane, iterative mapping rules can be used to generate hierarchical branched fractals of non-self-similarity. This is especially effective for self-affine fractals. With such fractals the initiator is not mapped as self-similar any more, but disorted by an affine mapping. This means for plane structures that in the direction of the x-axis a different reduction factor is used than for the direction of the y-axis. For example, a square transforms into a rectangle.

The H-tree is, according to Batty and Longley (Batty, Longley, 1994), the best example of a tree, filling the plane. Through the different angles of its branches, more or less realistic structures can be produced. In addition, Hilbersheimer takles also with this idea for urban planning (Hilberseimer, 1927, 1937).

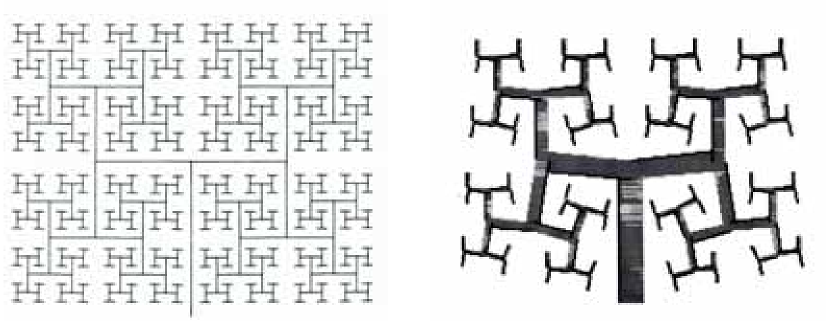


Figure 64: left - self avoiding H-tree with branches angles at 90degree; right - self avoiding H-tree with a slight decrease in the branches; angles down to 80 degrees. Also both contraction ratios shift slightly. Nevertheless, it remains strictily self-similar.

This classic space-filling curve is representative of traffic systems in residential areas. The analogy is that it is possible to visit every branch of this fractal without crossing another branch. This model was adopted to separate pedestrian movement from vehicular traffic. It is linked to the local scale of an urban settlement.

The human lung is also a fractal tree. It is the best example of how trees can grow in a constrained space. The growth of a lung as a tree structure basis initially based on an ellipse which expands into two increasing fractal dimensions. Woldenberg and Bennett et al. have made analogies between the human lungs, cities, architecture, etc. (Woldenberg, 1968, 2007; Bennett et al., 2007).

Next, we look at an example to illustrate the idea of individual and public transportation networks on a global scale. We have to consider that transportation networks consists of open and self-constraint structures. Self-constraint structures are linked to street networks where as open structures are attached to public transport systems, like supra regional train networks. They are mostly radially branched. This is the consequence of the request of high and efficient connectivity between an urban centre and its hinterland. Many transport systems include the characteristics of minimal path systems. To connect the different destinations they combine the elements of polygonal lines for high connectivity and branches to connect destinations far away from each other, including coequal a bundling of the network towards an urban centre.

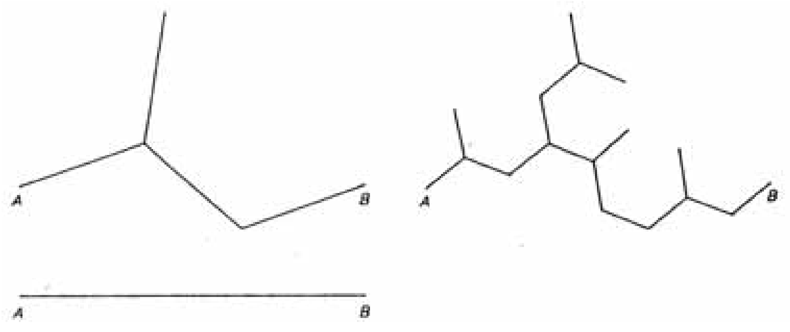


Figure 65: The fractal combines both structural characteristics of polygonal lines and branches. The reduction factor is chosen in combination with the arrangement of the individual elements (above left) so as to produce a hexagonal basic structure.

Finally, stochastic fractals, also representative of the organisation of settlements are chosen as an example for branched structures. According to Frankhauser (Frankhauser, 1992) these structures can also be noticed with regard to settlements. This principle rests on the system of minimal effort that should be carried out for connection to an existing transport system. In this research the development of Vienna along major routes - supra regional roads and boulevards - has already been mentioned. This historic development is analog to principle of dentristic structures. Still, with cities we have to consider the aspect of surface area.

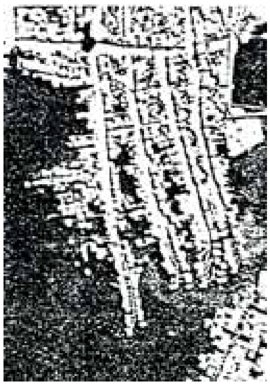


Figure 66: left - approach to dendritic structures in settlements, Alagados, Brasil;
right - dendritic structures in detail, boat settlement, Alagados, Brasil.

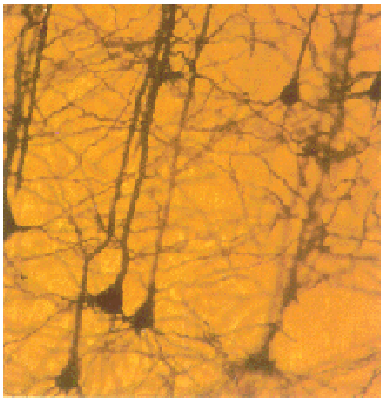


Figure 67: Dendritic structure of brain cells

5.4 Analysis Methodology and Formalization

In general we think in traditional Euclidean geometry. Complex systems, such as fractals, will not reflect the whole real world object when we describe it with Euclidean geometry. Benoit Mandelbrot pointed out that nature exhibits not simply a higher degree but an altogether different level of complexity; the number of distinct scales of length of natural patterns is for all practical purposes infinitely (Mandelbrot, 1982). Hence, a fractal curve exists of infinite elements which are infinit small and not tangible. This is the reason why length increases to infinite at an infinite small scale. Therefore, the description of a point on a fractal curve by co-ordinates is simply impossible. Even-, if we think that we can define a point of the curve from some distance, by zooming in detail, we will experience that we didn't catch the point of the curve where we expected it or to reach a certain point.

A new measure for fractal geometry, the fractal dimension [D] has been introduced. Bovill argues that the fractal dimension is the expression of degree of roughness, which means how much texture an object has (Bovill, 1996). In other words, the fractal dimension measures "how many points" lie in a given set; also, how "complicated" a self-similar figure is.

To understand how the fractal dimension is put together it is necessary to first have a look at lines, planes and cubes. A line has the dimension 1, a plane the dimension 2 and a cube the dimension 3. Why is a line one-dimensional, a plane two-dimensional and a cube three-dimensional? All three objects are self-similar. A line can be broken into e.g. three self-similar pieces, each with the same length, and each of which can be magnified by the factor 3 to yield the original segment. In general, we can break a line into N self-similar pieces, each with the magnification factor N. A square is broken into N^2 self-similar copies of itself; each of which must be magnified by the factor N to yield the original figure. Finally, a cube can be decomposed into N^3 self-similar pieces, of which each has a magnification factor of N. The dimension is simply the exponent of the number of self-similar pieces with magnification factor N into which the figure is broken.

The identification of length leads to the following assumption in the context of a plane:

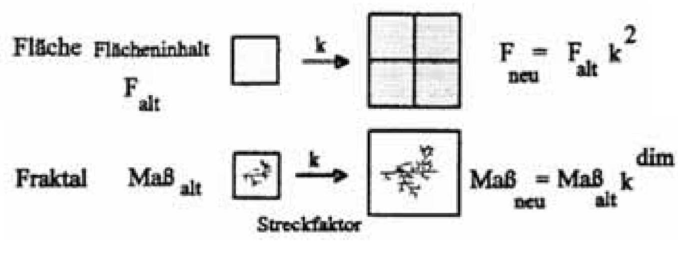


Figure 68: The fractal idea can also be explained by way of multiplication with a "stretch factor".

The characteristic of fractals is that within stretching or decomposing they do not perform like lines, planes or cubes. Therefore, the dimension can be any fractional number. Not only-, fractals require an extension of the concept of dimension; they also require different dimensional approaches.

Self-Similarity Dimension D

The self-similarity dimension D proceeds from the fact that there is a relationship between the scaling factor and the number of copies into which the original construction is divided or stretched after iteration. If we stretch a square (N1) with one iteration step we will get four pieces (N2); see figure 69. The fractal dimension results from the following equation and with this equation the dimension can be measured on two different scales:

$N2 = N1 \times k^D$

$\mathbf{D = \log (N2/N1) / \log k}$

$D = \log (4 \times 1)/\log 2 = 2$

N2… number of pieces second scale

N 1 … number of pieces first scale

k… stretching factor

D… fractal dimension

If a square is divided into four smaller pieces, the reduction will be ½. The stretching factor is equal to 1/r, where as r is the reduction factor. The following equation can be used for the fractal dimension:

$N = 1/ (r^D)$

$\mathbf{D = \log N / \log (1/r)}$

$D = \log 4/ \log (1/ \tfrac{1}{2}) = \log 4 / \log 2 = 2$

N…number of pieces

r … reduction factor

The above example has shown the fractal dimension of a plane as being 2. The next example will show the fractal dimension of the Sierpinski carpet.

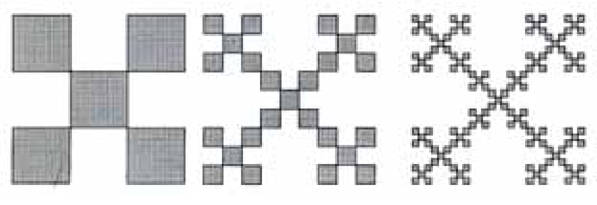


Figure 69: Sierpinski carpet

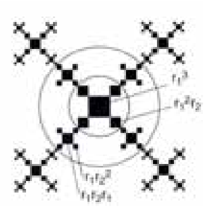


Figure 70: Multifractal

As it is seen in figure 70 N is 5 and the initial length has increased by the factor r = 1/3 after the first iteration step. $D = \log 5 / \log 3 = 1.47$. The result of the fractal dimension equation reflects that during the iteration the length of the perimeter increases disproportionately compared with a normal geometrical object, as seen in the example of the square before. These fractals were generated by just a single factor of reduction. Their structures are mono-fractals or homogeneous fractals. More complicated hierarchies appear, if the initial figure is generated through more than one reduction factor. These fractals follow a multi-fractal logic. Multiplicative cascades of random processes generate multi-fractal structures as in general additive processes generate simple fractals – mono-fractals. The multi-fractal dimension can be explicitly calculated. Figure 71 shows that elements of the same size are found in differently placed clusters. Multi-fractal logic links to the organisation of cities. Empirical analysis has shown that urban systems follow a multi-fractal logic. Different element sizes of sub-clusters appear in different places within an urban system. They can be located centrally or peripherally. In general, the fractal dimension is a global measure. With multi-fractals it can be a measure that varies from global to local.

Mono-fractals will have the same fractal dimension value in every point. For multi-fractals it is possible to identify all places where the exponent has the same value. Frankhauser points out that within the calculation of the Lipschitz-Hölder exponent a multi-fractal can be broken down into sub-centres where each has its own fractal dimension. Ergo, a whole spectrum of dimensions is obtained (Frankhauser, 1998).

α ^ (L,H) = log $\mu(\varepsilon)$/ log ε ε … interval
μ… mass

The equation shows a that each point is surrounded by an intervall. This also can be defined as a counting window ε. This intervall is linked with the mass $\mu(\varepsilon)$ within it. So, the Lipschitz-Hölder exponent can give information about the local behaviour of multi-fractals and also detect clusters of the same and different sizes. This evaluation offers an intrinsic view of the hierarchical organisation of urban systems.

Fractional Value Dimension and its Appliance to Analysis Theory

Because the fractality of empirical structures follows an irregular and inordinate morphology, different methods of measurement have been elaborated to apply the fractal idea to urban systems. Before the analytical methods are explained it is necessary to understand how the fractal idea is applied to the analysis of cities.

The fractal dimension of the Sierpinski carpet has already been explained. In figure 70 the initial figure had N=5 and the initial length was increased by the factor r=1/3 after the first iteration step. If we repeat this operation we get $N2 = N^2 = 25$ squares of length $l2 = r^2 \times L = 1/9 L$. If we assume this iteration procedure is continued to step n, the number of grey squares (see figure 70) will be $Nn = N\hat{}n$ of length $ln = r\hat{}n \times L$. With every iteration step the hierarchical distribution of free spaces produces clusters as seen in figure 70. Hence, the total surface of grey squares can be calculated through the equation:

$an = r \hat{} n \times L^2$	an… surface of each square
$A_n = N_n \times l^2_n$	An …surface of all squares
	L … length of the initial square

A curve can be produced showing at each step the border of the Sierpinski carpet. The total length increases at each step towards infinity. The fractal´s dimension incompatibility with Euclidean geometry has already been explained; therefore the measure theory has introduced a new measure - the fractional value dimension. We define a general measure *L* that is constant during the iteration.

L = const = Nn x (ln) ^D

For spatial analysis a new variable size ε is introduced and is an analogy to the length ln of constructed elements in a constructed fractal. Each value ε determines the number of elements N(ε) to cover the structure:

L = Nn x (ln) ^D

const = N(ε) x (ε) ^D

log N(ε) = log const – D log ε … bi-logarithmic representation of the function N(ε)

This curve is a line whose slope value corresponds to the fractal dimension. The following analysis methods carry forward this logic into concrete algorithms with which the fractal behaviour of urban structures and networks can be described. These analysis methods are: correlation analysis, radial analysis, and accessibility analysis (Batty, Longley, 1994; Frankhauser 1994; Frankhauser 1998).

Practical Application of the Analysis

To measure the fractality of urban agglomeration the software ***Fractalyze*** was developed for the Ministry of Public Works at ThéMA, Centre Naional de la Recherche Scientifique, Universite´ de Franche-Comte, Besancon, France. Fractalyze processes different analysis methods, but still the application rules are the same:

- The area or network of interest has to be transformed into a scaled raster image. This image contains two types of pixels: the network is represented by black pixels (occupied space) and the non-network surfaces are represented by white pixels (free space).
- The analysis follows the logic of iteration. At each iteration step the number of black pixels is contained within a "counting window". With every iteration step the counting window increases. The enlargement of the window changes the level of the analysed image artificially. Every analysis step consists of two elements varying according to the iteration step (i) of the window: number of counted elements (N) is represented by the black pixels of the image and the size of each window refers to the counted elements (ε); ε was already described as a variable size.
- An obtained series of points can be now represented on a Cartesian graph. The x-axis corresponds to the increasing size of the "counting window" or ε, where as the y-axis reflects the number of counted elements. Hence, we get an empirical curve. In the next step of the analysis the empirical curve is adjusted to an estimated curve. So, if the empirical curve follows a fractal law, the estimated curve has the form of a power law.

$N = \varepsilon$ ^D … fractal law

A non-linear regression is adapted to the power law which best fits the obtained empirical curve. It can be only an approximation to the fractal law, because an image is not a pure fractal - it is a discrete and finite function, but not a continuous one. For this reason, a generalisation of the fractal law is estimated and not the fractal law itself. There are several possibilities:

$N = \varepsilon$ ^ $D + c$	a… pre-factor of shape
$N = a\,\varepsilon$ ^D	c… parameter, which allows the deviation of the curve
$N = a\,\varepsilon$ ^ $D + c$	

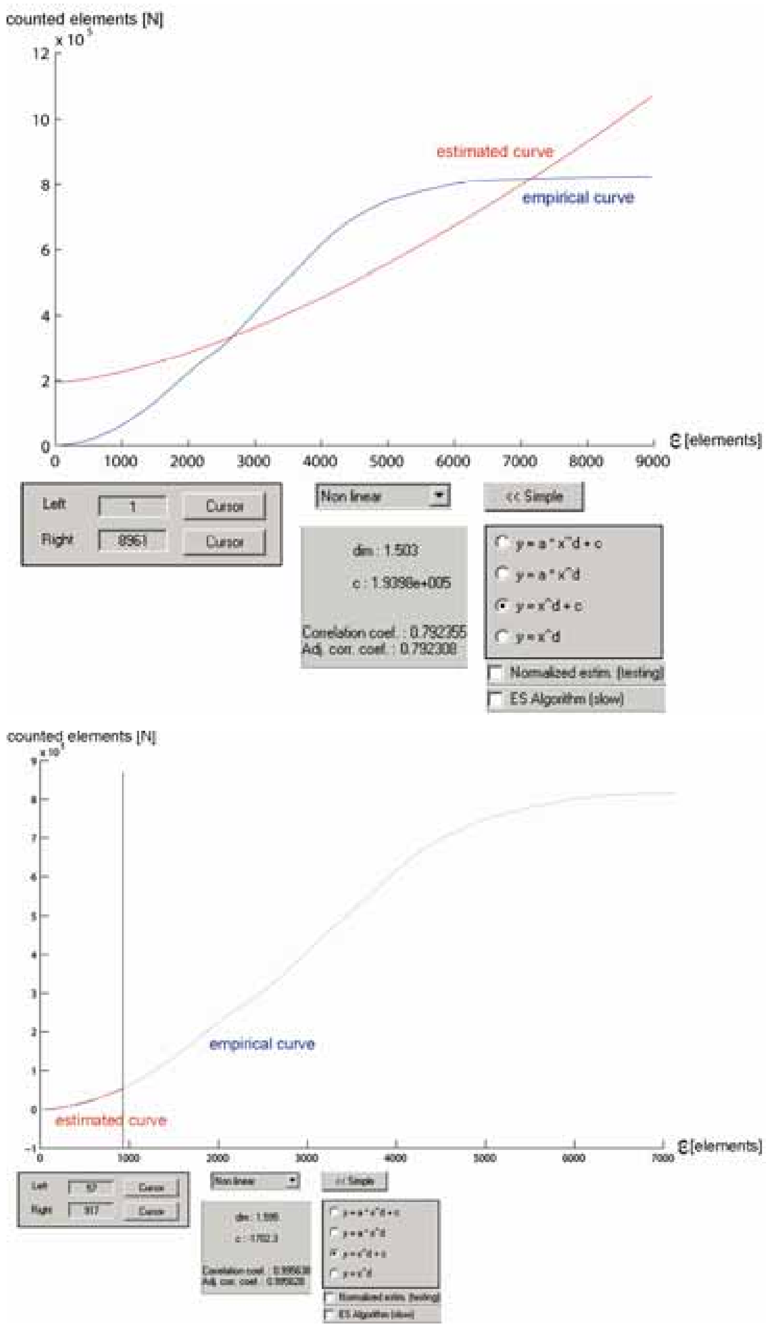


Figure 71: above - the diagramm shows the whole empirical and estimated curve for the analysis of Vienna starting from the historic centre; below - best fit between empirical and estimated curve for a distance up to 5 km.

If the fit between the empirical and the estimated curve completely diverges, two possible conclusions can be drawn: either the pattern or network under scrutiny is not of a fractal nature or it is of a multi-fractal nature. We have already linked the idea of multi-fractals to urban systems.

Hence, the empirical curve has to be divided into several parts corresponding to different estimated curves underlying the same fractal law. The estimated curve is calculated by minimizing the quadratic variances and a correlation dimension between the original curve and estimated curve.

- Next, we will have a look at the different values linked to the pure fractal law. The value D is the fractal dimension as described in the previous chapter. According to Tannier the parameter c corresponds to the point of origin on the y-axis and its absolute value may be very high. The parameter a is called the "pre-factor of shape". It gives a synthetic indication of the local deviations from the estimated fractal law. In the case of a mathematical fractal structure a should be equal to 1. In some cases a is equal to 0.5 or 3. If its value goes over 10 or below 0.1 the fractality of the structure under study is not confirmed (Tannier, Pumain, 2005, 12f).

As the fractal analysis is an example of on-going research, values including their interpretations underlie a scientific process. The estimations of fractal dimensions may obtain a great variety according to the chosen analysis method. The results of the analysis of the whole Viennese network will establish new methods of interpretation.

The Correlation Method

Each pixel of the rasterized image is surrounded by a small counting window ε. With every iteration step every window is enlarged. The number of occupied points in every window for every iteration step are enumerated. The mean number of points, ergo pixels, per-window of given size is calculated. Hence, the x-axis in the graph represents the size of the counting window ε; the y-axis represents the mean number of occupied points per window.

The Accessibility Method

First, a "centre point" is chosen. It refers for example to a specific location with high spending capacity or pedestrian movement in shopping streets. Using this counting centre results in the law of distribution of the occupied points around this chosen location. The centre point defines the starting point of the analysis. This starting point is surrounded by a small counting window. It enlarges with every iteration step in the way that the borders of the counting window are defined on the network. Therefore, the accessibility method is also an analysis to measure how tortured or winding a network is. The accessibility method incorporates the funtional aspect of an urban system. The y-axis represents the counting window and the x-axis represents the number of occupied elements.

The Radius Mass Method

For this method a centre point is chosen first. This starting point is surrrounded by a small counting window that enlarges with every iteration step continously. The difference with respect to the accessibility analysis is that the counting window enlarges independent of the occupied points of the image. As the shape of a pixel is rectangular, the counting window is also rectangular. This analysis method has a spatial aspect; the "mass" of the occupied points for the given size of a counting window is crucial. This accessibility method has a funtional aspect of an urban system. The y-axis represents the counting window. The x-axis represents the number of occupied elements.

The division of the empirical cuve into several parts for the best fit between estimated and empirical curve determine different correlation coefficients for the diverse analysis methods.

analysis method	**correlation coefficient**
correlation	≥ 0,99999
radius mass	≥ 0,97
accessibility	≥ 0,97

Figure 71A: Best fit - correlation coefficient

The Scaling Behaviour Curve α

This method is useful for identifying so called spatial ruptures, measured changes, in the spatial organisation of urban built-on structures and net-works. In the analysis of the Viennese network we focus on this mode for the visualisation of the spatial layout. The scaling behaviour curve does not correspond directly to the fractal dimension but is subject to different types of perturbations. In the scaling behaviour curve three different terms influence the slope value.

- Perturbations appear on the curve of scaling behaviour as fluctuations around a constant mean value.
- Both the change in the fractal dimension D and authentic ruptures in the scaling behaviour are measured. They appear as changes in the mean behaviour of the curve α.
- The fractal dimension D itself. If we assume that D varies with distance, we prefer to speak of the local value of dimension D (Frankhauser, 1998, 220).

The appearance of fluctuations due to structural changes, especially empty spaces, can be isolated and smoothed. Frankhauser argues that Gaussian smoothing has been found to be effective tool for eliminating the fluctuations in a gradual and well controlled manner (Frankauser, 2007).

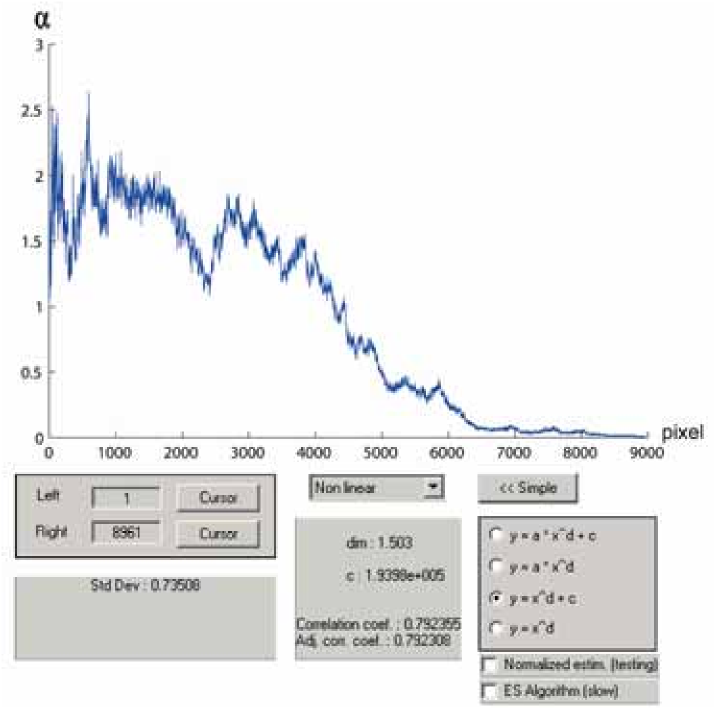


Figure 71B: Scaling bahviour curve, centre point: historic centre, Vienna 2006.

5.5 Empirical Analysis

Global Measure: Correlation Analysis - Main Street Network

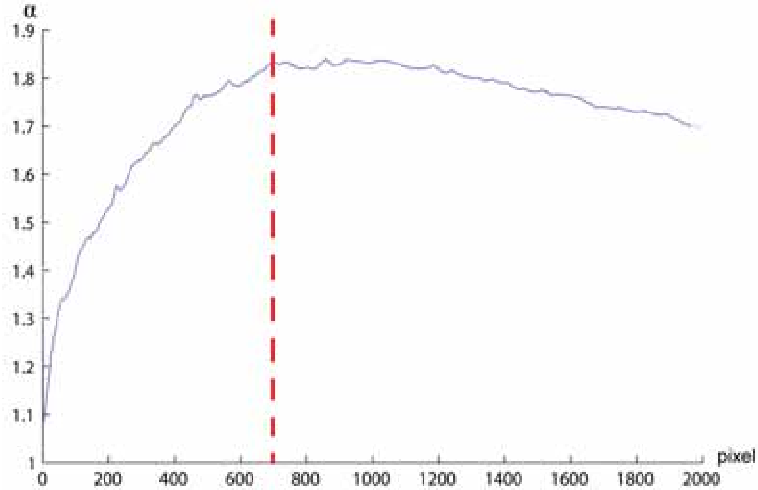


Figure 72: Scaling behaviour curve, correlation analysis, main street network; D= 1.417. At the distance of 700 pixels (2.8 km) the linear structure appears to be more of a plane structure.

Figure 73: In the map the change over from a linear to a more plane structure is marked by the red square. It refers to the distance of 2.8 km.

The correlation analysis of the main street network shows that the structure changes within the distance of 2.8km. Over the distance of 2.8km the net manifests itself as a network (plane structure). For distances greater than approximately 3 km the structure is more regular. The size of 3 km is the size of a larger quarter in an urban system. The scaling behaviour curve declines at the end for large distances, because of the vacancies in the system. The fractal dimension of 1.4 correlates to a system that is not uniform and homogeneous; vacancies exist on different scales.

Correlation Analysis - Whole Street Network

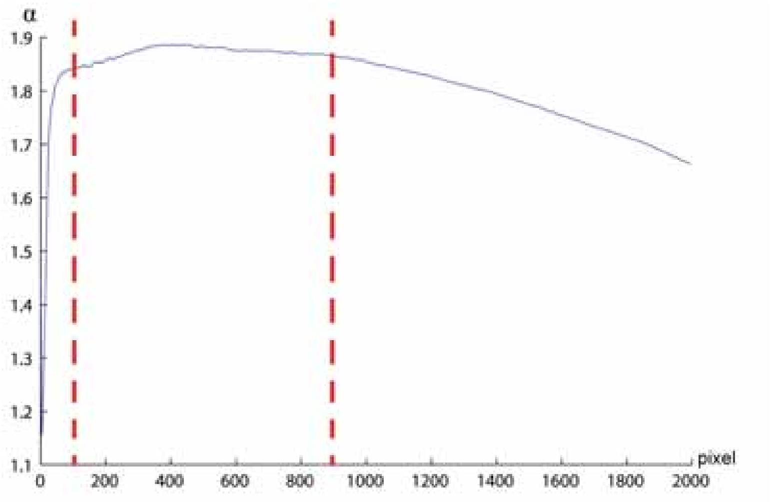


Figure 74: Scaling behaviour curve, correlation analysis, whole street network; D = 1.626;

Figure 75: The two red squares refer to the two different modes that can be seen in the scaling behaviour curve. The smaller square indicates 100 pixels (500 meters) where as the big square marks 900 pixels (4.5 km).

Within the whole network the linear structure changes into a plane structure at the distance of 500m; that is the distance where the network already appears as a network. At the distance of 4.5km the curve decreases, because of the appearance of vacancies of different sizes, e.g. parks, public spaces, castles, etc. The structure is less uniform. Still, we can see that the Viennese Network is quite homogeneous at a distance scale between 500 m and 4.5km. The fractal dimension D = 1.626.

Local Measure: Accessibility Analysis & Radial Analysis

For these analysis methods different centre points in the city were chosen by different indicators. The indicators consist of historic context, street pattern and functionality. In addition, the space syntax analysis had an influence on the choice of centre point 1, 2, 3, and 5. Every center point is analysed using the accessibility analysis as well as the radial analysis. The centerpoints are:

Point 1: historic centre (street intersection: Kärntnerstrasse/ Graben)
Point 2: shopping area (Reumannplatz/ metro station U1)
Point 3: shopping area (street intersection: Mariahilfer Strasse/ Neubaugasse)
Point 4: historical wine district (street intersection: Grinzinger Allee/ Daringergasse)
Point 5: Vienna International Centre (United Nations Agencies: street intersection: Leonard Bernsteinstraße / Lassallestraße)

Figure 76: Centre points for accessibility analysis and radius mass analysis

Centerpoint 1: Historic Centre - Accessibility Analysis

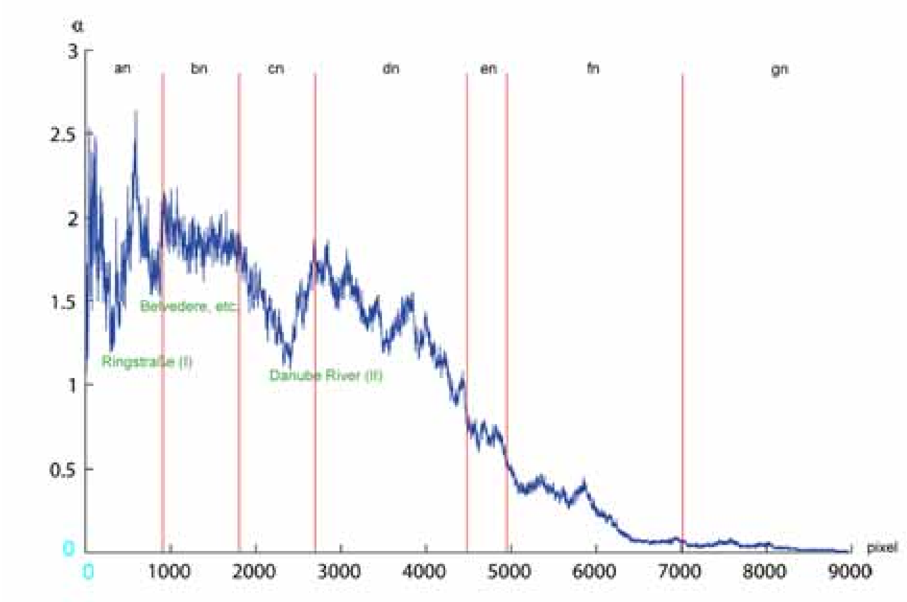


Figure 77: Scaling behaviour curve of the accessibility analysis, centre point 1. It is cut into the parts an-gn for a better understanding of the different fractal behaviours of urban street patterns.

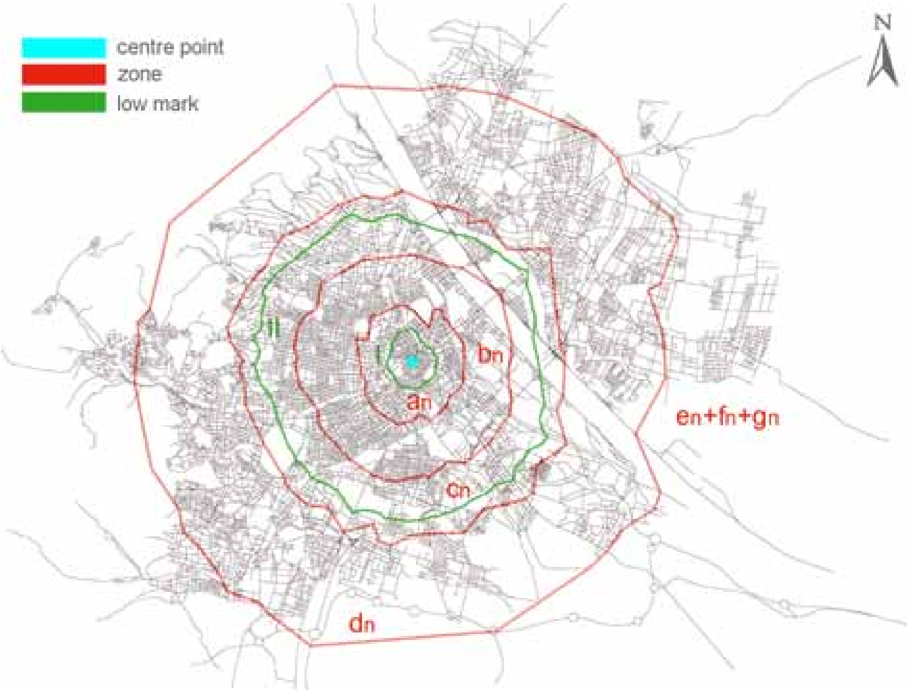


Figure 78: Zones an-gn of the scaling behaviour curve in its spatial context for centre point 1, historic centre, 1010 Vienna

For the first centre point the historic centre, close to St. Stephen's cathedral was chosen. It is an administrative centre as well as a shopping and tourist area. Within the analysis the zones en, fn, and gn are combined, because in their spatial behaviour there is no essential information. These zones are interesting from the perspective of their fractal dimension for understanding the systematic of accessibility for the whole urban system. The fractal dimensions are as follows:

centre point 1 - zones	distance (km)	D accessibility analysis
curve total	45.0	1.50
zone an	0.0-5.0	1.6
zone bn	5.0-8.5	1.63
zone cn	8.5-14.5	1.60
zone dn	14.5-22.5	1.59
zone en	22.5-24.5	1.51
zone fn	24.5-45.0	1.41
zone gn	35.0-45.0	1.18

Figure 79: Accessibility Analysis for centre point 1, historic centre

The fractal dimensions show that the accessibility decreases as distance increases. A tolerance level of between 1.63 - 1.18 is quite low for a network; the system is highly fractal. The more fractal a system is the more urban planning intervention in a highly flexible mode can be carried out, because vacancies are allocated on a variety of different scales.

We can understand the accessibility analysis also as a "detour" or "loop way" measure, because its definition of the iteration steps is directly linked to the network, where as the radial mass analysis defines squares as counting windows. The absence of interconnectedness causes longer routes to a specific place in the urban system. Hence, the accessibility analysis defines also how "tortured" a net work is.

The scaling behaviour curve already shows the spatial thresholds in the Viennese system. In *zone an* (0-5.00km) the first low mark (1.25km) appears at the Ring. This can be explained in its historical context. The Viennese Ringstraße around the Inner City has a length of 5.2km (including Franz-Josephs Kai along the Danube Canal). It represents the former city wall that was built in the 13th century. During the first Turkish siege in 1529 it was extended to a Bastion including a glacis-stripe. No vegetation or buildings were allowed on the glacis. In 1850 the Viennese outskirts (districts II – IX) were suburbanized, and the bastion including the glacis became an urban barrier. Under the emperor Franz Joseph I the glacis was vegetated and the Viennese used it as a recreation location. In 1857 the city wall, city gates and the glacis were broken down and the whole area became a boulevard with monumental buildings and parks. Nowadays the Ringstraße contains the parliament, city hall, state theatre, etc. and big public spaces and parks. As Klaus Humpert points out, within the growth of urban systems the new suburbia has to be connected with the old urban nucleus – hence, a new network appears (Humpert, 1997). Given the historical view we can now derive the large scale of urban intervention, which leads to a less connected network that occupies vacancies on large scale.

The next low mark (3.00km) within *zone an* represents the areas of Belvedere, the Viennese general hospital (altes AKH), the beginning of the Augarten, and of the Prater as main vacancies. In the south there is the Belvedere, the former summer castle of Prince Eugen of Savoyen in the Viennese 3rd district. It is surrounded by a baroque park. In the North-West there is the "old" Viennese hospital. It was partly finished in 1697 and accommodated 1042 persons at that time. It was finally completed in 1834 and organized as a town within a town. Nowadays it is a university campus. In the north we find the beginning of the Augarten, a public park with the oldest baroque garden of Vienna in the 2nd district of Vienna, a former hunting ground in 17th century. Finally, in the east of *zone a* the Prater, also a former hunting ground and meadow, the name of which goes back to the 12th century.

Within *zone bn* (5.00-8.50km) the scaling behaviour curve decreases steadily. First, the distance from the centre point increases, and secondly, the vacancies are more spread and the network has a tendency towards less density. Vacancies are established by the beginning of the industrial zone, and train station areas in the south, west and north. In addition, the beginning of the wine area in the north results in a less dense street network; and parts of the Danube River can be recognized in the slope of the curve.

Zone cn (8.50-14.50km) includes several aspects: distance to the centre point, partial periphery, less dense grid, huge vacancies, industrial zone, Danube River, Danube Island between the Danube River and New Danube, part of Transdanubia. The biggest influence on the low mark is apparently made by the Danube River and the New Danube River (east), the area of the Prater, the recreation area of Oberlaa and Wienerberg (in the southern part of the 10th district) in the south and the former summer palace, Schloß Schönbrunn, in the south-west of Vienna (13th district).

Zone dn (14.50-22.50km) can be described as a peripherial and industrial zone. The curve is constantly decreasing with one major low mark that can be identified as the industrial zone and Danube River. The street network steadily decreases in connectivity.

Zone en, fn, and gn (22.50-45.00km) represent the remaining edges of the periphery and highway transport connections.

From the perspective of accessibility, the historical supra regional routes increase the accessibility and the peaks appear at the edge of the different zone circles. Hence, long straight routes increase accessibility over distances within the network whereas a highly connected network in a particular quarter supports "steadiness" of the accessibility, where more choices are possible. Still, this has to be considered as a local view of the whole street network. From a global view, see figure 78, the circles are very radial, concentric or mono-centric, and this links to the historical development of Vienna. Within zone d we see that the circle shifts in the west as this area - as seen in the plan – contains huge vacancies before net work clusters appear again. Accessibility increases. In general, the shapes of the circles refer to a theoretical urban model of mono-central towns and cities.

Centerpoint 1: Historic Centre - Radius Mass Analysis

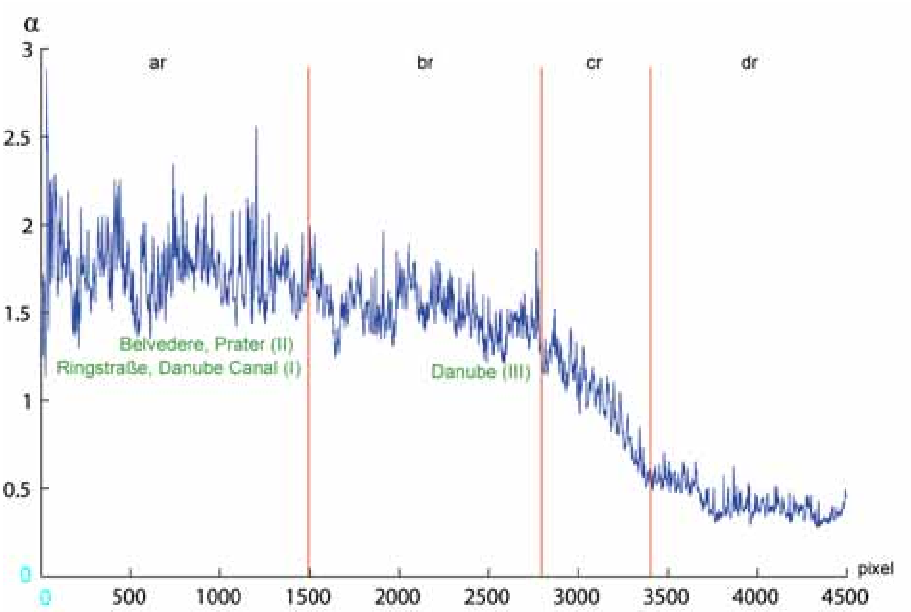


Figure 80: Scaling behaviour of the Radius Mass Analysis, centre point 1. The scaling behaviour curve is cut into parts ar-dr for a better understanding of the different fractal behaviours of urban street patterns.

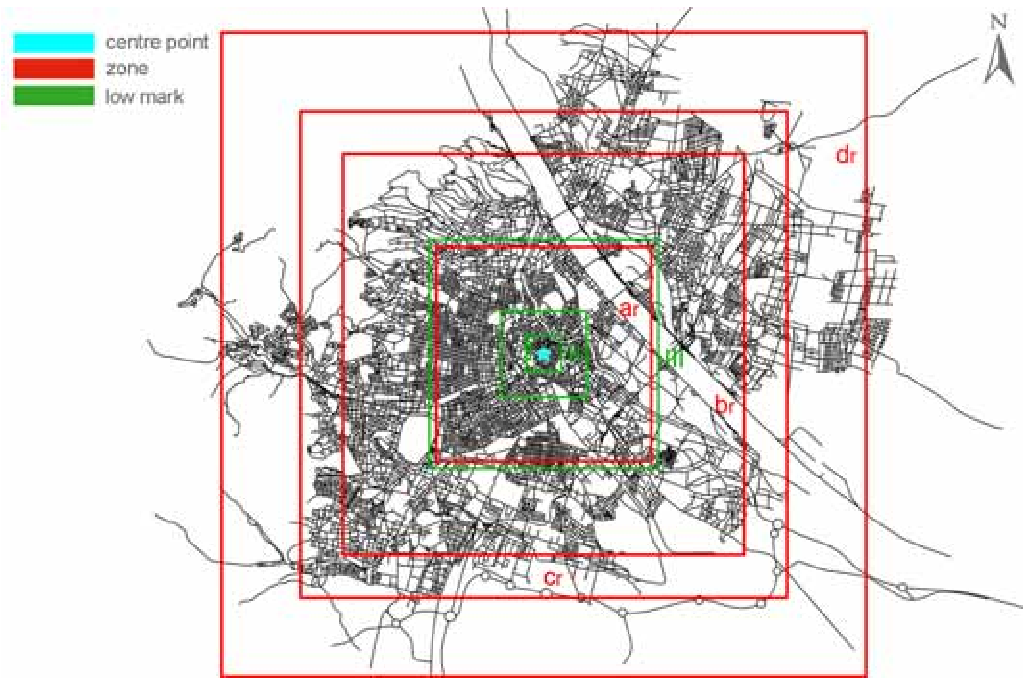


Figure 81: Radius Mass Analysis applied to the plan of Vienna;. the red squares mark the different zones where as the green squares indicate the major thresholds of the scaling behaviour curve

centre point 1 - zones	distance (km)	D radius mass analysis
curve total	22.5	1.63
zone ar	0-7.5	1.69
zone br	7.5-13.5	1.67
zone cr	13.5-17.0	1.61
zone dr	17.0-22.5	1.49

Figure 82: Radial Mass Analysis for centre point 1, historic centre

What we see at first glance is that the radius mass analysis of the historic centre is very constant up to 13.5km. The obvious fluctuations in the curve are normal, because even a constructed fractal system is not absolutely fractal and has endings. At endings the fluctuations appear more heavily. In terms of urban agglomeration these endings are the thresholds within the system.

The low marks are the same with small variations as already discussed in the accessibility analysis. Unlike the accessibility analysis the low marks in the radius mass analysis are more blurred and alleviated. We can locate the reason for this curve behaviour in the information we get from this analysis. The radius mass analysis has a spatial aspect. It displays the spatial distribution of the elements (pixels) without respect to the functional property of the street network, which the accessibility analysis does have.

If we summarize the low marks of this analysis we get following spatial background for the detailed zones:

Zone a, I (at 1.25km): parts of the Ring Street, Danube canal

Zone a, II (at 3.00km): Belvedere, Augarten, Prater, general hospital (old and new AKH)

Zone b, III (at 8.00km): Prater, Danue River, New Danube River, Danube Island, train station in the south, Schönbrunn palace, recreation locations Oberlaa and Wienerberg

Where the accessibility analysis and the radius mass analysis are more coherent, more connected the net work is. The connectivity is linked to the natural metric; the absence of interconnectedness causes longer routes to a specific place in the urban system.

centre point 1 - distance (km)	D network	D radius mass analysis
0.00 - 7.50	1.633	1.687
7.50 - 15.00	1.610	1.664
15.00 - 20.00	1.595	1.540
20.00 - 22.50	1.559	1.46

Table 83: Comparison of fractal dimension D between Accessibility Analysis and Radius Mass Analysis for centre point 1

We can see that the accessibility analysis and the radius mass analysis converge with their fractal dimensions when taking the same distances. This means that Vienna can still have a better connectivity in these zones, but is already very highly connected. The distance of

20-25 km represents the periphery. The divergity between Dnetwork and Dradius mass is noticeable. The fractal dimension D for the radial mass analysis in the distance 20-22.5km is lower than 1.5. It gives us an indicator for the need for connectivity. We have to consider that the "empty" areas in figure 81 in the north-west and south-west belong to the green belt around Vienna. Green areas on different scales are a very important issue with regard to urbanity (see also Salingaros, 2003, 2004). Nevertheless, the former agricultural areas in the north-east and east of Vienna need more connectivity. To undertake improving connectivity this area, a decent urban planning intervention with ownership structures and land use regulations has to be considered.

In general, it must be noted that the different fractal dimensions for the different zones of the accessibility analysis and the radius mass analysis are chosen by the functional ruptures appearing in their spatial layouts, and the best fit with regard to the estimated curve - represented by the correlation coefficient. The table 83 represents an average of the best fit and distances to compare the fractal dimension of both analysis methods.

Centre point 2: Shopping area - Reumannplatz - Accessibility Analysis

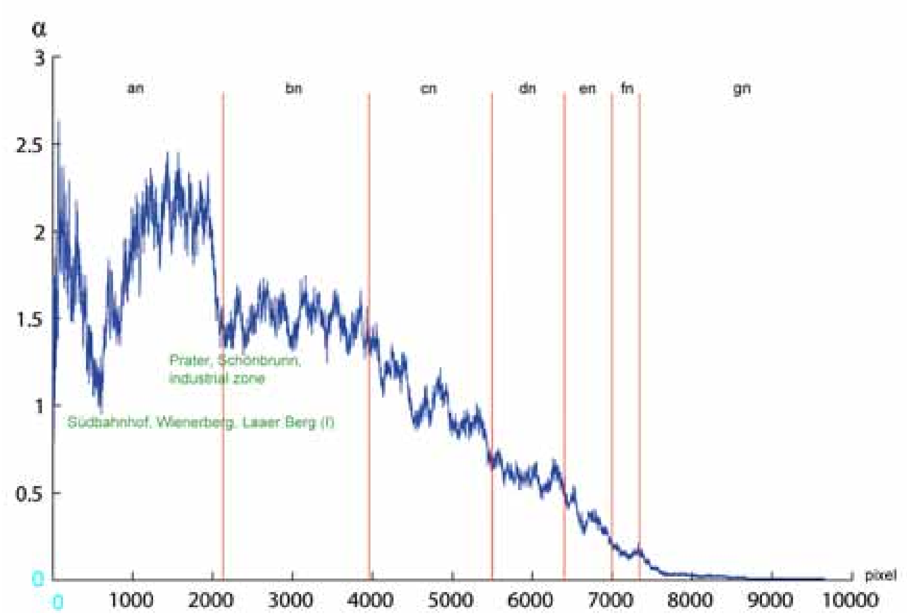


Table 84: Scaling behaviour for Accessibility Analysis for the centre point 2, Reumannplatz, with its different zones an – gn.

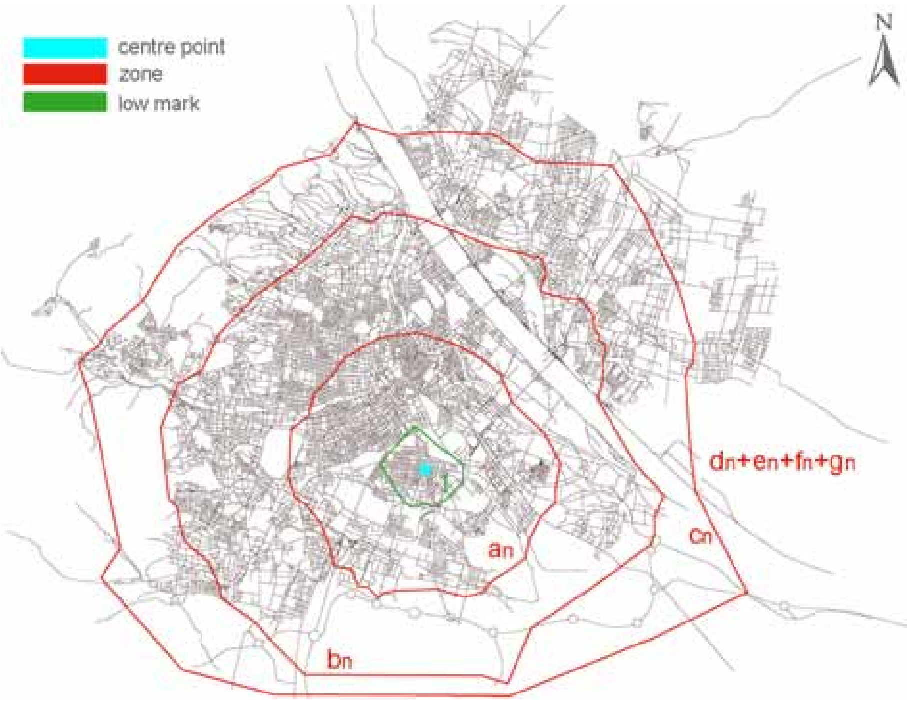


Figure 85: Zones an-gn of the scaling behaviour curve in their spatial context for centre point 2, Reumannplatz, 1100 Vienna. The green polygon (I) marks an important low point within zone an.

As centre point 2, the main shopping street and pedestrian zone of the 10th Viennese district was chosen for the analysis. This district, called Favoriten, has the highest population out of all Viennese districts. In its historical context it was the first district outside the second wall - built in 1704 around Vienna - which was suburbanized to the former Vienna.

For the analysis the zones dn, en, fn, and gn are summarised for the visualisation of the fractal analysis with regard to its urban context for the same reason as in the analyses of the historic centre. Still, we should note that these different zones were chosen for their best fit to the correlation coefficient between estimated and empirical curve. The best fit links to the different curve behaviour in sections within the whole scale behaviour curve.

On a city map it is obvious that the centre of the 10th district is organized as an "urban island" with green areas, industrial zones and a train station around it. From a geometric view, the chosen centre point of the shopping street is not located in the centre of gravity of the local urban mass. Hence, the eccentric location of centre point 2 will give a slightly shifted fractality towards the centre of gravity. Despite consideration of this fact, the functional service centre, Reumannplatz, was chosen as it represents the use of this local urban pattern.

The following table shows the results of the analysis:

centre point 2 - zones	distance (km)	D accessibility analysis
curve total	48.5	1.495
zone an	0.0-10.5	1.595
zone bn	10.5-19.4	1.584
zone cn	19.4-27.5	1.533
zone dn	27.5-32.0	1.455
zone en	32.0-35.0	1.392
zone fn	32.0-36.5	1.295
zone gn	36.5-48.5	1.067

Table 86: Accessibility Analysis for centre point 2, Reumannplatz

The range of the fractal dimension D varies from 1.595 to 1.067. Compared to the analysis of the historic city centre (1.63-1.18), the fractal dimension D demonstrates the localisation of centre point 2 towards the periphery as a less connected street pattern emerges.

The first spatial threshold (I) within *zone an* (0-10.5km) appears at a distance of 2.90km; see green polygon. If we look at the plan the vacancies emerge as the train station including cargo (Südbahnhof), the Schweitzer Garden, and the area of the Arsenal in the north-east. Südbahnhof is the former central train station of Vienna, which combines two terminal stations. In the south there are the recreation areas of Laaer Berg and Wienerberg including the Böhmischen Prater; and a train station for supra-regional trains (Matzleinsdorferplatz) in the north-west.

The fractal shift appears at the border of the green polygon in the west, where a small part of the street network is not taken in consideration within the first low mark of the scale behaviour curve. In general this will not affect the results of the analysis, but we have to be conscious of this fact.

The second low mark within *zone bn* (10.5-19.4km) represents the vacancies of the industrial zone in the south, the Schönbrunn palace in the west and the Prater in the north-east. Even the Danube River, Danube Island and the New Danube River appear as a minor low mark in zone b. We can see that the curve is quite steady and constant after the major low point. The reason for this lies in the fact that the pattern, with its high connectivity in the north and its low connectivity in the south stays constant within a small range. Small thresholds can be noticed as fluctuations in the curve.

Zone cn (20.00-27.50km) represents Transdanubia and the periphery. A lot of huge empty spaces appear in the south-east, south, and south-west. Because of this the polygon shifts towards Transdanubia. In this area in general the street network is less connected. Lichtenberger points out that this urban agglomeration is relatively young. The historic construction tradition is not manifested. It is important to consider that medieval Vienna was not a "bridge town". In 1439 the first wooden bridges were built across the unregulated Danube River. With the regulation of the Danube in 1870-74 the possibility of the urbanisation of Transdanubia was offered to the former flood plain (Lichtenberger, 1978, 322f).
In the south only the supra regional highways are left. Also, the curve decreases as distance increases. The fractal dimension D = 1.54 is coherent to this spatial layout.

Zone dn, en, fn, and gn (27.5-48.5) represent the periphery of Transdanubia, the 14th district, called Hütteldorf in the West, and the edges of the supra regional highway.

In this analysis too, the combination of a well-connected net and long straight streets emerges as local peaks. Cases in point are the Kagraner Bridge across the New Danube River and the Prater Bridge across the Danube River including their street extensions. The local peaks appear at the changeover from zone bn to zone cn in the north-west as seen in table 86. The long straight routes start in both cases in zone an. The streets represent major roads as a highway and a main road B - see visualisation of the planned urban hierarchy, figure 120 , or space syntax results, figure 35.

Centre point 2: Shopping area - Reumannplatz - Radius Mass Analysis

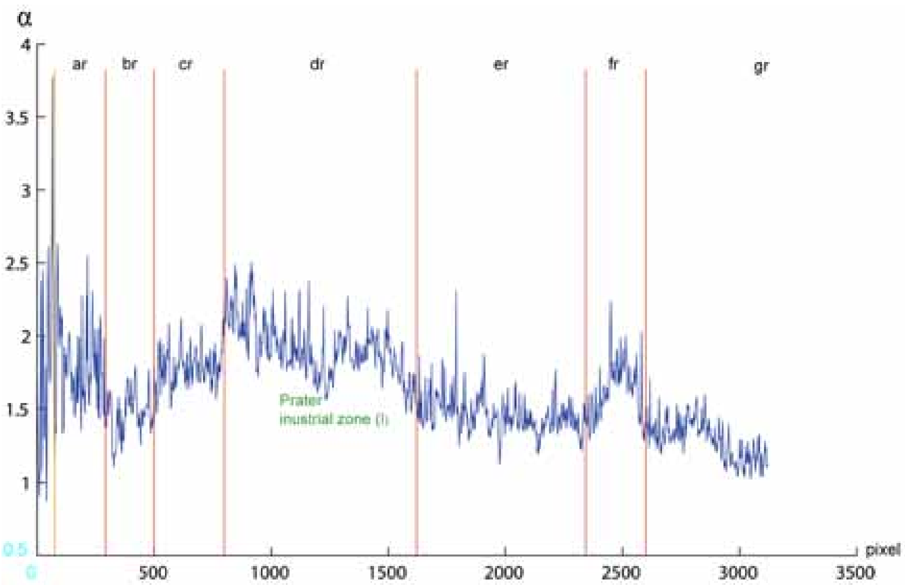


Table 87: Scaling behaviour of Radius Mass Analysis; centre point 2

Figure 88: Radius Mass Analysis applied to the plan of Vienna; the red squares mark the different zones where as the green square (I) indicates the major threshold within zone dr.

Within the radius mass analysis of centre point 2 we see a very interesting effect at the beginning of the curve. The bi-logarithmic equation of the fractal dimension increases towards an unrealistic quotation. In the chapter on the theoretical approach to fractals, we discussed the equation of the fractal dimensions for lines, squares, cubes, and fractals. Hence, we can consider that the "peak" in the scale behaviour in table 87 at the distance of approximately 175m expresses an unrealistic value.

The reason for this can be explained as an unstable behaviour of the curve within the first iteration steps of the counting window ε. Therefore, the curve can be cut at the beginning to get better values (Tannier, 2007). This cut is marked with a yellow line in the scaling behaviour curve.

The results of the analysis are shown in the following table:

centre point 2 - zones	distance (km)	D radius mass analysis
curve total	15.5	1.654
zone ar	0.175-1.5	1.648
zone br	1.5-2.5	1.617
zone cr	2.5-4.0	1.646
zone dr	4.0-8.0	1.676
zone er	8.0-11.75	1.645
zone fr	11.75-13.0	1.658
zone gr	13.0-15.5	1.625

Table 89: Radius Mass Analysis for centre point 2, Reumannplatz

At first glance we see that the fractal dimension of *zone br* at 1.617 is quite low. Therefore, *zone dr* has the highest value of the analysis. The comparison of the fractal dimension with the spatial layout will give the answer to this fractal dimension behaviour.

The fractal dimension of *zone ar* (0.175-1.5km) illustrates the spatial "island behaviour" of Favoriten´s centre. *Zone br* (1.5-2.5km) is a spatial connectivity vacuum around this area – the train stations Südbahnhof and Matzleinsdorferplatz cause this. Hence, the whole of zone br is a low mark within the whole scale behaviour curve of the radius mass analysis. The counted element, ergo the mass, is very low in this zone. That is the reason for the low fractal dimension D of 1.617 compared to its surrounding zones ar - fr.
The spatial thresholds of *zone cr* (2.5-4.01km) are the recreation locations of Laaer Berg, Wienerberg, castle Belvedere and Arsenal and industrial zone in the south.
Even the industrial zone, the Danube River, and the Prater cannot influence the high fractal value of *zone dr*. If we take an in-depth-look at the urban plan of Vienna we see that this zone includes the highly connected network of districts 4 to 8 (former outskirts, suburbanized around 1860 to the historic centre), 15, and 16.

Zones er and fr (8.0-11.75km; 11.75-13.0km)can be seen in the same spatial context. In the north of their boundaries the net mass has major vacancies, caused by the area of Schönbrunn palace (zone er), the Danube River, Danube Island, New Danube River, Augarten, North Train Station in the north to north-east; and the industrial zone including highway connection in the south at the periphery as well the periphery and urban edge settlements in the north-west of Vienna.

Within *zone gr* (13.0-45.5km), Transdanubia, the urban periphery and empty spatial space are analysed The iteration stops, where no more elements are found. In this functional aspect we find the reason for the ending of zone gr at 15.5km.

We have already discussed the interface and coherence of accessibility analysis and radius mass analysis within the analysis of centre point 1. The following table will compare both analyses to identify the efficiency of the street network linked to centre point 2, Reumannplatz.
It should be noted that the distances chosen for this comparison are of a mean value with regard to the coherence of the estimated and empirical curves. In the conclusion and discussion chapter there will be an in-depth-look and theoretical statement concerning the handling of the analysis methodology. For the aspect of research this comparison was chosen in this way.

centre point 2 - distance (km)	D network	D radius mass analysis
0.00 - 2.50	1.563	1.631
2.50 - 5.00	1.540	1.662
5.00 – 10.00	1.612	1.667
10.00 – 15.00	1.585	1.642

Table 90: Comparison of fractal dimension D between Network Analysis and Radius Mass Analysis for centre point 2

We can see that the values of the accessibility analysis and the radius mass analysis drift quite far apart. This is due to the fact that centre point 2 is chosen as part of the Viennese industrial zone. Hence, longer routes for transport with fewer intersections are given in its spatial nature. We can see that the values of fractal dimension D in the radial mass analysis are quite high. Enough "mass" exists. The difference between the analyses gives an indicator of greater connections of the street network. In the distance from 5.00 -10.00 km the fractal dimensions converge more. This is the influence of the high number of street connections of the historic centre and the inner districts of Vienna. Altogether, centre point 1, the historic centre, has much more network coverage.

Centre point 3: Shopping area - Mariahilfer Straße - Accessibility Analysis

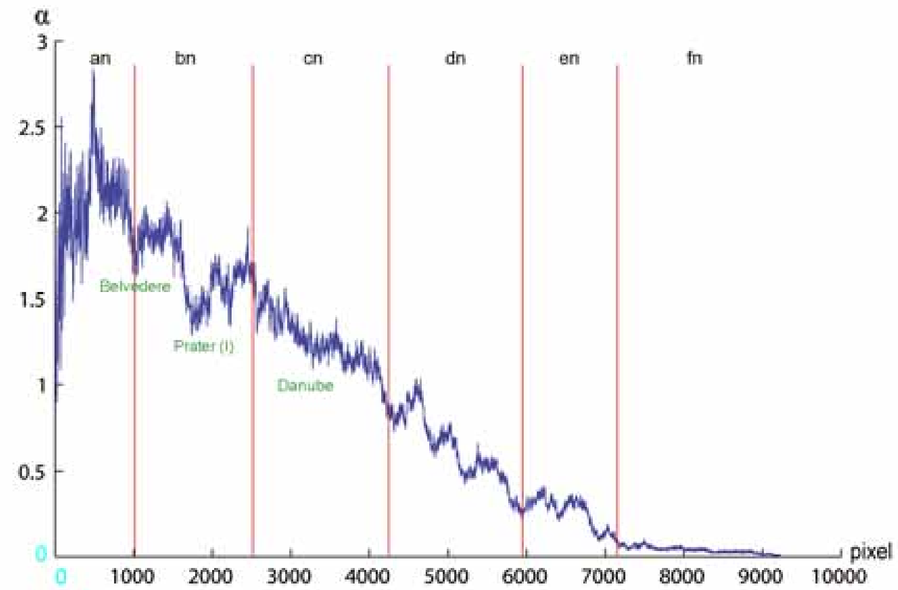


Table 91: Scaling behaviour for Accessibility Analysis for the centre point 3, Mariahilfer Straße, with its different zones an-fn

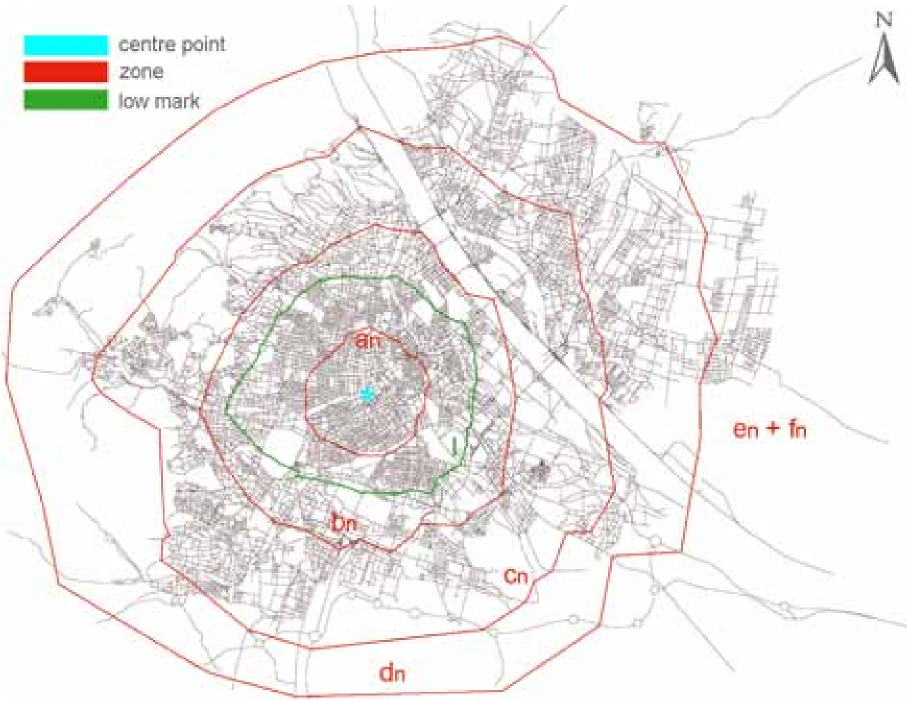


Figure 92: Zones an-fn of the scaling behaviour curve in their spatial context for centre point 3, Mariahilfer Straße, 1070 Vienna.

For the third centre point the most popular shopping street of Vienna was chosen. It is situated on the border between the 6th and 7th Viennese districts – Gumpendorf and Neubau.

Before the first Turkish siege in 1521 Mariahilfer Straße was already an important street connecting Vienna with Bavaria. In 1663 Mariahilfer Straße became a mail-processing street and a lot of inns and public houses appeared. During the second Turkish siege in

1683, the urban agglomeration was destroyed and rebuilt afterwards. It got its current name in 1862.

This centre point lies in an area within the former city wall - the ring - and the former second wall, called the belt. Its build-up surfaces are very dense. Hence, the network grid also appears as well connected. The street net linkage, therefore the accessibility to its surrounding urban areas like the historic centre or the living areas of the 5th district, the 8th district and the 16th district are in the upper range.

The cut of the scaling behaviour curve is due to same reason as in the analysis of centre point 2. Within this accessibility analysis we summarised the zones en and fn in the visualisation of their spatial appearance, see figure 92. From a global view we observe in figure 92 that the polygons of the different zones are almost radial-centric. The polygons shift slightly at the periphery. Vicinity to the historic centre is evident, as the circles of the accessibility analysis of the historic centre are radial-concentric.

The fractal dimension D of the different zones is as following:

centre point 3 - zones	distance (km)	D accessibility analysis
Curve total	46.50	1.497
Zone an	0.0-5.0	1.615
Zone bn	5.0-12.5	1.621
Zone cn	12.5-21.3	1.582
Zone dn	21.3-30.0	1.483
Zone en	30.0-36.0	1.366
Zone fn	36.0-46.5	1.155

Table 93 : Accessibility Analysis for centre point 3, Mariahilfer Staße.

In this analysis the fractal dimension varies within a tolerance of 1.62 to 1.15. If we compare it to the results of the historic centre, 1.63-1.18, we find analogous values. In comparison to centre point 2, 1.58-1.067, the values are quite different. The lower connectivity (as in centre point 2) of the urban location embedded in an industrial zone, leisure parks and the spatial layout of the urban island has an immense influence on the fractal results.

Zone an (0-5.0km) has its spatial threshold in the appearance of the first low mark on the border to zone b. It is represented by the Belvedere palace in the south-east, the Stadtpark in the east, the hospital (AKH) and old AKH (university campus) in the north, a train station (Westbahnhof) and the beginning of Schönbrunn palce in the west, and another train station to the south (Matzleinsdorferplatz) of centre point 3.

The Mariahilfer Straße emerges as a local peak in the polygon. Two indicators are apparent for this behaviour. First, it is a main communication road and also a connection to the supra regional highway and second, the Schönbrunn palace, with its park and zoo next to the main road connection, is a vacancy in the density and connectivity of the street net work.

Within *zone bn* (5.0-12.5km) the scaling behaviour curve decreases. Nevertheless, the fractal dimension D of this zone has the highest value of 1.621 within the accessibility analysis. This value indicates that if spatial vacancies do not appear on a wide variety of different urban scales, a less strong hierarchy exists. All the major vacancies are on a large scale. These are: Schönbrunn, the recreation areas of Laaer Berg and Oberlaa, the train stations Südbahnhof and Nordbahnhof, the baroque garden Augarten, and the Prater. The low mark in zone bn (at appr. 10.0km) emerges due to these vacancies and the presence of the periphery in the north-west.

Zone cn includes several areas: the Danube River, part of Transdanubia in the east, industrial zone in the south, and the periphery from the east to the north-west. The scaling behaviour curve decreases continuously. The distance to the chosen centre point, and the empty spatial spaces of the periphery and the Danube River, including the Danube Island and the New Danube River all influence the curve in this zone. Hence, the Danube River appears as a minor low point; see figure 92. Towards the periphery the network connectivity decreases. This influences the accessibility mode. A local peak appears for the Wagramerstraße, a major road, connecting the historic centre to the periphery of Transdanubia and beyond.

Zone dn (21.3-30.0km) can be described as the areas of the periphery of Transdanubia, highways, small spatial agglomerations in the south-west and west, and part of the Danube River.

Zone en, fn (30.0-36.0km; 36.0-46.5km) include the remaining highways and the edge of city at the area of Transdanubia.

Centre point 3: Shopping area - Mariahilfer Straße - Radius Mass Analysis

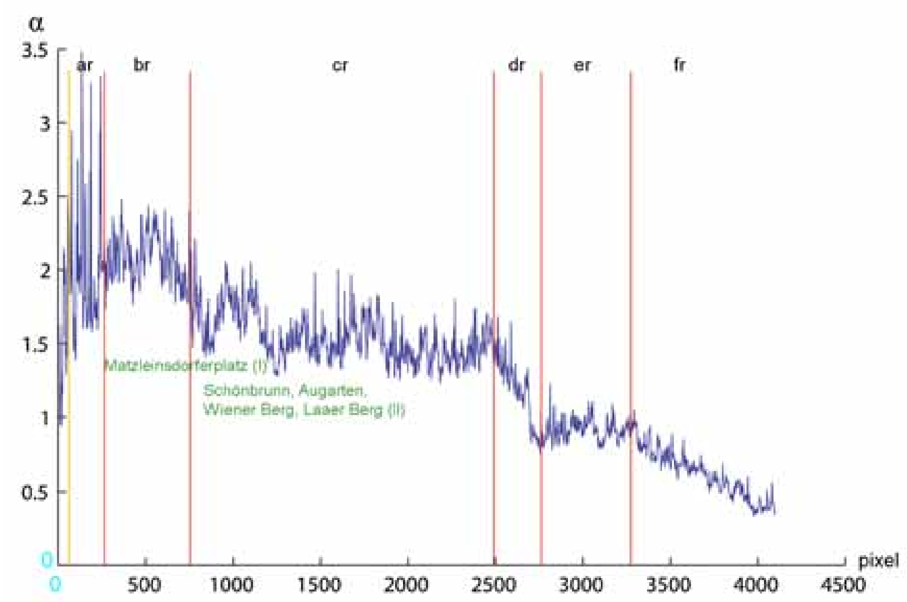


Table 94: Scaling behaviour of Radius Mass Analysis; centre point 3

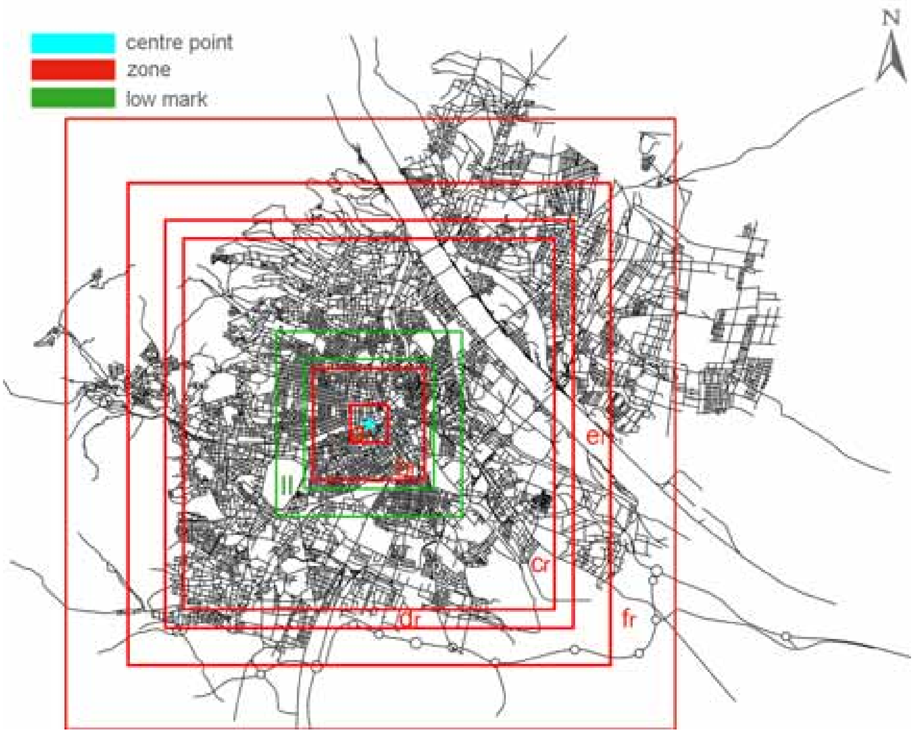


Figure 95: Radius Mass Analysis applied to the plan of Vienna; centre point 3.

The scaling behaviour curve of this analysis has very high fluctuations. We do not have to take this fact into consideration, because they are an expression of a micro-local disturbance. They represent micro-local deviation from the structure. Also, we cut this curve at the beginning to avoid the influence of the unstable behaviour of the fractal calculation.

The fractal dimensions for the radial mass analysis of centre point 3 are:

centre point 3 - zones	distance (km)	D radius mass analysis
curve total	21.0	1.64
zone ar	0-1.25	1.634
zone br	1.25-3.75	1.71
zone cr	3.75-12.5	1.675
zone dr	12.5-13.75	1.635
zone er	13.75-16.25	1.594
zone fr	16.25-21.0	1.533

Table 96: Radius Mass Analysis for centre point 3, Mariahilfer Staße.

Zone br (1.25-3.75km) has an exceptionally high value. It aggregates the highly connected street network of the historic centre and the inner districts lying within a small distance.

Zone cr (3.75-12.5km) has the advantage of a large area. The curve decreases constantly as the network thins out towards the periphery. Two low marks occur. As the curve decreases, the low marks appear in a more minor way as is usual in the context of a radius mass analysis. This zone also includes the Danube River, Danube Island and New Danube River. We can summarize the vacancies:

First low mark: train station Matzleinsdorferplatz, beginning of Schönbrunn palace, hospital AKH (old & new), Stadtpark, Belvedere palace, train station Südbahnhof, and the Danube canal.

Second low mark: Schönbrunn, the recreation location of Wienerberg & Laaerberg, Augarten, train station Nordbahnhof, beginning of the periphery in north-west, beginning of the Prater.

At the edge of the city – *zone er, fr* (13.75-16.25km; 16.25-21.0km) – the network mass decreases.

centre point 3 -distance (km)	D accessibility	D radius mass
0.00 - 2.50	1.553	1.67
2.50 - 5.00	1.631	1.706
5.00 - 10.00	1.628	1.679
10.00 - 15.00	1.614	1.644

Table 97: Comparison of fractal dimensions D between accessibility and radius mass analysis , centre point 3

We can see in figure 97 that in the distance from 2.5 up to 5.0 km we have the highest value for the radius mass and the accessibility. This area is well connected, but as the dimensions do not converge, the degree of roughness of the network is not at an optimum level. From 10.0 to15.0 km the network is better connected.

Centre point 4: Wine area - Grinzinger Allee - Accessibility Analysis

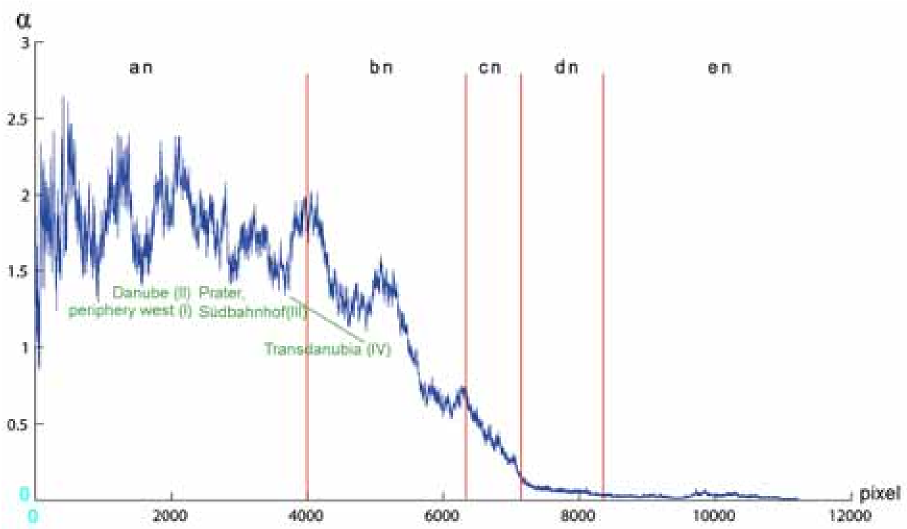


Table 98: Scaling behaviour for accessibility analysis forthe centre point 4

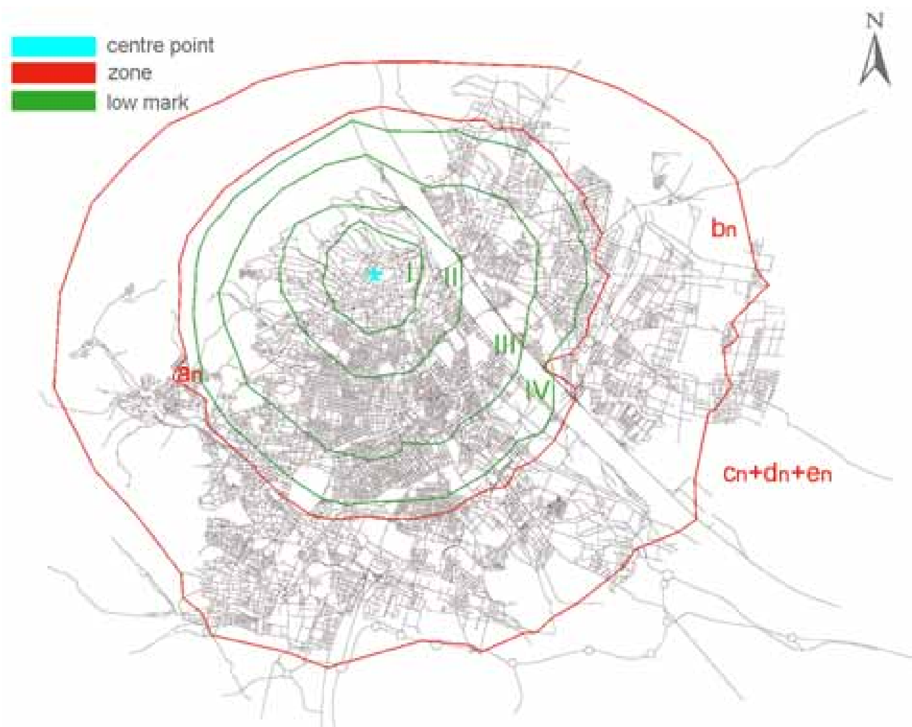


Figure 99: Zones an-en of the scaling behaviour curve in their spatial context for centre point 4, Grinzinger Allee, 1190 Vienna.

The street intersection of Grinzinger Allee with Daringerstraße is centre point 4. Grinzing was known as a village from 1114 AD. It was destroyed several times by the Turks and the French. Until 1891 Grinzing was a self-governed community of winegrowers. Later, it was suburbanised as part of the 19th Viennese district, Döbling.

centre Point 4 - zones	distance (km)	D accessibility analysis
curve total	57.5	1.47
zone an	0-20.0	1.57
zone bn	20.0- 31.2	1.531
zone cn	31.2-35.5	1.402
zone dn	35.5-41.25	1.204
zone en	41.25-57.5	1.095

Table 100: Accessibility Analysis for centre point 4, Grinzinger Allee

In this analysis the fractal dimension varies from 1.47 to 1.095. If we compare these results to the analysis before (historic centre: 1.63-1.18; Reumannplatz: 1.58-1.067; Mariahilfer street 1.62-1.15) we can notice not only the periphery close to this centre point, but also the less connected grid including dead ends in the street system. The appearance of dead ends is also represented by the high fluctuations in the scaling behaviour curve. In general, the fractal dimensions are low. This analysis represents the edge of the network system and the village layout as a historic vineyard area.

Zone an (0-20.00km) correlates to a large distance. The reason for this lies in the fact that the correlation coefficient within this area, with respect to the estimated curve correlates very well. Hence, we can assume that there are no major changes in the constitution of the network for this area within this distance. The low marks I to IV follow the same spatial regularity very closely. Low mark I (mean value 4.58km), as the first spatial threshold in zone an emerges with the start of the periphery in the west, north and east.

Low mark II (mean value 7.71km) includes the Danube river, periphery in the west and the low-connected grid of Transdanubia in the east. We can also find in this low mark the end of the spatial system in the north. Low mark III (mean value 14.46km) represents huge vacancies of Transdanubia in the north east and east; the New Danube river south east; the beginning of the Prater; the train station Südbahnhof in the south; the train station Westbahnhof in the south; periphery in the west and the absence of the street network in the north. Low mark IV (mean value 18.07km) demonstrates the growing absence of the street network from the west to the north; the Danube River in the north; the periphery and low -connected grid of Transdanubia; the New Danube River in the south east; the Prater area; the train station of Südbahnhof in the south and also the island behaviour of Favoriten´s centre.

Altogether, already within zone an (0-20.0km), the periphery and absence of the network system have major indicators. What we notice is the eccentric location of this centre point.

Zone bn (20-31.20km) has a high decrease not only because distance, but also through the emerge of huge vacancies, low connection of the grid, the periphery and the absence of the street network in the north, east, south and west.

Zones cn, dn, en (31.2-57.5) are only interesting from the theoretical point of view. No important spatial information is given. It is interesting, that for centre point 2, Reumannplatz, at a distance of 36.5 to 48.5 the fractal dimension is 1.067 where as in this analysis at a distance of 41.25 to 57.5 (zone en) the fractal dimension is 1.095. One reason could be the major change in the spatial layout within this distance for centre point 2. In centre point 4 the system stays more constant.

Centre point 4: wine area - Grinzinger Allee - Radius Mass Analysis

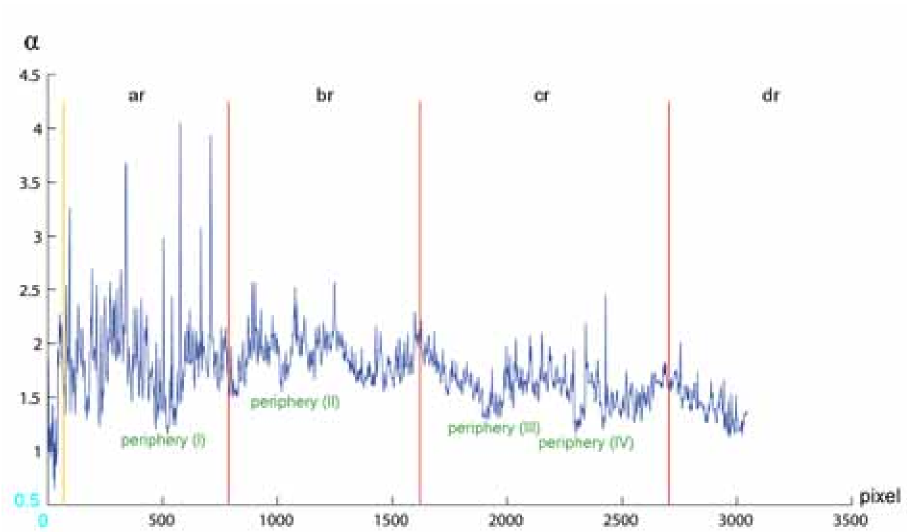


Table 101: Scaling behaviour of Radius Mass Analysis; centre point 4

Figure102: Radius Mass Analysis applied to the plan of Vienna; centre point 4.

The scaling behaviour curve of the radial mass analysis of centre point 4 stays very constant on a global scale. Within zone ar we find several unrealistic bi-logarithmic equations of the fractal dimension towards approximately 4.0. This unstable behaviour of the curve expresses fluctuations on a medium scale in the system. We have to distinguish these fluctuations from the unstable behaviour appearing at the beginning of the curve within the first iteration steps of the counting window ε. For a better result, the unstable behaviour at the beginning of the curve has been cut; see yellow stroke. The system appears quite unstable at the periphery in the sense that the mass (pixels) being counted is high towards the urban centre and very low at the edge of the city system. The counted mass is not distributed equally within the counting window ε.

The fractal dimensions for the radius mass analysis of centre point 4 are as following:

centre point 4 - zones	**distance (km)**	**D radius mass analysis**
curve total	15.25	1.635
zone ar	0-4.0	1.607
zone br	4.0-8.0	1.645
zone cr	8.0-13.9	1.631
zone dr	13.9-15.25	1.614

Table 103: Radius Mass Analysis for centre point 4, Grinzinger Allee

It is interesting that *zone ar* (0-4.0km) has the lowest fractal dimension D in this analysis. If we look at the plan we notice the low-connected network and the periphery in this zone. The low mark I (2.5km) occurring in this zone represents the periphery and the Danube River.

Zone br (4.0-8.0km) with the highest fractal dimension value of 1.645 can be explained by the appearance of a strong and highly connected grid and, at the same time, the network still existing at the periphery. The mass is at a maximum in response to the distance of this zone. The low point I (5.0km) summarises the periphery, Danube river, Danube canal, and a hospital (Orthopädisches Krankenhaus) linked to two grave yards (Gersthofer Friedhof, Hernalser Friedhof) as spatial thresholds.

In *zone cr* (8.0-13.9km) the low mark III (9.8km) demonstrated the major vacancies of absence of the network in the north: periphery, Prater, Danube River, New Danube River, the Westbahnhof train station, and the less connected grid of Transdanubia. For the low point IV (11.5km) we find more or less the same spatial behaviour, with the difference of greater distance to centre point 4 and the higher absence of the street network at the edge. In general we find a high value of mass in the area of the former outskirts, nowadays the inner districts of Vienna, but at the same time a greater absence of the network at the edge. That is the reason for a lower fractal dimension value D, as for zone br.

Zone dr (13.9-15.25km) already takes in the beginning of the industrial zone in the south. The end of the total distance is occurs at 15.25km.

centre point 4 - distance (km)	D accessibility	D radius mass
0.00 - 2.50	1.47	1.597
2.50 - 5.00	1.527	1.627
5.00 – 10.00	1.559	1.645
10.00 – 15.00	1.58	1.629

Figure 104: Comparison of fractal dimensions D between accessibility and Radius Mass Analysis for centre point 4

Figure 104 shows that the highest coherence of accessibility analysis and radial mass analysis is a the distance of 10.0 - 15.0km. We find the reason for this in the spatial layout of parts of the historic centre, the rectangular street grid of Ottakring - the 16th Viennese district - and the other well-connected districts with high network coverage, including well-connected parts of Transdanubia. In addition, the street network in these parts is dense. The absence of the street network in the north is the opposite of this. We have to take this into consideration. In general, the fractal dimension D in this comparison is quite low compared to the other centre points.

Centre point 5: United Nations Agencies (UN) - Accessibility Analysis

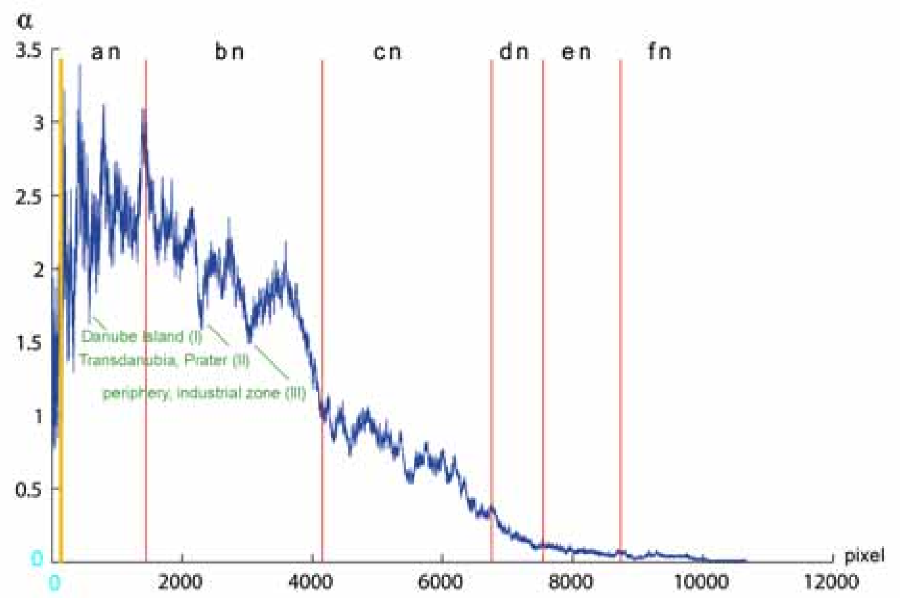


Table 105: Scaling behaviour for Accessibility Analysis for the centre point 5, UN, with its different zones an-fn

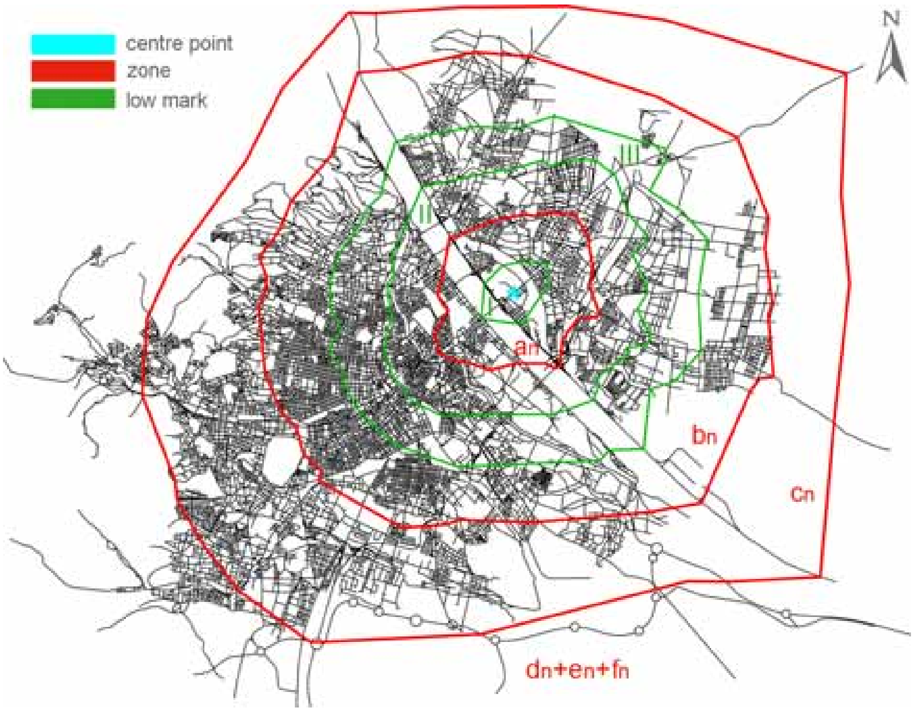


Figure 106: Scaling behaviour curve in its spatial context for centre point 5, UN, 1200 Vienna.

As centre point 5 is the location of the United Nations Organization (since 1980 in Vienna). This building is situated on the artificial Danube Island that is surrounded by the Danube River and the New Danube River.

As in the analysis before, the beginning of the scaling behaviour curve is cut due to unstable behaviour (Tannier, 2007). We see in this analysis that the curve has very high fluctuations in zone an (0-7.5km). Thus, we find two effects in this analysis: first, the unstable behaviour at the curve's beginning with respect to the counting window ε; and

second, disturbance on a spatial micro-level. It has already been explained that these deviations do not have be taken into consideration. Therefore, the analysis´ curve is cut at the beginning as described. Dead ends, separated network clusters, vacancies and a singular main street connection, connecting Transdanubia with the historic centre, influence these disturbances.
Compared to the "urban island" of Favoriten we don´t have one net work cluster representing the island being well connected with historic main streets; but a real topographical island that is not well-organized in itself and also poorly connected to its spatial neighbourhood.

The fractal dimensions D for the accessibility analysis of centre point 5 are as follows:

centre point 5 - zones	distance (km)	D accessibility analysis
curve total	53.0	1.476
zone an	0-7.25	1.526
zone bn	7.25-20.75	1.599
zone cn	20.75-33.75	1.482
zone dn	33.75-37.75	1.302
zone en	37.75-43.5	1.202
zone fn	43.5-53.0	1.117

Table 107: Accessibility Analysis for centre point 5, UN

The fractal dimension being in a tolerance between 1.599 and 1.117 is very low for a network. This urban environment is highly fractal and a lot of planning interventions on different scales can be carried out. Vacancies exist on a wide range of scales.

In *zone an* (0-7.25km) the topographical and spatially low-connected Danube Island including the spatial threshold of the rivers has a main influence on the lower fractal dimension D in *zone an* (0-7.25km) compared to zone bn. The singularity of the main road connection between Transdanubia and the historic centre is shown by the low point I at approximately 2.7km. We can see it in the spatial representation of this low mark.

Zone b (7.25-20.75km) has a fractal dimension D of 1.599. This value is influenced by the very well-connected historic centre including the inner districts. Low point II incorporates the Danube River, huge vacancies in Transdanubia, the Prater, the Belvedere palace, and the former emperor's winter residence (Hofburg). Low point III is located more towards the periphery: beginning of Transdanubia´s periphery, the spatial thresholds of the Prater and the train station Südbahnhof in the south, and the lower-connected and more winding street network of Döbling in the north west of Vienna.
Zone cn (20.75-33.75km) with a fractal dimension D of 1.482 represents the edge of the city, still connected to the network.

Zone dn, en, fn can be described as the ending of the spatial appearance of the network. We see in zone fn that the fractal dimension D is 1.117, which is close to the fractal dimension 1 of a line.

Centre point 5: United Nations Agencies (UN) - Radius Mass Analysis

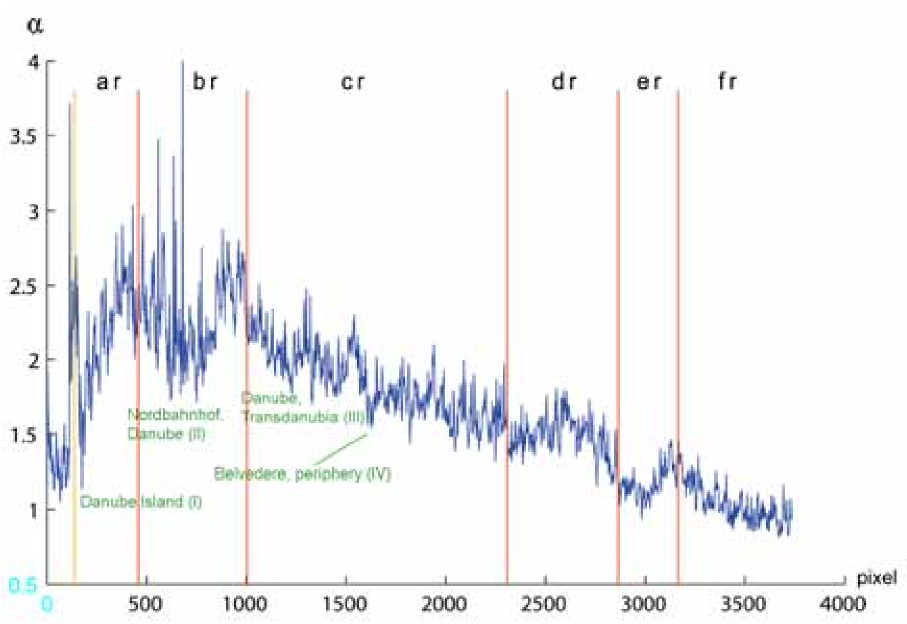


Table 108: Scaling behaviour curve of radial mass analysis; centre point 5

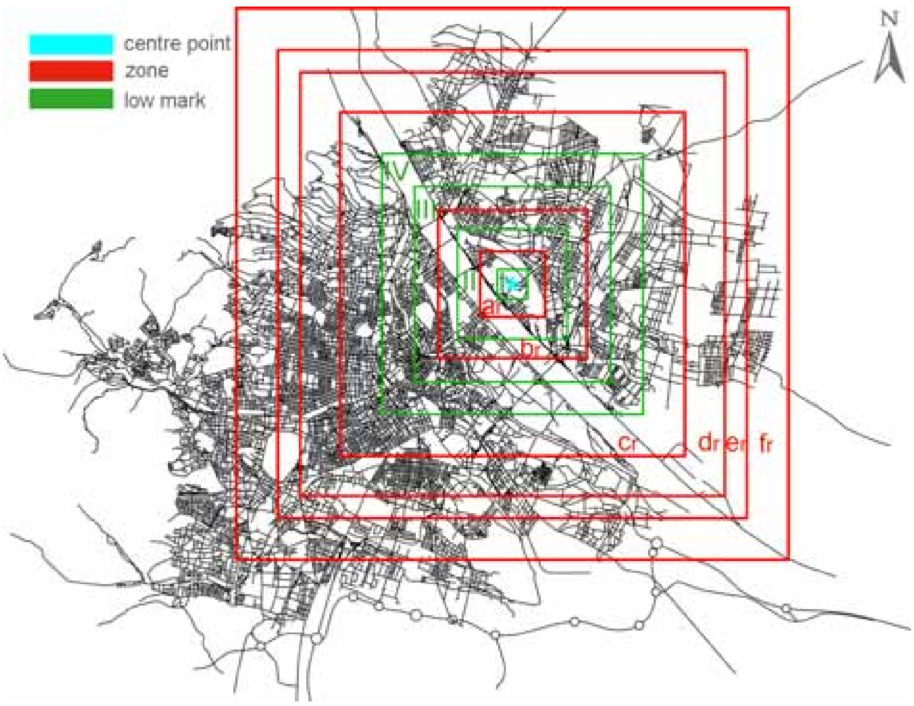


Figure 109: Radius Mass Analysis applied to the plan of Vienna; centre point 5.

Let us have a look at the spatial distribution of elements given by the radius mass analysis for centre point 5. The fractal dimensions for the radius mass analysis for centre point 5 are as following:

centre point 5 - zones	distance (km)	D radius mass analysis
curve total	18.6	1.641
zone ar	0-2.2	1.543
zone br	2.2-5.0	1.64
zone cr	5.0-11.6	1.662
zone dr	11.6-14.3	1.641
zone er	14.3-15.8	1.605
zone fr	15.8-18.6	1.584

Table 110: Radius Mass Analysis for centre point 5, UN

In general, the values for zones ar – fr (0-18.6km) are in a range of 1.662-1.543. As in the accessibility analysis the fractal dimension of 1.543 in zone ar is lower than in zone br with 1.64. The spatial aspect of the island emerges. *Zone cr* (5-11.6km) obtains the highest value of 1.662. It indicates the spatial layout of the historic centre, inner districts, and some of the periphery. In *zone dr* (11.6-14.3km) the majority of mass occurs due to the "Manhattan grid" of the 16th Viennse district, Ottakring. *Zones dr, er, and fr* (11.6-14.3km; 41.3-15.8km; 15.8-18.6km) are the areas of a less connected grid including the appearance of the periphery.

If we summarize the low marks of this analysis we get following spatial background:

Zone ar, I (at 1.0km): Danube Island, New Danube River

Zone br , II (at 3.7km): Danube River, train station Nordbahnhof,

Zone cr, III (at 6.6km): Danube River, New Danube River, baroque garden Augarten

Zone cr, IV (at 8.1km): Belvedere, Prater, Danube River, Transdanubia, and periphery

Next, we compare the accessibility analysis with the radius mass analysis of centre point 5:

centre point 5 - distance (km)	D accessibility	D radius mass
0.00 - 2.50	1.404	1.56
2.50 - 5.00	1.51	1.643
5.00 – 10.00	1.588	1.666
10.00 – 15.00	1.603	1.64

Table 111: Comparison of fractal dimensions D between Accessibility and Radius Mass Analysis for centre point 5

The values diverge in every zone. As in the Radius Mass Analysis of centre point 2, though, enough "mass" exists, the fractal dimension D for accessibility is highly fractal. Additional streets with more connections can be carried out in the urban system. The best coherent values are found between 10.0 and 15.0 km. Again, the highly connected "Manhattan grid" is an indicatior for the best fit in this analysis.

5.6 Conclusion and Discussion

Like every theory, the fractal methodology has its limitations. Within fractal analysis of urban systems several application difficulties arise, such as " does the abstract concept of rastarized images apply to the realistic sitution of the width of streets? How should the manual segmentaion of the scaling behaviour curves for the correlation coefficient be taken into acount? Can the idea of a topological fractality give better results?
We have to consider that the analysis of a street network is a totally new application of the fractal theory and therefore it raises new difficulties. Nevertheless, the program *Fractalyze* has the ability to support research for a better understanding of the complex structure of cities. It supports an in-depth view of the of accessibilty , urban mass, and the correlation of both that detects the need for new architectural and urban planning implementations; represented by buildings and streets. With this knowledge it is possible to analyse human settlements with regard to their functionality. A good distribution of elements in a wide range of scales (built up surfaes and network) is a parameter for the best fit in the context of funtionality for a city.
The basis for the following conclusion is a conversation between the german-french scientist Pierre Frankhauser and the author from May to June 2007. Therefore, it represents the actual state of research. It can be outlined as "state of the art" in fractal methodology for urban systems.

One application rule for the analysis is a scaled raster image. This image contains a binary idea of pixels: built and non-built surfaces. Within the analysis of a street network a graph for the representation is chosen. Every street exists of a line. After the transformation into a scaled raster image every pixel is associated with a metric factor. In this work the scale is that one pixel is equivalent to five metres. Hence, every street in the analysis is a street of five-metre width. In reality this is not the case. Does the result depends on the quality or the scale of the rasterized image? Ergo, the result of the analysis depends on the quality and scale of the raster image. Can the use of a "holohedral" graph - to work with the original width of streets - solve the problem of the graph?
In general, it has to be considered that there is no important information below five-metres for such analysis. Within the common fractal analysis the surface aspect does not come into play; only distances with a unit of five-metres are counted. One problem occurs with the quality of the raster image and its counted neigbourhood.

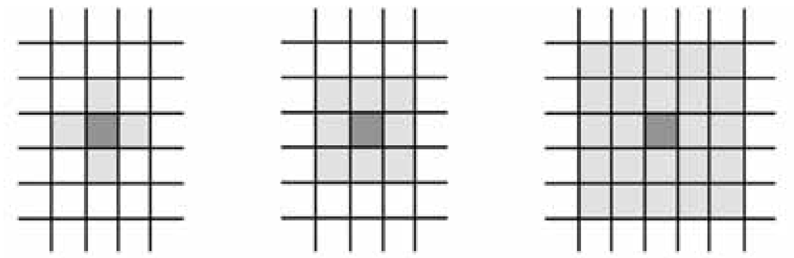


Figure 112: different neigbourhoods from left to right: Von-Neumann-neigbourhood, 3x3 Moore-neigbourhood, expanded 5x5 Moore-neigbourhood

Diagonals are interpreted as manhatten-metric and therefore polygons exist of x-y-distances/ -lines. Von-Neumann and Moore neigbourhoods are implemented. For fractals this does not make a big difference.
The analysis of full surface streets is a different analysis. The scaling of the street width would have to be considered. It is an interessting fact, but the algorithm gets quite complicated (for further information see Frankhauser, 2007).

Von-Neumann and Moore-neighbourhoods lead directly to the idea of a *topological fractality*. This would substitute the counting of singular elements, in our case pixels, with the counting of knots. It replaces geometry with configuration. The fractal dimension that approximates the idea of a configurational graph is represented by the geometric term ramification, the Riemann-Hurwitz formula. Yet-, this is not well researched. Ramification is, for example, well known in botany.

Space syntax methodology works on the basis of topology. Another point of discussion is the possibility of combining the analysis methods of geometry and topology. At the moment in fractal analysis the centre points are manually, freely chosen. Of interest are mostly urban attractors in the context of history, finance and service or the centre point of a mass. The combination of space syntax with fractal analysis can support a certain degree of automation. First, a topological survey shows the most central location - global or local. Afterwards, these centre points are the base of operation for fractal analysis.
Automation vesus manual influence is always a critical issue in research. To which degree we should work with which tool? Both have advantages and disadvantages.
Within fractal analysis it is permitted to manually cut the first part of *scaling behaviour curve,* because of a high variability of elements at the beginning. The question of manually influencing a mathematical system rises. Why is the interpretation of the beginning of the curve not taken into account? The reason is simple: networks behave totally differently below a certain distance as shown in the correlation analysis. Branching does not exist, the network as a "grid" emerges within a certain metric distance (see correlation analysis), depending on the urban network. It is easy to see this behaviour in the shape of the scaling

behaviour curve and to manually cut the curve as required to analyse just the "network as a network". It is a question of stipulated information.

Another point of discussion is the manual segmentation of the curves for the best fit between the estimated and empirical curve for the correlation coefficient. For a while this topic has been the focus of scientific consideration. An automatic segmentation leads to imposed regulations that get stereotyped. Automation is only of interest for normative purposes.

PART III

EMPRICISM - HIERARCHY OF THE STREET NETWORK BY DYNAMIC INDICATORS

6.0 POLITICAL URBAN PLANNING: THE PLANNED HIERARCHY

Transport infrastructure and streetspace are not just any arbitrary part of a two-dimensional tessellation of land use parcels.
Steven Marshall, 2005

6.1 Introduction

Functionality is the premise for urban planning. It is linked to optimization of time costs. Franck points out, that the most classical methods for reduction of these costs are the speeding up of traffic and agglomeration of living and working areas. Both methods are the basis of political, public planning (Franck, 1992). The geometric layout and topological configuration are responsible for the use of private, public and mobile, immobile use of a city. They influence the city in its appearance and borders. Also, accessibility influences the economic status of an area.

The functional efficiency of mobile use for reaching individual private allotments requires an efficient system with regard to economy. A planned, spatial hierarchy in the context of an individual transport volume can regulate the requirements and needs of the population - in particular the optimization of time costs (Franck, 1992, 112).

Vienna as a developed structure is a mono-central city. The historic supra regional roads and boulevards have been constructed in a star-shape since the Middle ages. Due to private planning decisions, transforming into public ones during the end of the nineteenth century, the checkerboard pattern manifested itself as a grid and deformed grid, as the normative street pattern in the city. Evaluations of traffic volume, speed and geometry of streets arise a hierarchical structure that matches these evaluations. However, a precise classification of Viennese inner streets with regard to a permeable hierarchical structure has been disregarded up to now. The comprehension of hierarchical coherences and percentile quotients of the space of relevant streets is an important factor for more efficient public planning. It leads to optimal development and regulation of accessibility. Hence, the streets and roads have to be exactly defined in connection to the function of (e.g. collecting, distributing) of the different street types.

6.2 The Definition Problem of Vienna´s Inner Streets

Not to use a freely chosen definition for streets, the attempt was made to be as close as possible to rules and regulations regarding the definition of streets. Explanations of the different meanings of diverse street categories do not exisit for Vienna.

The existing correlation of meanings, for example local distributor road or collector, is not sufficient for a hierarchical structuring and handling of the Viennese street network. In the Viennese rules and regulations (Wiener Bauordnung - WBO) there are no definitions regarding the hierarchy of streets. In contrast, the rules and regulations of Lower Austria (Niederösterreichische Bauordnung - NÖBO) define in paragraph § 71, passage 1-6 (Regeln der Verkehrserschließung - rules of traffic development) the detailed street types. These are as following:

1. *Hauptverkehrsstraßen - Main Artery Road*

These are public traffic routes which serve through traffic between towns as well as source and destination traffic; they typically consist of two traffic lanes and two lay-bys along with sidewalks on both sides.

2. *Sammel- oder Geschäftsstraßen - Collector - or Shopping Street*

These are public traffic toutes which servee access routes (Aufschliessungs-strassen) and main roads along with the source and destination traffic. They typically consist of two traffic lanes and lay-bys with sidewalks on both sides.

3. *Aufschließungsstraße - Access Road*

These are traffic routes that exclusively serve the traffic between link roads (Aufschliessungsstrassen) and main roads; they typically consist of two traffic lanes and lay-bys with pavements on both sides.

4. *Wohnsiedlungsstraße - Residental Roads*

These are public traffic routes which are at present and in the foreseeable future of lesser significance for mixed vehicle and pedestrian traffic; they exclusively serve the traffic whose sources and destinations are to be found on these roads themselves. The traffic on these streets is reduced.

5. *Wohnwege - Access Routes*

These are public traffic routes that enable the access to construction sites for pedestrians as well as emergency vehicles.

6. *Gehwege - Sidewalk*

These are public traffic routes that do not serve access construction sites, but are intended solely for pedestrians use. The width of the sidewalk is measured according to the frequency of pedestrian use, within a minimum width of 1.25 metres.

There are two general regulations, which indicate a classification for the streets of the Viennese street network:

- "Richtlinien und Vorschriften für das Straßenwesen" (RVS), RVS Stadtstrassen 03.04.12 - (Regulations for Roadways)
- "Verordnung des Gemeinderates betreffend Feststellung der Hauptstrassen und Nebenstrassen" -V001/115 and the "New Classification of the Viennese Street Network", Documentation March 2005

The RVS applies to the street network of the whole federal territory of Austria, while the *Verordnung des Gemeinderats betreffend Feststellung der Hauptstrassen und Nebenstrassen* only applies to the federal state of Vienna (-V1-115 vom 12.5.2005, Amtsblatt 19/2005, gemäß §103 Abs. WStV [Wiener Strassenverordnung], LGBl. für Wien Nr. 28/1968 idF. 18/02). This ordinance declares that the district council has to establish by decree, considering the functionality and meaning of the roads, which streets are defined as main artery roads A, main artery roads B and side streets. (LGBl für Wien Nr. 28/1968 idF 18/02, §103 Abs.2(2)).

Landesgesetzblatt für Wien, § 103 Abs 2.:
„(2)[...] Der Gemeinderat hat unter Bedachtnahme auf die Bedeutung und Funktion der Straßen im gesamten Straßennetz der Stadt durch Verordnung festzulegen, welche Straßen als Hauptstraßen A, Hauptstraßen B und Nebenstraßen im Sinne des Abs. 1 gelten."

Federal Law Gazette for Vienna, law 103, paragraph 2:
„(2)[...] The borough council has to determine through directives, taking into consideration the significance and function of the roads for the entire road network of the town, which roads are to be considered A main roads, which B main roads and which subsidiary roads in accordance with paragraph 1."

The main roads for public, individual transport and main pedestrian zones are listed by name in the annexe 1 and 2 of the above mentioned regulation and also the documentation of the *New Classification of Viennese Inner Streets*, published by the Magistrate of Urban Development and Urban Planning, Vienna 2005. Additionally all side streets are declared.

RVS regulations are to be taken as norms for establishing the status of technology and science and contextualizing that with the demands of the traffic duct, traffic flow and street traffic. RSV regulations are published by the research community for traffic and highways. At present, RVS regulations are stated as mandatory service instructions for those responsible for the upkeep of roads, or in the form of decrees.

In the RVS are two tables regarding the division of inner streets:

- by their spatial functionality
- by the permitted maximum speed in combination with the organisation of the traffic for the longitudinal traffic

function	meaning with regard to travel distance	type of street
flow through - to conduct	supraregional traffic	high rate road
connecting	regional traffic	main road
collecting	areal traffic	local distribution road
provide access	local traffic	service road

Table 113: Relevant spatial function and arrangement of inner streets, RVS 03.04.12, 1

Straßentyp	Verkehrsorganisation	Zulässige Höchstgeschwindigkeit
Hochleistungsstraße	Trennen der Kfz von Fahrrad und Fußgänger	$50 \leq V_{zul} \leq 80$ km/h
Hauptstraße	Trennen von Kfz und Fußgänger, Trennen von Kfz und Fahrrad bei $V_{zul} > 30$ km/h	$30^{(1)} \leq V_{zul} \leq 50$ km/h
Sammelstraße	Trennen von Kfz und Fußgänger und Fahrrad bei $V_{zul} > 30$ km/h	$30 \leq V_{zul} \leq 50$ km/h
Anliegerstraße	Mischen Fahrrad und Kfz(2), Fußgänger getrennt, wenn Quantität es zuläßt(3)	30 km/h (bei vorwiegender Industrie-nutzung 50 km/h)
Wohnstraße (nach StVO)	Mischen Fußgänger, Fahrrad, Kfz, wenn Quantität es zuläßt(4)	Schrittgeschwindigkeit (10 km/h bis 15 km/h)
Fußgängerzone	Mischen Fußgänger, Fahrrad, wenn Quantität es zuläßt(4), Kfz-Verkehr zeitlich beschränkt	Schrittgeschwindigkeit (10 km/h bis 15 km/h)
Gehweg, Gehsteig, „Geh- und Radweg"	Mischen von Fußgänger und Fahrrad, wenn Quantität es zuläßt(3)	Schrittgeschwindigkeit bei gegenseitiger Annäherung

(1) In Ausnahmefällen bei starkem Fußgängerquerungsbedarf
(2) Nur bei $V_{zul} \leq 30$ km/h
(3) „Geh- und Radweg", s. quantitatives Kriterium, Diagramm 2, RVS 3.561, aus Qualitätsgründen ist grundsätzlich eine getrennte Führung von Fußgänger- und Radverkehr wünschenswert
(4) Richtwerte: MSV bis 50 Kfz/h und beide Richtungen
zumutbar: MSV bis 100 Kfz/h und beide Richtungen
MSV (Kfz/h): maßgeblicher Spitzenstundenverkehr eines durchschnittlichen Werktages

Table 114: Correlation of speed limit "vzul." and traffic organisation regarding traffic for long-distance traffic, RVS 03.04.12, 3

The regulation clearly categorizes the streets by their functional aspects for main roads A, main roads B and side streets. For Vienna no accurate classification of the inner streets exists, nor any definition for termini between main road and side road. Typologies such as go through street, collector or service street are not mentioned as regards content.

The magistrate MA 18 - Urban Development and Urban Planning - of Vienna suggests the following definition for main roads A and main roads B. These definitions are just a commentary illustration and no legal definition.

Main roads A:

The main roads A are community streets of special importance and are evaluated by different criteria such as traffic model, road of right of way, and no limit-30-zones (Magistrat Wien, 2006).

Main roads B:

During the extension of the national highways in April 2002, excluding the motor highway and express way, all national highways were assigned to the respective federal states. These former national highways are now the main roads B and have the character of an rural or in-town road with higher importance to traffic (Magistrat Wien, 2006).

The RVS avoids an explanation of meanings of street types according to a classification regarding function or speed. Also in this case there is no definition regarding street types.
What follows is that the regulation and the RVS are incompatible. A practical example is the Quellenstrasse in the 10th district of Vienna in 2006. This street is listed in the *Verordnung des Gemeinderats betreffend Feststellung der Hauptstrassen und Nebenstrassen* as a main road A. By mainroads the RVS (table above) suggest a traffic organisation where individual traffic is in engineering terms to be splitt up into cars and bicycles. The Quellenstrasse has no design-engineering division regarding the diverse individual traffic members and none is planned for the future either (status 2006). Bike traffic is conducted over Gudrunstrasse.

How can Vienna´s inner streets be differentiated and accurate correlation and classification be set up?
On the basis of the leading publications a hierarchical cascade to classify the superior and secondary street network will be outlined. It is important to layout the interaction between the different “scales“ to understand the whole system. The classification of the regulation *Verordnung des Gemeinderats betreffend der Feststellung der Haupt- und der Nebenstrassen* is the basis of the superior structure.
For an exact differentation both above-shown RVS tables are combined. The reason is that they do not only interact on a topological level, but also with regard to the functional aspect of speed that is the major utilisation and functional indication for a street. Important parameters for a street are speed and volume of traffic.
The following cascade for individual transport is generated on this basis:

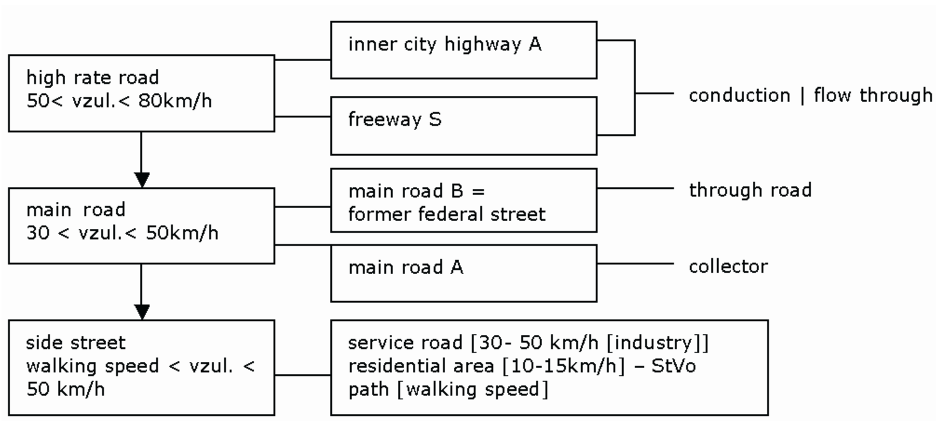


Figure 115: Hierarchy of Vienna’s inner streets

In the Viennese street network all streets displayed in the figure 115 exist in Vienna. Pedestrian zones – 10-15km/h - have to be treated differently. Mostly they are a shopping streets with the hierarchical impact of a collector street, e.g. Kärntner Straße, Favoritenstraße, Mariahilfer Straße. The comparision between the displayed diagram above and the norm and regulations for Lower Austria produces the following correlation:

street type – Lower Austria	**street type - Vienna**
main artery road	main road B
collector - or shopping street	main road A
development street	service road
housing estate street	residential area
path	path
sidewalk |foot path	sidewalk |foot path

Figure 116: Correlation of street types Lower Austria and Vienna

In order to display a cascade referring to the different movement activites, the planned hierarchy has to be divided into different modes. This modal split will be according to the different traffic participants: private motor car traffic, public transport, cyclists and pedestrians.The essential factors with regard to the spatial usage of space in a cross-section of a street embedded in the context of classic urban planning are indivdual motor car traffic and public transport. In this chapter pedestrian traffic will be disregarded, because every street type - except the motor highway, has a sidewalk as an integrated engineering strategy. The main axses for pedestrians are very sparsely located and for this reason also obsolete in this construct of ideas. Parking lots will be not integrated in the hierarchical structure, because their appearance is the subject to individual decisions by each district. Also, there is a major difference in the usage of space, depending on whether they are implemented as cross parking (Querparker) or longitudinal parking (Längsparker). The general problem of parking is solved by the norm and regulation that stipulates by law that for every newly built flats there must be a parking space in a basement garage. Cyclists can be spatially integrated into the flow traffic.

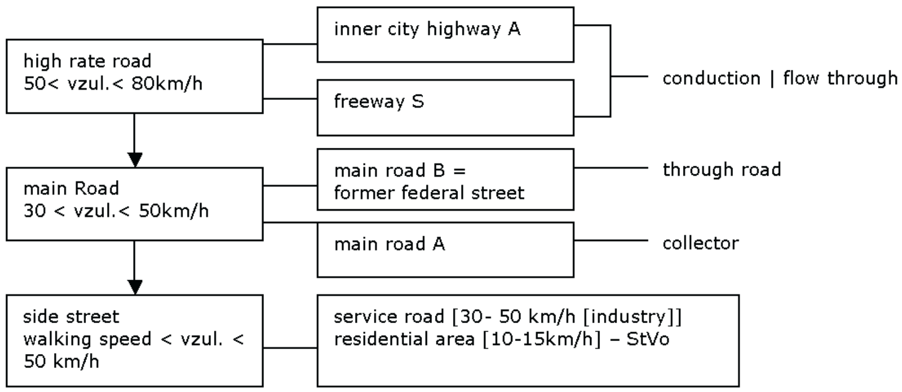


Figure117: Hierarchy of the Viennese Innerstreets for individual car traffic

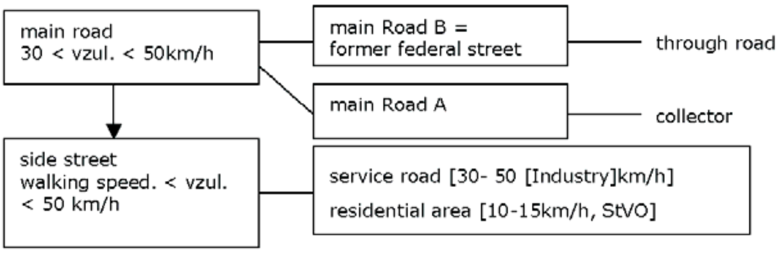


Figure 117A: Hierarchy of Vienna's inner streets for public traffic

The formula for the different hierarchical scales for public transport is as follows:

Public transport side streets = Public transport network - Public transport main roads

Sidewalks and foot-paths are ignored, because they are not integrated into the public spatial space in urban planning, e.g. Blue Danube Islalnd, etc. Seperate treatment is also effective for the pedestrian zones.

6.3 Methodology of the New Evaluation for the Street Network

The categories of main and subsidiary roads were introduced in the year 1988. In November 2003 the new masterplan for traffic (individual motorised traffic, MPV) was finalised by the Viennese municipal council. Within the framework of an evaluation the new categorisation of the Vienna road network came into effect in 2007.

The new categorisation aims at promoting public, non-motorised traffic, car sharing and pedestrians. It also aims at reestablishing the quality of public transport stops. The new network structure is intended to correspond more closely to the transport policies of the city of Vienna and contain clear regulations for dealing with the road usage conflicts arising during rebuilding and development work as well as when the traffic regulation measures are taken.

The adapted main road A network therefore takes into consideration not only roads vital for motorised private transport, but also routes important for public transport and highly frequented pedestrian areas.

In order to realise the goal of a reduction in private traffic on these roads, the sign-posting of a main road network for current public routes was generally assigned to various functions according to priorities. Priority was given, in the interests of the whole city, to public transport over pedestrian and flowing motorised private transport. The status

afforded motorised individual transport, which hitherto took up the majority of the traffic routes, was significantly reduced.
The following assessment criteria and rubric will be explained in the following summary of the final report on the *Recategorising and Reevaluation of the Vienna Road Network*:

Public transport:

The focus in this research work lies on individual transport. For the sake of completeness the public transport is discussed in this part of the chapter.

For the arrangement of the public transport main roads, all public transport routes were given a point-based rating. The rating was based on the following criteria:

- frequency of passengers
- structural public transport routes
- right of way of scenario
- intervals during schooltime

All routes served by a public transport line were taken into the main street framework for public transport. The following lines were considered as main lines:

Tram routes: D, J, N, O, 1, 2, 5, 6, 9, 10, 18, 21, 25, 26, 31, 33, 37, 38, 40, 41, 42, 43, 44, 46, 49, 52, 58, 60, 62, 65, 67, 71, WLB

Bus routes: 1A, 7A, 10A, 11A, 13A, 14A, 15A, 23A, 24A, 26A, 29A, 31A, 33B, 35A, 39A, 40A, 48A, 51A, 57A, 59A, 62A, 63A, 66A, 68A, 69A, 74A, 83A, 84A

For these routes the following point scheme was used:

ammount of passengers	over 10000 passengers/day	10 points
	7001 to 10000 passengers/day	8 points
	5001 to 7000 passengers/day	7 points
	1000 to 6000 passengers/day	6 points
	below 1000 passengers/day	0 points
structuralizing public transport line	structuralizing line	10 points
	non structuralizing line	0 points
give way / yield arrangements	existing and/or planned	10 points
	none	5 points
interval during school days	less than or equal to 5 minutes	10 points
	more than 6 up to 10 minutes	0 points
possible maximum number of points		40 points
minimum needed points for evaluation as a public transport main road		26 points

Figure 118: Evaluation model for public traffic

Non-motorised private traffic:

The pedestrian main road network consists of pedestrian zones (MA46, MA18) and main business precincts (Vienna Economic Assosiation) with particular significance for non-motorised private traffic. The cycle network was not included in our definition, as their demands are to be fulfilled independently of those of main road functions.

Motorised private transport:

The following points were considered for the evaluation:

- Linking areas of the city/ links with the region
- Density of traffic
- Right of way scenario
- Reinstation of alignment and restrictions

For a reevaluation of the road categories, 10 points were given where one of the points was matched, where a point was not met 5 points were awarded. Taking into consideration the minimum demand that a motorised private transport main road should display no reinstations or restrictions and that at least 2 of the 4 points have to be met, for a street to categorised as a main road it must have a mimimum point tally of 26. The general maximum point tally is 40, the lowest 20.

„Für eine neue Bewertung der Straßenkategorien wurde bei entsprechender Übereinstimmung mit einem Merkmal 10 Punkte vergeben; bei Nichtübereinstimmung 5 Punkte. Unter Berücksichtigung der Mindestanforderung, dass eine MIV Hauptstraße keine Rückbaumaßnahmen bzw. Beschränkungen aufweisen soll und dass zumindest zwei der vier Merkmale einer MIV-Hauptstraße erreicht werden müssen, ergibt sich eine Mindestpunktezahl von 26, die zur Kategorisierung einer Hauptstraße führt. Diese Punktevergabe erfolgt in Anlehnung an das Punkteschema der Evaluierung des öffentlichen Verkehrs. Die generelle Maximalpunktezahl beträgt 40, die Miimalpunktezahl 20 Punkte.“ (Areal Consult, 2005, 12)

In the course of evaluation it became apparent that a specification of the points under the heading of “right of way scenarios” and “reinstation and restrictions” is necessary. It became particularly apparent with very short connections (e.g. roads linked to the belt) that the point “right of the way scenarios” is not an important criterion for the evaluation of a street as a motorised public transport street. For this situation 5 points were awarded. A similar situation tends to arise with very long routes which are not, in the main, punctuated by their whole length with right of way signs. The “reinstaion and restrictions” were examined for the whole of the route evaluated. Semi-stop islands were not regarded as motorised private transport reinstation, but are instead seen as transport rights of way.

Height and tonnage restrictions as well as narrow or winding sections of roads were considered restrictions.

main road		**side road**	
connecting quarter or with region	10points	connecting districts, general connectivity	5 points
traffic volume > 10000cars/24h	10points	traffic volume < 10000cars/24h	5 points
right of way road	10points	continuously accessible non-right of way road	5 points
no retreating work no limitations in height and weight	10points	with retreating work with limitations in height and weight	5 points
possible maximum number of points			40 points
minimum needed points for evaluation as a main road			26 points

Table 119: Evaluation model for motorised individual transport

Conclusion:

Due to the reevaluation the overall area of the main roads A rises from the previous standing of 222 842 m² to 239 693m². This equates to an increase of approximately 10 per cent. It is apparent that essentially, despite the reevaluation, a comparatively good agreement between the figures was reached.

6.4 Visualisation of the Planned Hierarchy

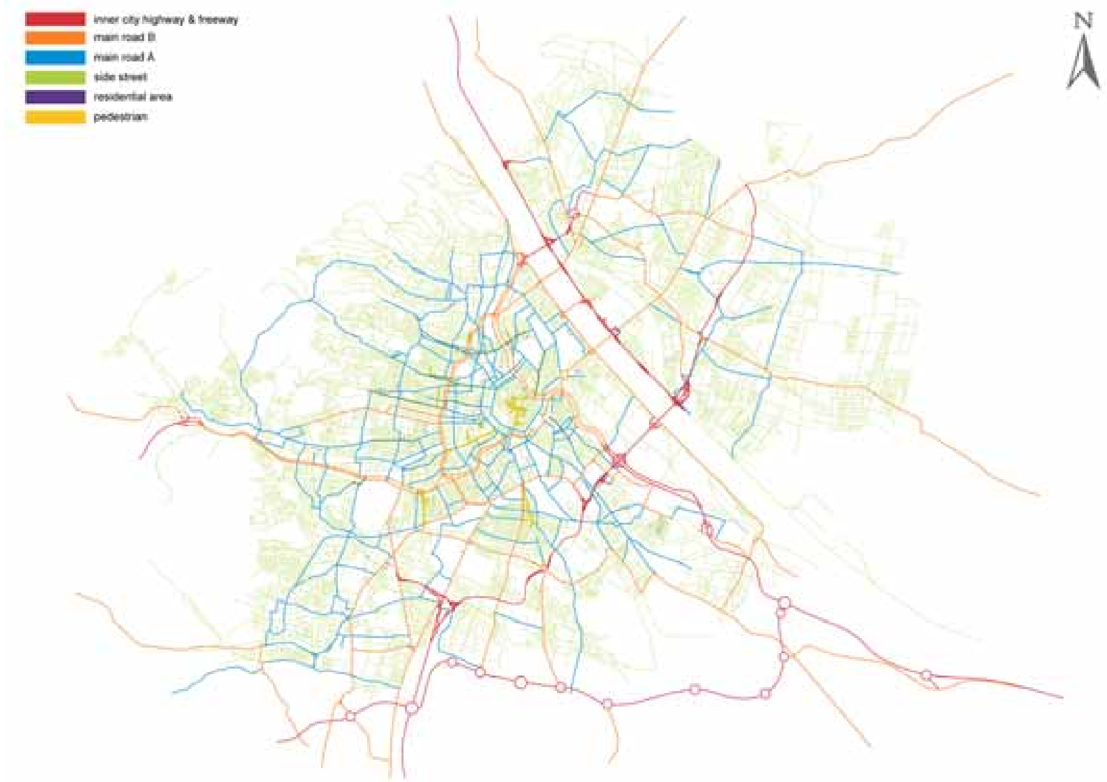


Figure 120: Visualisation of the street network with regard to its functionality on the basis of individual transport. The diagram “hierarchy of innerstreets for individual transport” was used.

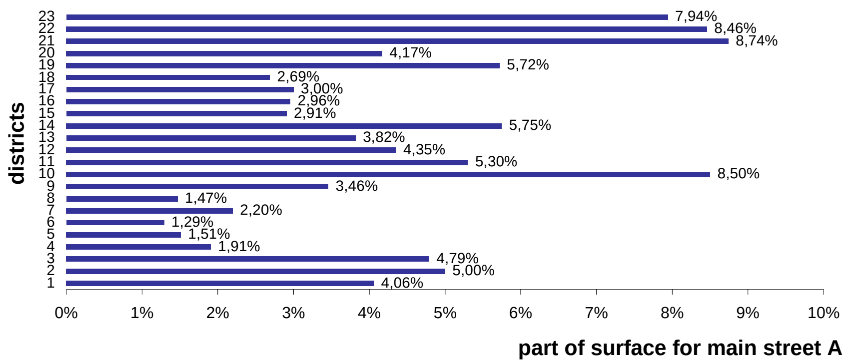


Figure 121: Distribution of the percentage of surface for every Viennese district for main roads A. Historic development can be read in this diagram, because within the enlargement of historic European towns, their centres have less space and therefore more narrow streets. Ergo, where space is narrow less percentage of movement channels for traffic is implemented. The districts with a high percentage are located on the periphery or represent industrial areas. Hence, this diagram reflects Viennese history by its network.

6.5 Structure Function Model: Correlation of the Empirical Analysis with the Traffic Census

In order to evaluate the Viennese street network, the volume of car traffic was interwoven in the methodology as part of the evaluation model. Hence, the structural and functional components are already linked. Still, for an accurate understanding and survey of the hierarchical impact it is important to deal with the structural model and the traffic model as autonomous units for the correlation.

For the following comparision the traffic model of the year 2000 was chosen.

Figure 122: Visualisation of the traffic census, Vienna 2000

It contains highways main roads B and main roads A. The different types of streets were related to hierarchies: highway - hierarchy 1, main roads B - hierarchy 2, main roads A - hierarchy 3.

All together, 76 counting points were picked and splitted into three parts: 22 counting points for highways, 27 counting points for main roads B, and 27 counting points for main roads A. With regard to the traffic census, DTVw, representing the annual average of daily traffic volume from Monday to Friday, was selected.

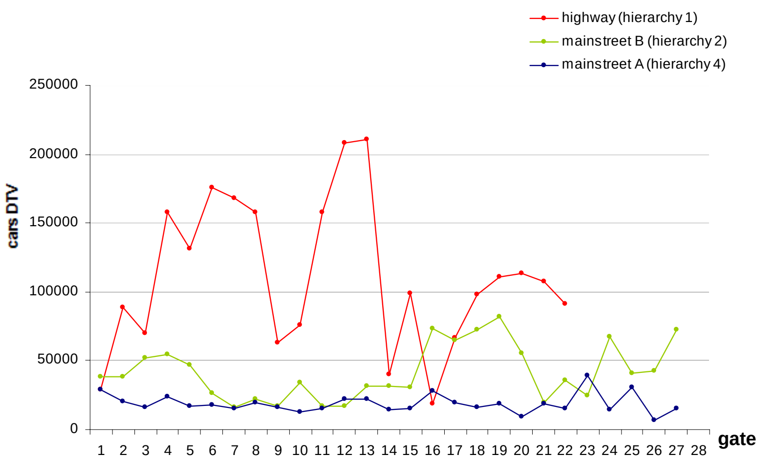


Figure 123: Distribution of hierarchy 1 to 3 by the indicator of car volume

The histogram shows very clearly the hierarchical impact of traffic volume in the context of the street hierarchy. For a better visualisation the average traffic volume was calculated.

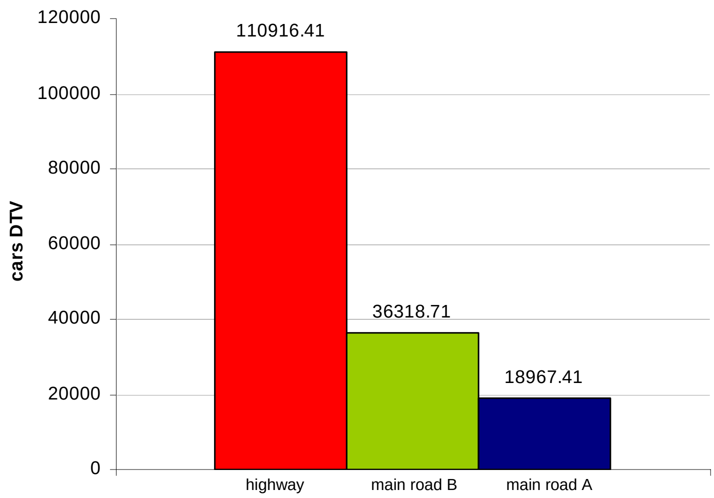


Figure 124: Mean traffic volume for hierarchy 1 to 3

We can conclude that the traffic volume correlates with the hierarchical evaluation of the different street modes perfectly.

6.6 Conclusion and Discussion

City planning can strongly influence natural movement and hence influences the natural location process. The built environment functions independently of these processes. Urban patterns emerge as dynamic processes constructed through time raccording to the individual needs of a city. Therefore, political planning supports optimizing or constraining these processes. The origin of political planning intensions can be found in the Roman ancient world in Vienna, in the form of the Roman military camp Vindobona along the limes-border of the Roman empire.

Political planning has a long tradtion in urban planning. Different intentions have led to different concepts. One movement from 1960 to 1975 heavily modified the appearance of Vienna, the *geschlossene Planung.* This concept implemented a scientification and led to a low flexibility in urbanism. In this era political planning became part of federal, hence country-wide and general, development. The ideal case of this conception persued a vertical and horizontal integrated development. Individual town planners created a “brave new world”, to speak in Huxley´s words (Huxley, 1932). The aim was the realisation of a right final condition - the optimal order of spatial space. This urbanism represented the conception of density and urbanity; urbanity through density; and well-suited traffic conditions. Vienna´s map from 1971 illustrates this ideology for the first time.

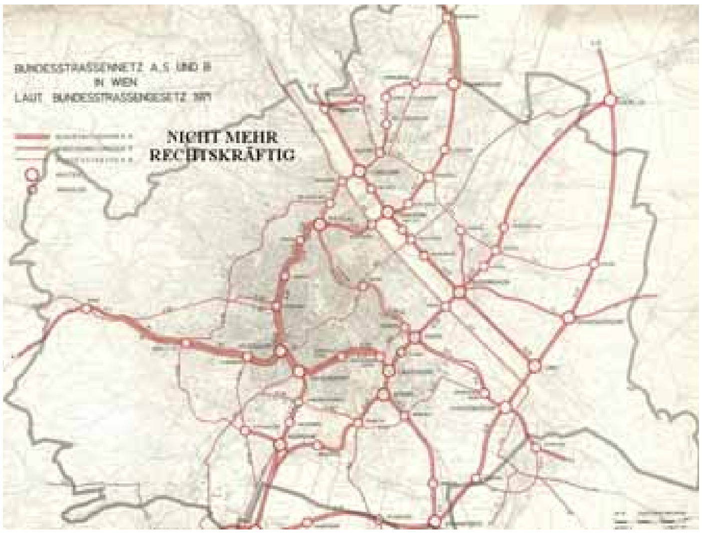


Figure 125: Federal street network for Vienna 1971

The idea of sustainability and a more “open” urban management started in the period of postmodernism, from 1975 on. Ecology and sustainability were major goals including also the renovation and restoration of the historic structure. A wide range of models, even the acceptance of a city´s fragmentation, developed evolutionarily as a result of the “divine” city planner of the previous period.

Generated Globalisation leads to a convergence of cities. Through cultural contacts new forms of urbanism can emerge. Hybridization can be a very interesing result. Normation and regulation, the fear of globalization, is more part of urban management and not of the multifaced population (Temel, 2007). The effect of political planning interventions and actions are of importance. This leads again to concept of *sustainability*, the formulated idea from the seventies for urbanism. Sustainability penetrates the living space of humans. It means the maintenance of a permanent socio-cultural reproduction. It consists of: avoidance of traffic- and environmental proplems, social stress, or unneeded open space.

Optimal living circumstances are regulated by - among other things - building rules and regulations, supply of services, connection with the traffic network of all kinds, accessibility, distance to work, and quality of the neighbourhood. In general, sustainability can be defined as the linkage of ecology, economy, and socioculture (Czerkauer, Merl, 2006).

The urban population demands quality of life within the scope of diverse costs. Nowadays, suburbia offers urban pseudo sustainability with dreasonable costs. Unregulated suburbia became an overall conept, because the historic city is too expensive. There, the focus is on renovation and restoration of the traditional situation and not an implementation of a functional sustainable planning paradigm for a qualitative living standard.

A realistic urban sustainability can be reached by an optimal *modal split* between individual and public transport, free space, and so on. Unfortunately the implementation of a modal split is not a maintained condition within urban management. The modal split can be evaluated on the basis of sustainable indicators: value creation, employment, unemployment, taxes, population, income, individual living space, and so on. In turn, hierarchy is linked to it as a functional paradigm. In terms of traffic, hierarchy is important as it develops all allotments within an urban system. The conducted idea in the seventies of focusing traffic was too rigid. Suitable traffic conditions linked to sustainable indicators should be implemented in a liberal environment.

Combinations of geography, architecture, and urban planning are an important step towards a qualitative, functional city in all respects. In other words, the implementation of sustainability conducted through a modal split including hierachical functionality will lead to a "human city".

7.0 SEGMENT ANALYSIS: HIERARCHICAL ORGANISATION BY ROUTE CHOICE

Cities are large physical objects
animated and driven by human behavior.
Bill Hillier, 1996

7.1 Introduction

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

That the paths, once identifiable, have continuity as well, is an obvious functional necessity. People regularly depended upon this quality. The fundamental requirement is that the actual characteristics are less important. Paths which simply have a satisfactory degree of track continuity were selected as the dependable ones in an environment like Jersey City. It can be generalized that other kinds of characteristics along a continuous track were also continuous, despite actual changes.
People tend to think of path destinations and origin points: they liked to know where paths came from and where they lead. Paths with clear and well-known origins and destinations had stronger identities, helped tie the city together […](Lynch, 1960,52ff).

Within spatial cognition people decode spatial information. Kown as cognitive maps, people define their position in their environment and also define their routes through the network. Cognitive Mapping makes the orientation within an urban system possible. The idea of continousness is important for this orientation.
Beside the adaption of continuousness the cognitive knowledge of the network has an influence in the route choice. For driving accross the whole city, people will tend to recognize the street pattern in terms of main roads. In the case of pedestrian movement the network will be read on a small-scale structure. There is even a difference between tourists and citizens. Not knowing the network so well, a tourist will choose the path with the least angles for the best orientation; the citizen the shortest Euclidian path (Hillier, 1994; Turner, 2000, 2001).
Montello summarizes two categories of distance: cognitive distance that concerns people's belief about distance where the destination cannot be seen; perceptual distance that concerns beliefs about directly observable destinations (Montello, 1991). People tend to think of route choice in terms of cognitive distance, but network users very often do make

perceptual decisions and not cognitive ones. Hence cognitive distance appears to be inconsistent. The usage of the network is based upon the interaction of these two ways of navigating a network. Before starting a journey, first the route will be chosen using knowledge of the city´s cognitive map; and secondly, decisions are made in situ by perceptual indicators. This situation can occur in rush hours when people get stuck in a traffic jam, then side street streets beside the focused path with fewer cars are preffered.
Sadalla and Magal found out for the estimation of lengths of paths that if a trip has fewer turns, even if the physical distance is longer, people find it shorter (Sadalla, Magal, 1980). Hillier argues that the least-angled path is best and metrically shortest paths the worst. He goes on to explain that people navigate with a mental mode or architectural mode of distances, but with a geometric mental mode of connectivities. This is not a simple account of distances, and has major implications for how cities are designed (Hillier, 2005). Hence, for route choice analysis a route is divided into segments. Each segment is perceived as a single element of the interdeterminate length, but turns themselves are remembered, ergo a weighted graph (Sadalla, Magal, 1980; Turner, Dalton, 2007).

A conclusion can be summarized on the basis Lynch already noted in the 1960s : the idea of continuousness correlates to the appearance of the number and degree of angles. The key concept is the idea of as few turns as possible to achieve a route from origin to destination. The cascade is determined by the quantification of how likely the selected space is part of the trip between origin and destination. By visualising the cascade of a path beeing chosen for a route a hierarchical flow pattern can be originated.

7.2 Methodology: Betweeness Centrality versus Centrality

In the field of space syntax, angular analysis is also known as *betweenness centrality*. Integration is the topological measure of *centrality*. So, what is the distinction of angular analysis from integration? Angular analysis consists of a weighted graph to calculate the syntactic metrics . It is the predicition of simulation of movement through, and occupancy of space. *Choice*, a space syntax term of the angular analysis, quantifies how likely the selected space is part of the trip for all the possible combinations of origin and destination. In contrast, integration is a non weighted standard measure.
The idea of integrating angles into the calculation of street systems appeared with the discovery of diverse interesting phenomena. There are two major indicators: General it is easier for people to place themselves when the grid is not deformed that when it is. People linearize routes when taking it to have shallower turns toward their goals. In the case of

angles people tend to round angles to 90 degrees. The subject memory of turns is better in right-angles, so when there is a doubt, a turn is rounded to 90 degrees for a better placement of oneself for choosing a route for a trip in the urban network (Turner, 2001). Three types of human turns exist in this regard: no turn, fork, right angle (Conroy, 2001).

From there, segment analysis or angular analysis is about the *absolute* change of direction (Turner, 2000) by moving (pedestrian, vehicle, etc.) from A to B. The basic idea is the minimal change of direction. Hence, the distinction is between *minimum angular path* (MAP), (Turner, 2000) and the minimum distance path (Euclidean measure) between two points. As already mentioned the tourist will mostly follow the minimum angular path and the local the Euclidean distance. The major impact of angular analysis is to use the way people orientate themselves (cognitive assumptions of networks by angles, linearizing routes, etc.) to visualise the choice of routes in a street network.

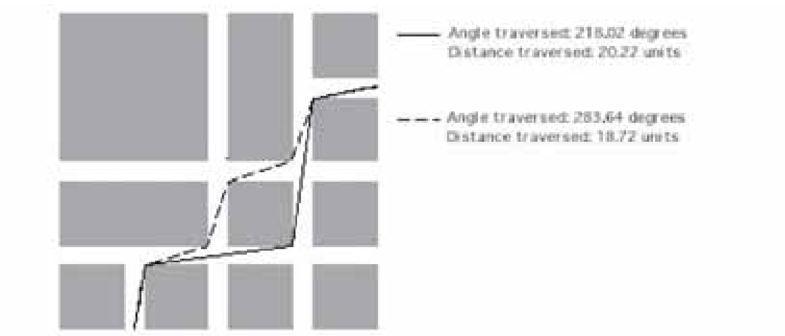


Figure 126: Minimum Euclidean path and minimum angular path

For the segment analysis a weighted graph is calculated. The weighted sum of the edges is calculated and each edge is weighted by the angle of connection. In the calculation of a path from A to B, normally integration would be calculated. Therefore, we have to look back to the proposed question of the distinction between angular analysis and integration:

Integration is a measure of depth and focuses on the correlation of movement and mean depth (see chapter on global and local measures of space syntax). It has to be noted, that researchers assume the integration measure with regard to centrality as an indicator of how people move around. Axial Integration is the causal factor of movement. As discussed above, some turns are more important to pedestrians than others, conditioned by the human´s cognition. Turner points out that a slight shift of 15 degrees is not considered a turn (Turner, 2000). This links to Lynch´s continuous path theory and supports the importance of different angles to the human mind (Lynch, 1960) in the context of orientation. Axial Integration works with topological steps; every turn is equal and coherent to one topological step. A singular axial line defines one syntactic step on a non-weighted calculation. One key outcome is that the results of standard axial mean depth and angular mean depth, both calculated for line A, are completely different.

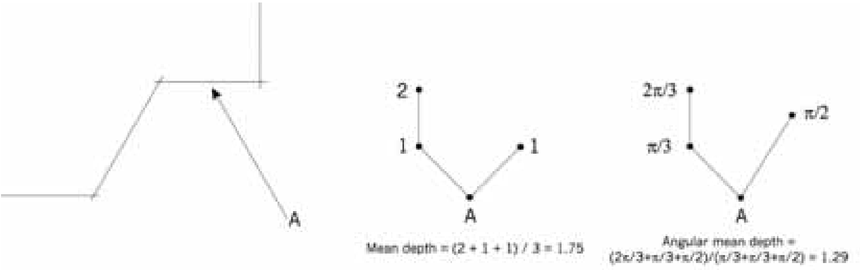


Figure 127: Mean depth - integration versus mean depth angular analysis

(Note: The results of the shown figures have no units; the use of degrees or any other measure for angles has no consequence for the result of mean depth.) It still has to be considered, that mean depth and angular mean depth are two different views of a system. Mean Deapth is an analysis of how deep or shallow a system is. The more shallow a system the better connected and easier to move around it is. Integration as 1/MD or 1/RRA enables to measurement of the relative accessibility of space within a system and links to the idea of centrality. The more central an area is, the better the accessability. Therefore angular analysis enables to illustrate a hierarchical impact in betweeness centrality. This links to the choice of routes. The origin and destination of a journey is important - the major inquiry to an analytical request.

Formally, angular analysis weights any j-graph by the angle (in radiants) of each connecting pair of axial lines. To calculate angular mean depth, the shortest angular path from every axial line to every other axial line in the system is calculated. The angular mean depth L « a for line a is the sum of the shortest angular paths over the sum of all angular intersections in the the system. It is not the number of lines in the system, for reasons which will be come apparent.

$$L^{\alpha}{}_{a} = \frac{\sum_{b \in V(L)} l_{ab}}{\sum_{e \in E(L)} w_e}$$

l ab… shortest angular path between line a and b
V(L)…set of axial lines in the system
E(L)…set of all edges in the system (connections between axial lines in the system)
we…weight (angle) of each individual connection

In conclusion, it should be pointed out that lines which are cut in the middle have no impact on the result. They can simply be cut into two and calculated as usual, because the splitting of a line into two segments does not change the total angle of the whole line. In this case the calculation of mean depth will have the same result.

7.3 Empirical Analysis and Visualisation

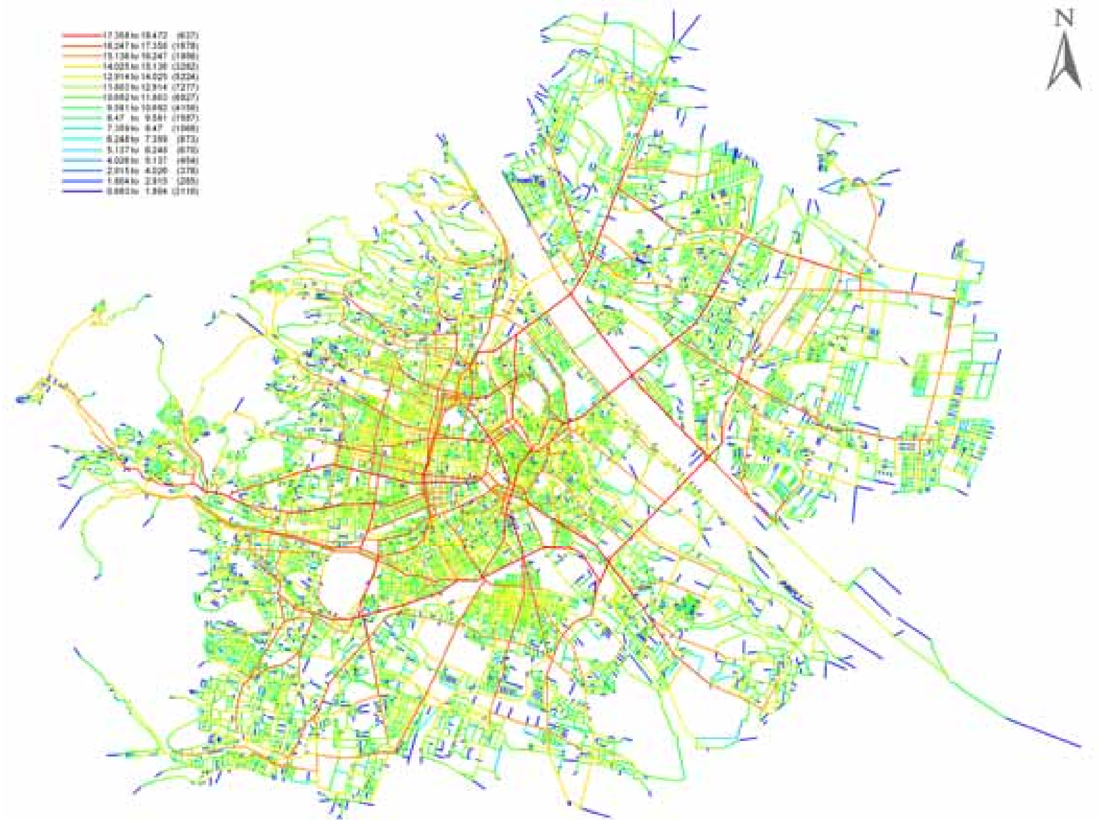


Figure 128: Angular Analysis, Choice N, Vienna 2006. The analysis of route choice shows that the continuousness of paths is linked to Vienna´s historic development. Mainly chosen paths are linked to historic supra regional roads, boulevards, the former city wall and second wall, and also to urban intervention such as gridification in the 16th Viennese district.

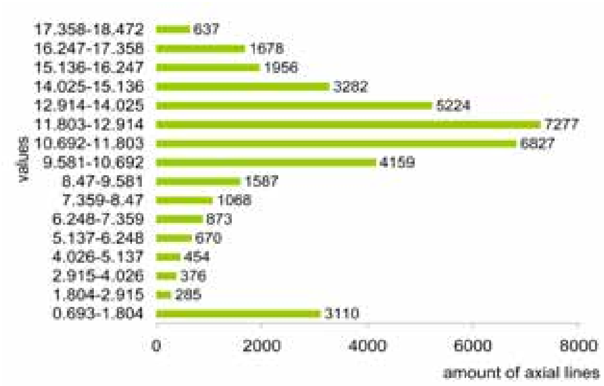


Figure 129: Segment Analysis ln2 N; results of angular analysis for Vienna, 2006. The continuousness of paths is well established in the middle field of numerical results. Therefore, orientation in Vienna is in a good mode.

Figure 130: Angular Analysis, Choice N, 5 per cent core; this core highlights the former city wall, second wall, and partly the historic supra regional streets - the skeleton of the city.

Figure 131: Angular Analysis, Choice N, 7.5 per cent core; main artery roads are highlighted

Figure 132: Angular Analysis, Choice N, 10 per cent core; it represents the main artery roads of Vienna.

Figure 133: Angular Analysis, Choice N, 15 per cent core; dense main network of Vienna

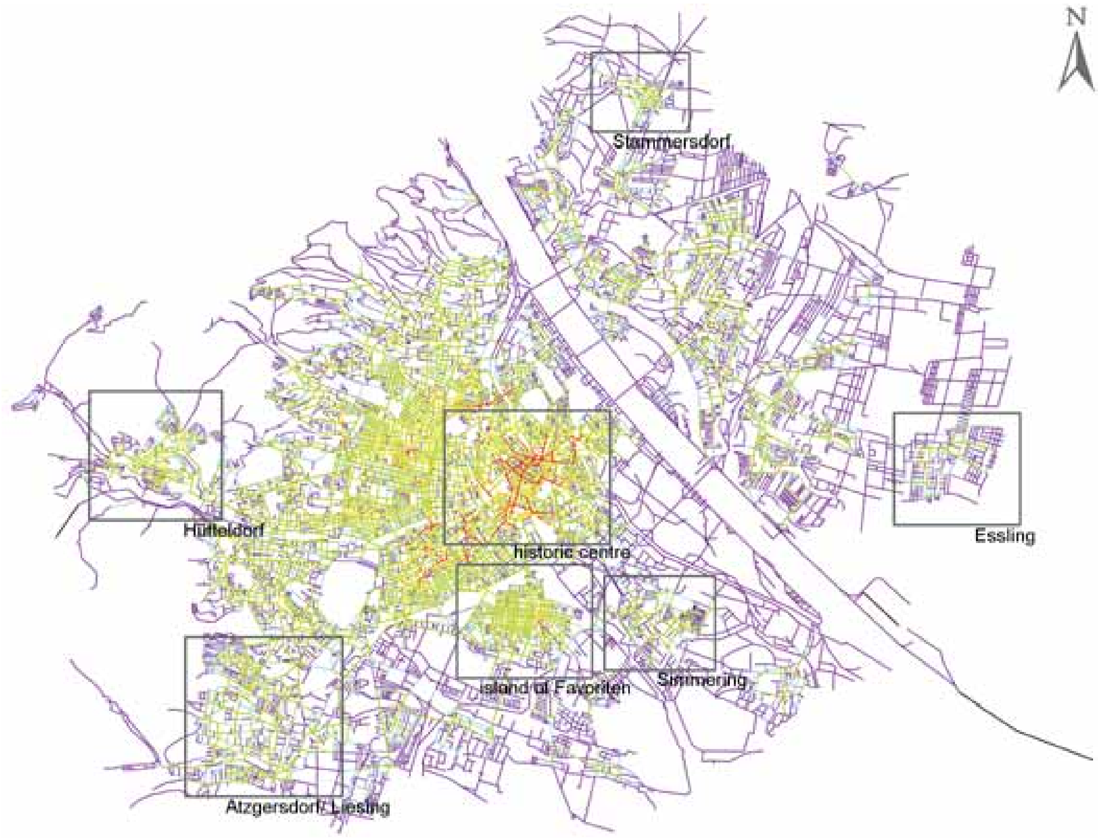


Figure 134: Angular analysis 1200m; as an interesting side-effect Choice 1200 (metric) highlights sub-centres. These can be identified as former villages (Hütteldorf, Atzgersdorf, and so on). Also the island effect of Favoriten´s centre emerges.

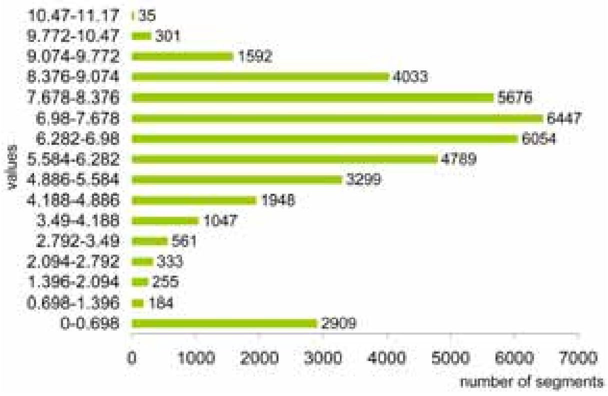


Figure 135: Angular Analysis, Choice 1200m, Vienna 2006

7.4 Structure-Function-Model: Correlation with the Traffic Census

For this correlation the values of angular analysis were allotted to their relevant street hierarchy in the urban system. The street hierarchy is represented by the car volume for the correlation matrix.

Again, the traffic model of the year 2000 was chosen. It contains the traffic census of highways - hierarchy 1, main roads B - hierarchy 2, and main roads A - hierarchy 3. Altogether, 76 counting points were picked. They split into three parts: 22 counting points for highways, 27 counting points for main roads B, and 27 counting points for main roads A. Regarding the traffic census, DTVw, representing the annual average of daily traffic volume from Monday to Friday, was selected.

Figure 136: Visualisation of the traffic census, Vienna 2000

In the next step the chosen counting points of the traffic census will be compared to the value range of the angular analysis with regard to a hierarchical impact. We will see, if the cognitive route choice follows the same laws as the traffic volume, ergo, the planned hierarchy of the chosen streets for a journey in real life.

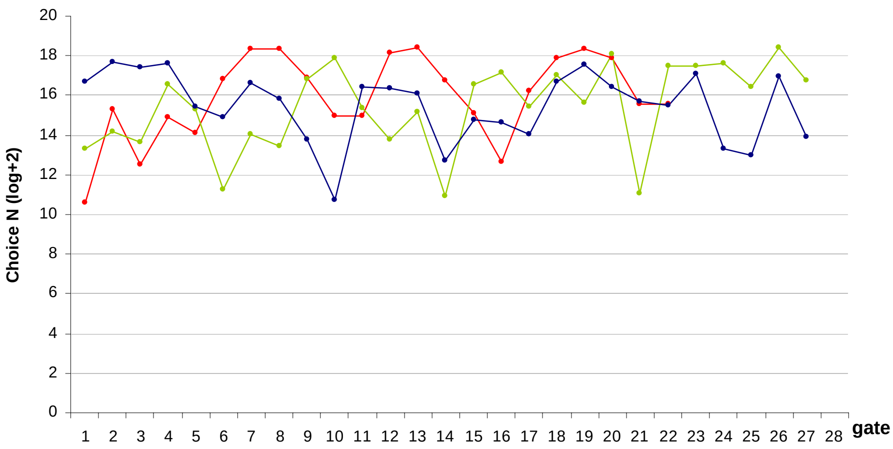


Figure 123: Coherence of angular analysis, choice N ln2 and street hierarchy by governmental planning and traffic volume.

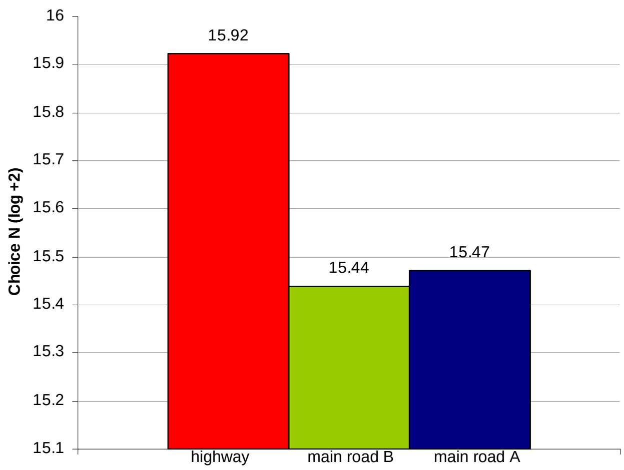


Figure 138: Coherence of angular analysis, choice N ln2 and street hierarchy by governmental planning and traffic volume.

The hierarchical coherence between the most used routes from A to B and the traffic volume is not as clear as in the structure function model of the “planned hierarchy”. The highway has the highest mean value with 15.92, the main road B has a value of 15.44 and main road A 15.47. Independently of the highway the hierarchical impact of the main streets is not clear at all in the context of cognitive route choice. The calculation of the correlation shows a very interesting result.

The correlation between highway and anguar analysis values is 0.58916; between main road B and angular analysis values 0.41417; and between main road A and angular analysis values 0.14712. We can observe that the the higher the hierarchical level (e.g. highway) the better the correlation, and the lower the hierarchical level the less correlation between route choice and traffic volume. This means, that at the top (highway) of the hierarchy, the hierarchical impact is very well established, whereas at the bottom of the hierarchy there is no longer a necessecity any more for a high distinction of route choice for a journey. Car traffic volume and cognitive route coice are independent of each other, because planned hierarchy stresses the use of pre-set conncections by speed limitation, geometry, one way signs, public transport like buses and trams, etc.

7.5 Conclusion and Discussion

Cognitive literature has stressed the fact that cognitive maps are not necessarily realistic constructions. They are exaggerated, transformed entities that simplify reality. One major criticism is the perception of distance by individual actors within an urban system. Another point of criticism is that pedestrians and drivers will choose the route based on the characteristics of time, origin, destination, and purpose. These attributes offer alternative routes and the individual cognition will combine these attributes with the optimal route choice for the appropriate trip. Chiaradia and Polydoropoulou (Chiaradi, 2007; Polydoropoulou et al., 1994) summarize the process of decision-making as a dynamic one including a learning process of the actor´s cognition.

Variations in a driver´s route choice can be influenced by the spatial layout and socio-demographic layout of the built environment. Spatial layout consists of the network infrastructure, intersections, and so on whereas the socio-demographic layout describes households characteristics, education, etc. The possible factors influencing route choice (micro, intermediate, and macro scale) are summarized by Jan (Jan et al., 2000).

driver	age, gender, income, level, education, household structure, race, profession, length of residence, number of drivers in family, number of cars in family, etc.
route	travel time, travel cost, speed limits, waiting time
road	type of road, width, length, number of lanes, etc.
traffic	traffic density, number of turns, stop signs, traffic lights, travel speed, probability of accident, reliability and variability in travel time, etc.
environment	aesthetics, land use along roads, scenery, ease of pick-up and drop-off, safety, parking, etc.
trip	trip purpose, time budget, time of trip, mode use, number of drivers
circumstances	weather conditions, day/night, accident en route, route and traffic information, etc.

Figure 139 : Factors for a route choice

Every urban system provides secret paths to optimize time costs, arising through waiting time, rush hour and stop and go traffic, traffic lights or construction sites. Also, driving is on a psychological scale and influences the individual route choice. For example, secrets paths mean less stress for the driver as the disturbing factors can be better estimated. Fewer actors using these routes is equivalent to less individual behaviour and implicates a less dynamic complex system. Even for secret paths having a longer Euclidean length, the reduced stress factor of fluent driving behaviour, privilege these route choices.

In Vienna we find popular secret paths parallel to main routes in both directions. Figure 140 shows two secret paths "inside" and "outside" the Viennese Gürtel in both driving directions.

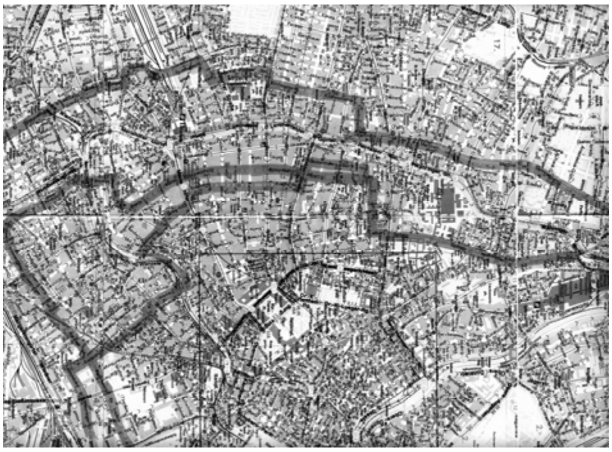


Figure 140: Viennese secret paths to avoid heavy traffic on main roads of Gürtel - former second wall

Chiaradia (Chiaradia, 2007) provides guidance on factors affecting the driver´s mode to understand the strategies drivers use to determine or change their route. These factors are spatial knowledge about the built environment; travel-related decisions which also include job and residential location; activity schedule, vehicle ownership, imperfection of travellers, and also pre-information and information on the network.

In the context of a pedestrian´s route choice some driver´s influencing variables are effective. The level of knowledge of the network implements different modes. Primary factors for a pedestrian´s route choice are the shortest Euclidean distance, time budget, stop-overs, sub-ordinate subjects on the route, and beauty of the chosen route- these all play an important role. These can lead to different decisions on a two way route - origin to destination or destination to origin.

Greene implies the questions (Greene et al., 2007) whether "one goes back the same way that one comes back"? Conroy Dalton (Conroy Dalton, 2001, 2003) posed the problem of identical outwards and return segements in route choice as *The British Library Theory*. It is named after both the practial application of the experiment and the location. Identical topological and metric paths link two destinations - desk location A, inquiry desk – in a generic reading room of a british library. Because of their over-all symmetry it seems obviously that all users choose each selected path equally. Instead, most people follow the "longest leg", a diagonalization of the grid, a route which deviates from their destination. Changes of direction may influence route choice. Besides a psychological effect a route can seem quicker from one end and may not be perceived so from the other end. Conroy Dalton points out that route choice is a competition between a selection of the simplest

route and the desire to maintain a heading closest to the direction of the destination from the origin in the context of angularity (Conroy Dalton, 2001).
A technical problem within segment analysis is the *resolution problem*. Segment analysis is a simple algorithm of a weighted axial graph. Turner (Turner, 2001) highlights that the problem of "choice" is linked to increasing resolution. Through the segmentation of an axial map the integrated long lines turn into a segmented mass of shorter lines. Each time, a step has to be taken to pass from one segment to the next. Hillier´s analytical theory targets length and linearity in a deformed grid of diverse routes. The solution to this problem is additive implementation of steps. For example, with the segmentation of a straight line, 0 degrees, no step, whereas with the segmentation of a T-junction, 90 degrees, 1 step is included. A continous range in-between completes this heuristic system. Hillier and Iida (Hillier, Iida, 2004) have performed this solution with a software written by Iida as an on-going research.

Finally, a route can be expressed as the sum of all psychologcial, socio-demographic and functional decisions of all potential choices during a journey (Conroy Dalton, 2001). This raises the question of the impact of diverse transport management technologies such as vehicular guidance, control, and safety systems when receiving Global Positioning System (GPS) signals. This technical assistance is in use for locomotion of all kinds such as pedestrian movement, bicycles, and cars. Through the introduction of electronical assisstence systems a subversive system change is carried out. It launches the option of central control of a former de-central coordinated system. Car and driver transform more and more into a mechanical part of the whole traffic system. Permanent interaction with the system on order to avoid traffic jams influences route choice and planning. Therefore it generates a passive influence on traffic and a dynamic route choice. A socio-technical system emerges as an instrument of behaviour control. Soft stress on the actor determines activities for a better performance, capacity and functionality of a system.
Hence, new terms of *active* and *passive route choice* as an effect on individual or system-oriented route choice should be introduced. Within passive route choice important psychological indicators are omitted. Missing psychological paradigm in passive route choice leads to different results in modelling.

PART IV

CONCLUSION AND DISCUSSION

III. EPILOGUE

Wissenschaft ist die Suche nach dem
"Wie das Leben funktioniert";
wir selbst sind das Leben.
(Georg Kattinger, 2007)

Science is the search
for how "life is put together";
we ourselves are life.
(Georg Kattinger, 2007)

In this research four different static urban models [within the context of morphology and dynamic indicators as being the heuristic principles] serve as the basis for the research question of the phenomenological appearance of an urban and, therefore, spatial hierarchy. The approach to this topic is from different viewpoints of graph theory, dynamics, physics, and cognition solved by a mathematical approach. Even knowing the inherent difficulty in linking these different aspects in a limited research project, it was important to do so to extract the best aggregation for the underlying question.

Life itself was the inspiration for combining all these controversial and, at the same, time linked matters. The linkage was defined through using hierarchy as the *sacred rule*, in all its diverse spatial appearances, and then adequate modelling, being the underlying and responsible structural impact, is assigned. Within static modelling, an extraordinary conception of hierarchy emerged. Static models have the advantage of describing and presenting the aspects of a system for a precise moment and, due to this, it identifies different attributes of an individual aspect.

In general, hierarchy is effective in various systematic forms of every living system. For this case study the most significant representations of spatial network analyses and complex systems were chosen. In general, the idea of hierarchy can be defined with regards to many more aspects from social hierarchies, to ecological hierarchies, economical hierarchies, etc. Being aware of the impact of these hierarchies on urban systems, the decision was taken to focus on the architectural mode of networks. Within some theoretical applications, like Christaller´s Central Place theory and stochastic fractals, the economic influence penetrates the spatial analysis in this research. Interdisciplinary work and the combination of architectural and geographical scale has to be the focus, with urban planning support to solve problems of functionality, which is often linked with the aspect of segregation and separation.

This leads to the idea of dynamic models. According to Agbossou, agent-based models can let you be more realistic by representing human cognition in the field of a social domain. In this case, agents who can "think" are used. Another advantage is the facility of easily integrating the temporal dimension in the model. In case of the spatial dimension, reactive agents who have the ability to react to events also support taking time into account. Therefore, both kinds of agents are the basis for dynamic models. To show the principle of a hierarchy for dynamic models, the definition of local and global interaction scales has to be implemented. Within cellular automata the principle of hierarchy can be explored by a probabilistic model that determines when it is time to change the cell´s spatial resolution. Each resolution in turn defines an organization level (Agbossou, 2007).

Dynamic and static models serve ideologically, among other things, the idea of sustainability. Hierarchy as a tool for optimizing functionality is linked with sustainability. (Within the chapter on urban planning this topic was briefly mentioned.) Ergo, hierarchy represents a functional element of sustainability. Sustainable urban planning and building influence, through the main topics of ecology, economy ,and socio-culture, the large-scale aspects of life.

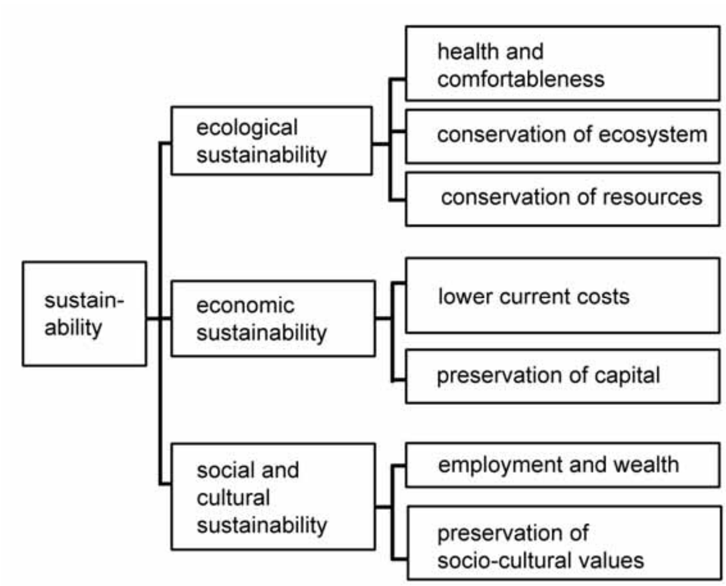


Figure 141: Coherences of sustainability

The functional attribute of a spatial hierarchy supports time saving costs, resources, costs, and so on. Therefore within urban planning and building procedures the diverse hierarchical manifestations have to be implemented for the best fit of a city. The best fit can be reached inter alia by the implementation of hierarchical street patterns as grids and radials, capillaries (Salingaros, 2003), kidney shapes, etc. (Lynch, 1981).

To support this best fit, different methods were used to identify hierarchy not just as an phenomena, but also in its phenomenology. Phenomenology is an objective tool for describing and recording given phenomena. It was used as a heuristic tool to identify different characteristics of the urban hierarchy.

A.) Space Syntax

By the application of this analytical theory to Vienna, the topological emergence of a spatial hierarchy in the form of the relationship between centre and periphery was identified. The analysis highlighted the nearly radial-concentric or mono-centric shape of the city. One reason is that within political planning interventions no highways or main through roads cut this historic European town into two urban chunks. These main traffic channels are located outside the historic centre and hence preserve the urban nucleus. In this analysis, not only was the relationship between historic centre and periphery analysed but also sub-centres such as former villages, which complete the cascade of a hierarchy between bottom and top.

The so called “edge city” (Garreau, 1991), as an urban form where periphery becomes another form of centrality, was not the focus here. Shopping malls, as artificial centres, are linked to the traffic flow (with a high accessibility by car) and therefore are not part of the overall configuration of a city. As a result, it is possible to detect the different areas of the city with regard to their individual internal ranking and therefore movement volume.

B.) Fractal Analysis

The fractal analysis used in this case study is based on metric attributes. It has the advantages of identifying the “texture” of a network. Correlation analysis identifies the metric area where the transformation from linearity to a structural network takes place; how winding (detour and accessibility analysis) a system gives an indicator for the functionality; and finally the mass of a network (radius mass analysis), which is another interpretation for the spatial aspect of a network. The results of these analyses in the form of the fractal dimension [D] offer the opportunity to detect the morphological layout of the network and evaluate it for further planning interventions.

AB.) Space Syntax versus Fractal Analysis

Within the methodology of space syntax and fractal analysis some coherence exists. Both theories incorporate the idea of accessibility. Space Syntax works with the concept of configuration, topology, connectivity, and centrality. It measures, by the number of syntactic steps, the accessibility of a system. In other words, the longer and more intersected a street is with other streets (open spaces) the more central it is. Hence, integration is important.

In contrast, the accessibility method of fractal theory works with the law of distribution of occupied points around a chosen starting point. The counting window around the starting point defines the metric distance and is defined on the network. The functional aspect of accessibility is shown by metric distance. The higher the fractal dimension [D], the better a network is connected because more occupied elements are counted. The “texture” (Bovill, 1996) of a network can be detected by a metric distance.

The idea “the more texture it has, the better a network is connected, the higher the accessibility” of a system is implemented in both methodologies. A high number of streets and high connectivity produces a higher metric radius of accessibility or a higher number of high accessible streets.

C.) Political Planning Interventions - Analysis

This empirical analysis within the context of hierarchy was of interest for describing how political planning deals with the idea of hierarchy and how strategic planning interventions are implemented under the condition of traffic. The assignment of Vienna’s streets to a hierarchy allowed the correlation with the traffic census. A high overlap between political evaluation of streets and traffic volume was the result. It is interesting that through the individual percentage of street space in each Viennese district the development of the city emerged.
The outcome of the case study highlights the importance of hierarchy for the best functional fit.

D.) Segment Analysis (Choice)

Cognition in the context of hierarchy is of interest with regard to the individual behaviour of people when travelling through a city. The travelling characteristics of individual choices and decisions is another dynamic indicator for the use of a street network. The aspect of cognition, in combination with graph theory, focuses on human behaviour. Important within this empirical analysis were the ideas of landmarks (Lynch, 1960) and continuousness of streets (angle weighted graph). The streets with the highest value in the analysis are streets which are also important from a historical perspective, for example, the former city wall and second wall, supra regional streets for supply, boulevards, and main routes along the river. Diverse per cent cores highlight these historic facts even more. Also, urban planning interventions during the 19th and 20th century are emphasised.

In general, traffic census and route choice only correlate in the highest range values of the network hierarchy. Streets in a lower hierarchy level (towards the bottom of the network hierarchy) seem to interfuse. Ergo, for route choice they operate more or less with the same probability being chosen. Extension of the network by adding additional streets can be linked to route choice to support the user with more opportunities when travelling.

CD.) Political Planning versus Segment Analysis

Both of these concepts incorporate the idea of individual choice linked to linearity. Urban planning interventions strongly correspond to the traffic census. This census is also influenced by speed limit. For example, a highway is mostly a straight long route for rapid transportation from A to B. This is supported by a higher speed limit. The high hierarchical level of a highway was not only highlighted in the urban planning-analysis but also in the segment analysis. Hence, on a global scale both analyses came up with the same results. In contrast, on an intermediate and local scale the analysis diverged. Why? In a traditional European city the local network of the traditional city is highly connected but "labyrinthine". Highly linear routes are not the majority (except for urban ruptures such as former city walls, supra regional routes, etc.). Therefore, the concept of political planning still works with the width of streets, one way routes, give way signs, and speed limit. This facilitates a link with the traffic volume and offers the best fit for an optimal traffic flow. On the other hand, segment analysis works with the idea of angularity. It highlights how the network works topologically within individual route choice on the basis of the theory of linearity. So, the intermediate and local levels are represented by nearly the same mean values in this analysis in a traditional European city.

All of the above described methodologies raise the ability of detecting the urban needs of a city and reacting in an adequate manner. By understanding the hierarchical impact on complex urban systems, optimal and effective urban planning can be carried out.
Until now the growth of cities has been the major focus of modelling. The trend in urbanity now also has to deal with the uncontrolled shrinking of cities, such as the donut effect (Berdahl, 2002). These hierarchical analyses can aid a systematic approach of analysing and implementing urban strategies that are able to improve the functionality of a city and, also, to support making an area more attractive through higher accessibility carried out through a network adaptation.

Another further need in the field of research is the linkage and integration of hierarchy in dynamic models, not just on the level of different resolutions, but in its widespread application. The research question is “How can the different aspects of hierarchy be incorporated into dynamic modelling?”. With this approach urban sustainability becomes totally effective. Urban planning and architecture then move towards a *humane city*.

PART IV

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List of figures:

All figures and visualisations not listed here are the work of the author. The City of Vienna, administrative department MA 18, provided a basic map of Vienna, the AREA Consult Report 2005, and traffic census. In addition, the Vienna Chamber of Commerce supported this work with data on spending capacity and pedestrian volume.

Figure I: Faller, Czerkauer, May 2007

Figure II: Faller, Czerkauer, May 2007

Figure 1: www.aiwaz.net, September 2007

Figure 2: www.aiwaz.net, September 2007

Figure 3: Marshall, 2005, 80

Figure 4: Marshall, 2005, 83

Figure 68: Insitut für Mathematik, Universität Lüneburg, May 2007, www.uni-lueneburg.de/mathe-lehramt

Figure 69: Frankhauser, 1998, 208

Figure 70: Frankhauser, 1998, 212

Figure 112: König, 2007, 11

Figure 113: RVS 03.04.12, 2001, 1

Figure 114: RVS 03.04.12, 2001, 3

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Figure 119: Areal Consult, 2005, 13

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Figure 125: MA 18, 2006

Figure 126: Turner, 2000,6

Figure 127: Turner, 2001, 30.4

Figure 136: MA 18, 2006

Figure 139: Jan et al., in: Chiaradia, 2007,3

Figure 141: basic histogram, Römmling, 2001, 2

Programs for empirical analysis:

Map Info Professional

Space Syntax Confeego, University of London & Space Syntax Ltd.

Depth Map, University of London

Fractalyze.org, Université de Franche-Comte

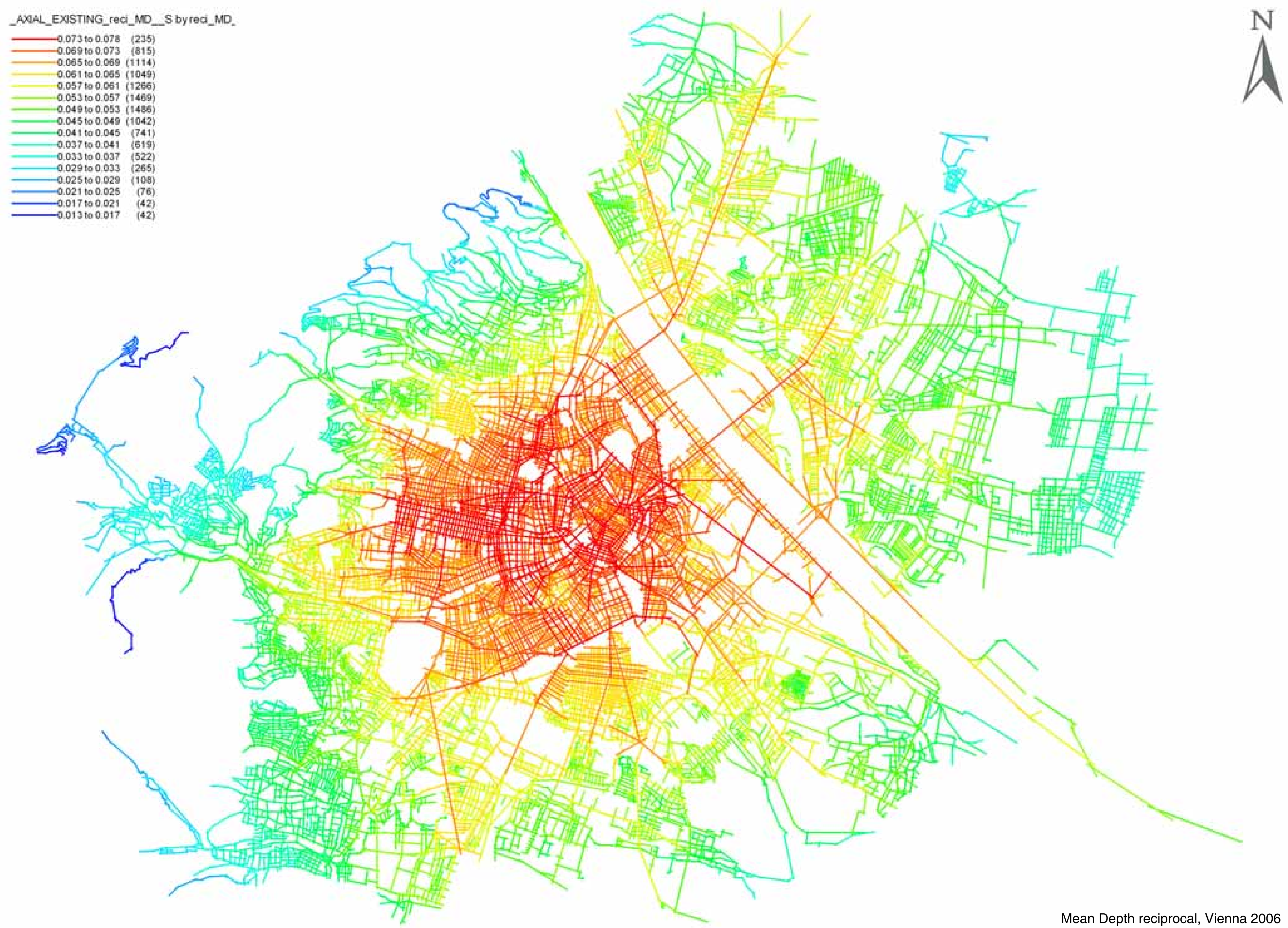
Adobe Illustrator

Adobe Photoshop

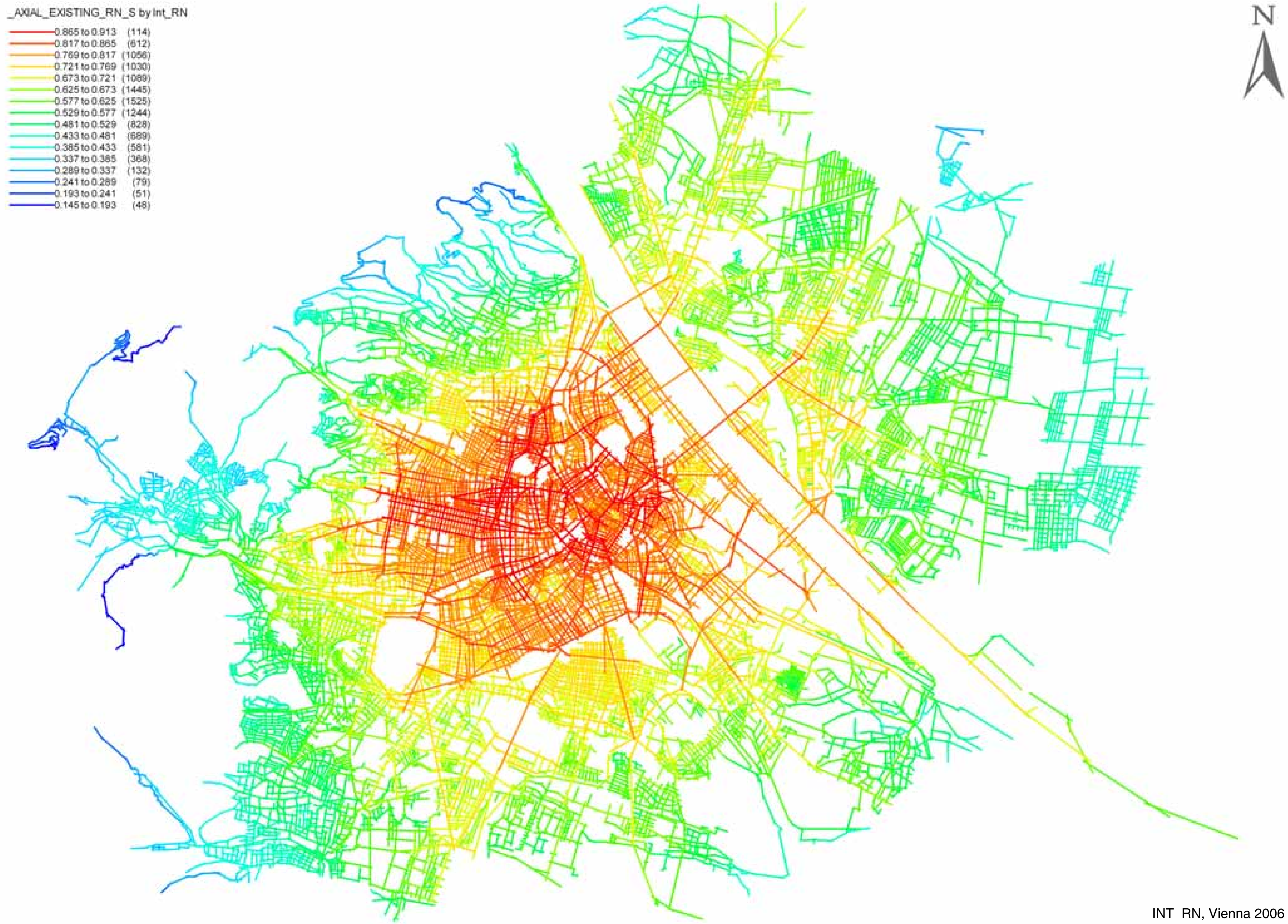
AutoCad

9. APPENDIX

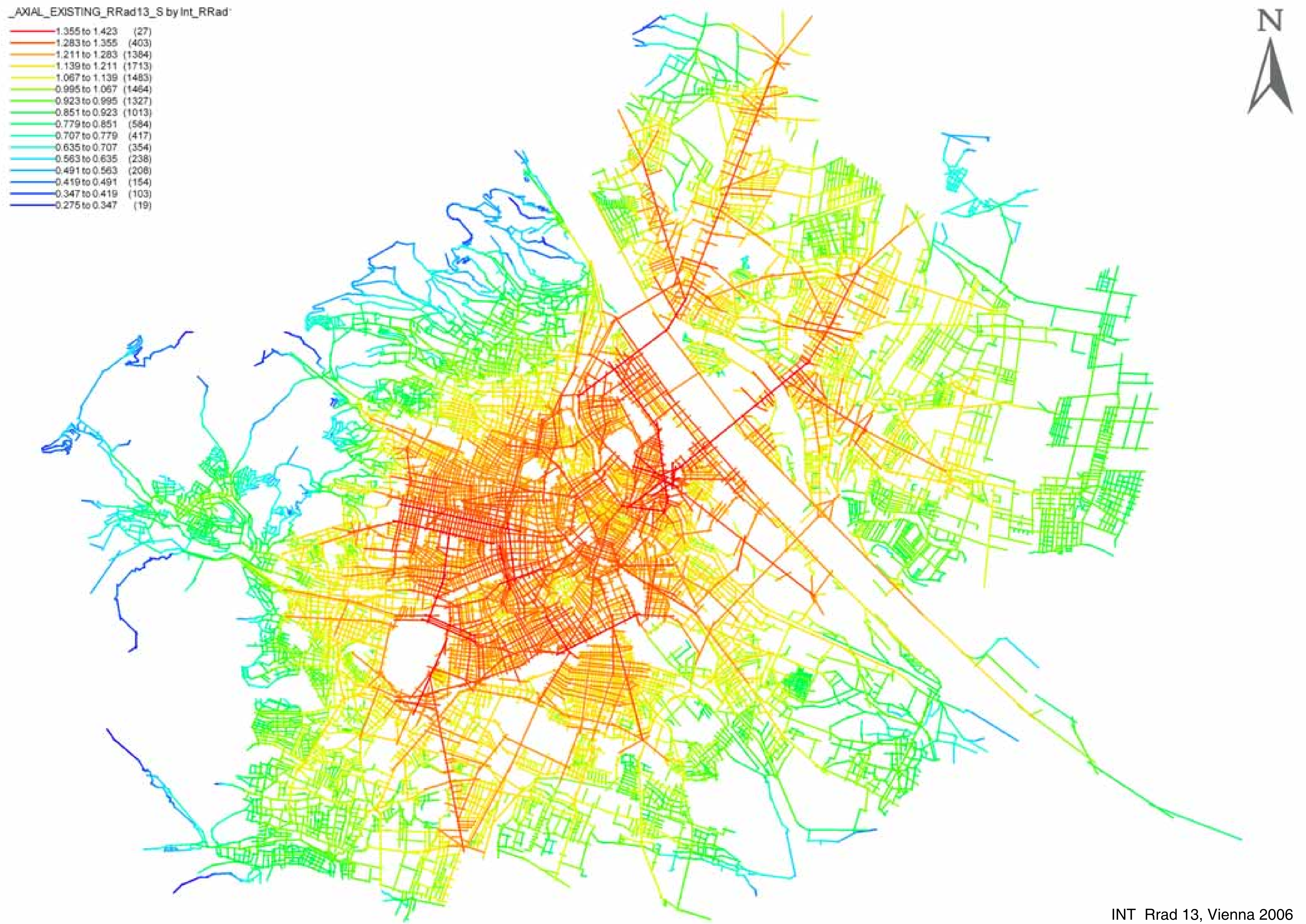
The following appendix includes some of the empirical analysis plans on A4 for a better differentiation of individual streets of the whole urban system. The individual visualisations will be in the same order as in the previous text.



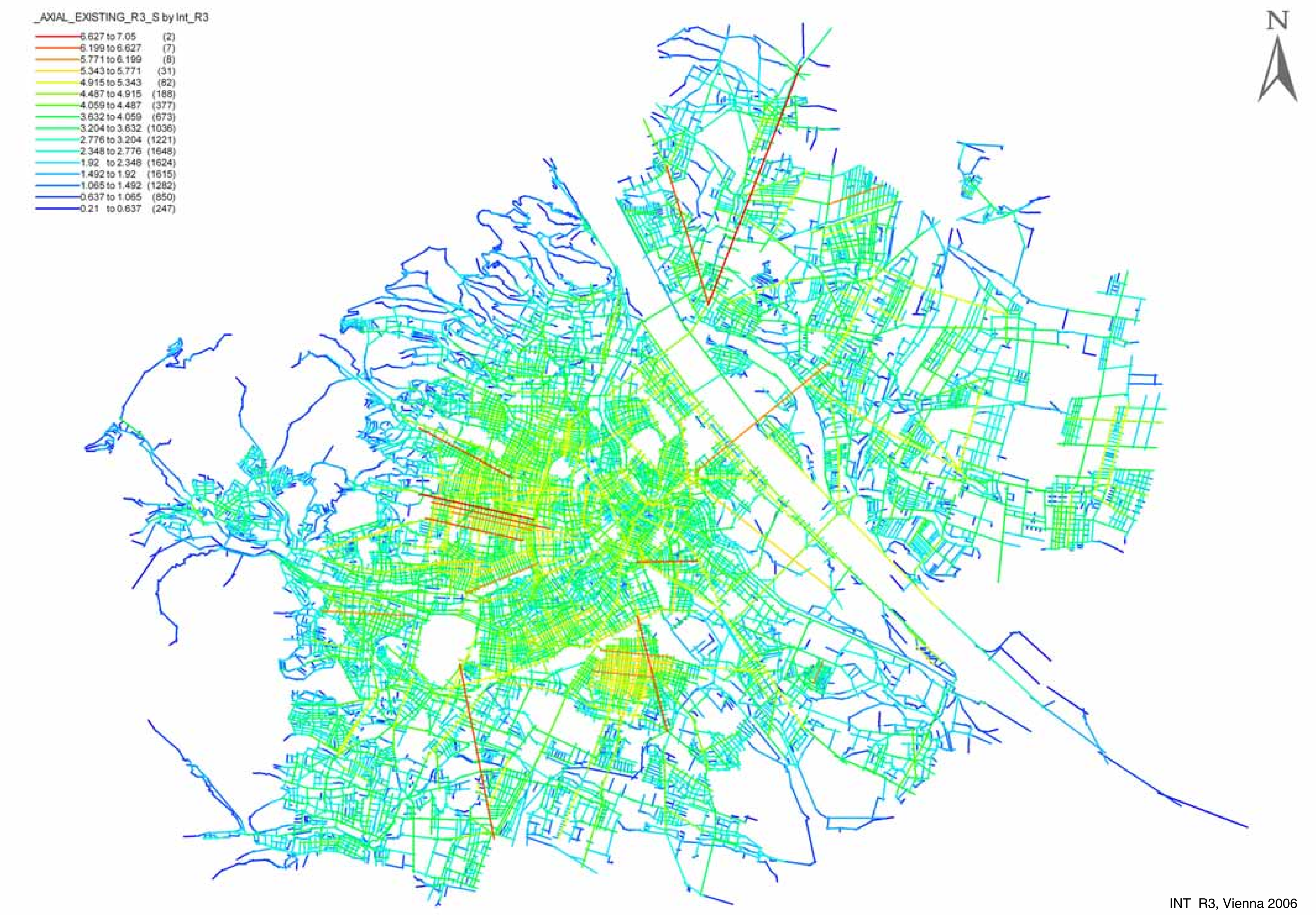
Mean Depth reciprocal, Vienna 2006

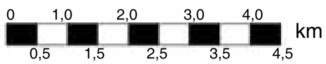


INT RN, Vienna 2006

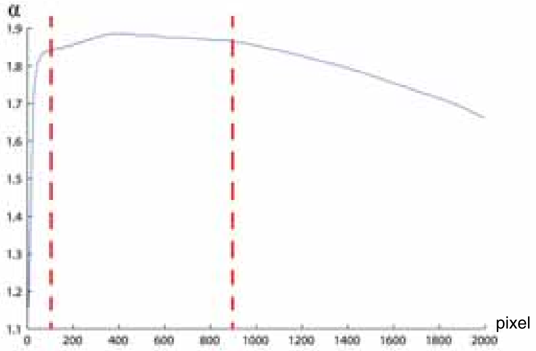


INT Rrad 13, Vienna 2006

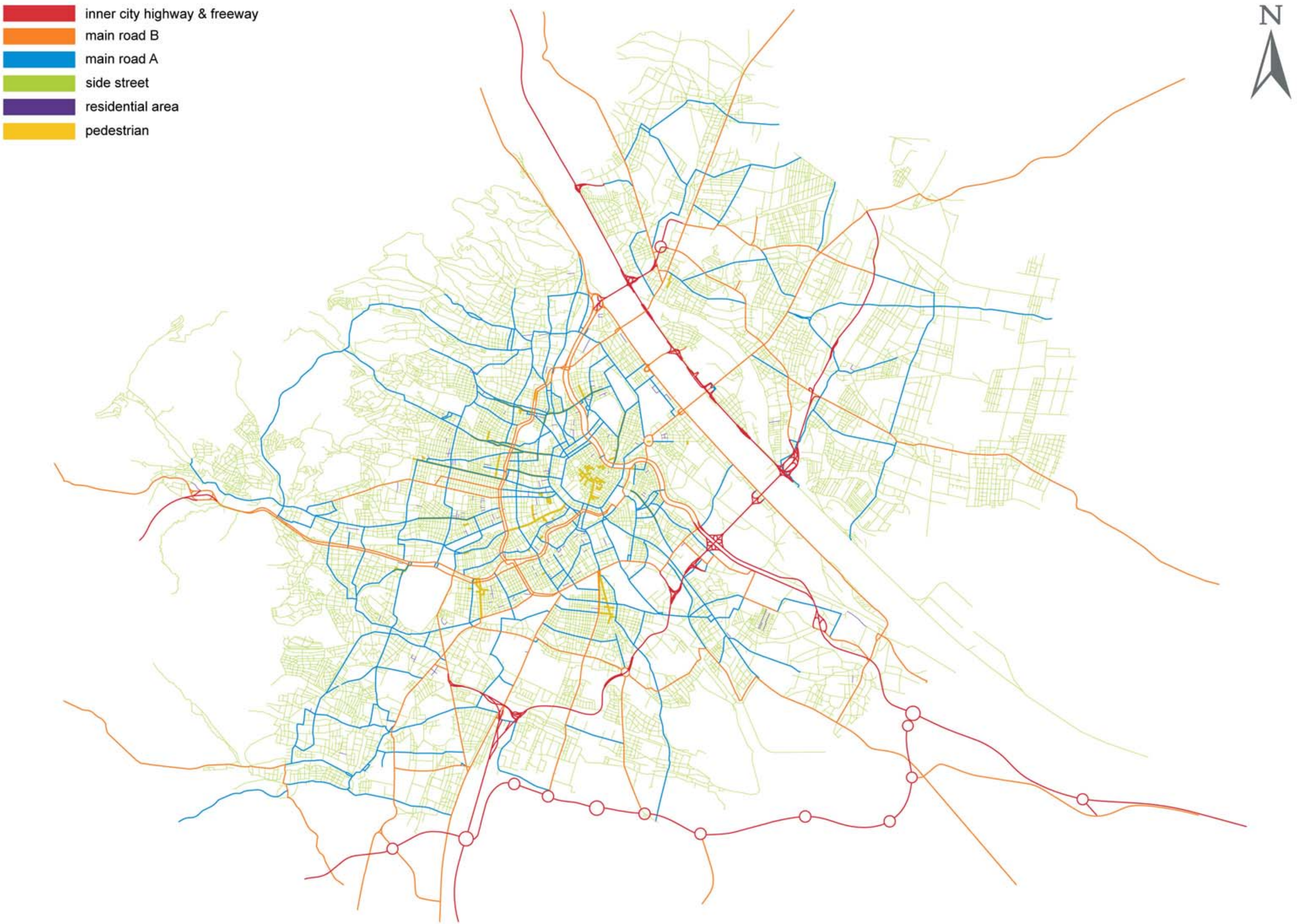

_AXIAL_EXISTING_R3_S by Int_R3
6.627 to 7.05 (2)
6.199 to 6.627 (7)
5.771 to 6.199 (8)
5.343 to 5.771 (31)
4.915 to 5.343 (82)
4.487 to 4.915 (188)
4.059 to 4.487 (377)
3.632 to 4.059 (673)
3.204 to 3.632 (1036)
2.776 to 3.204 (1221)
2.348 to 2.776 (1648)
1.92 to 2.348 (1624)
1.492 to 1.92 (1615)
1.065 to 1.492 (1282)
0.637 to 1.065 (850)
0.21 to 0.637 (247)
N
INT R3, Vienna 2006

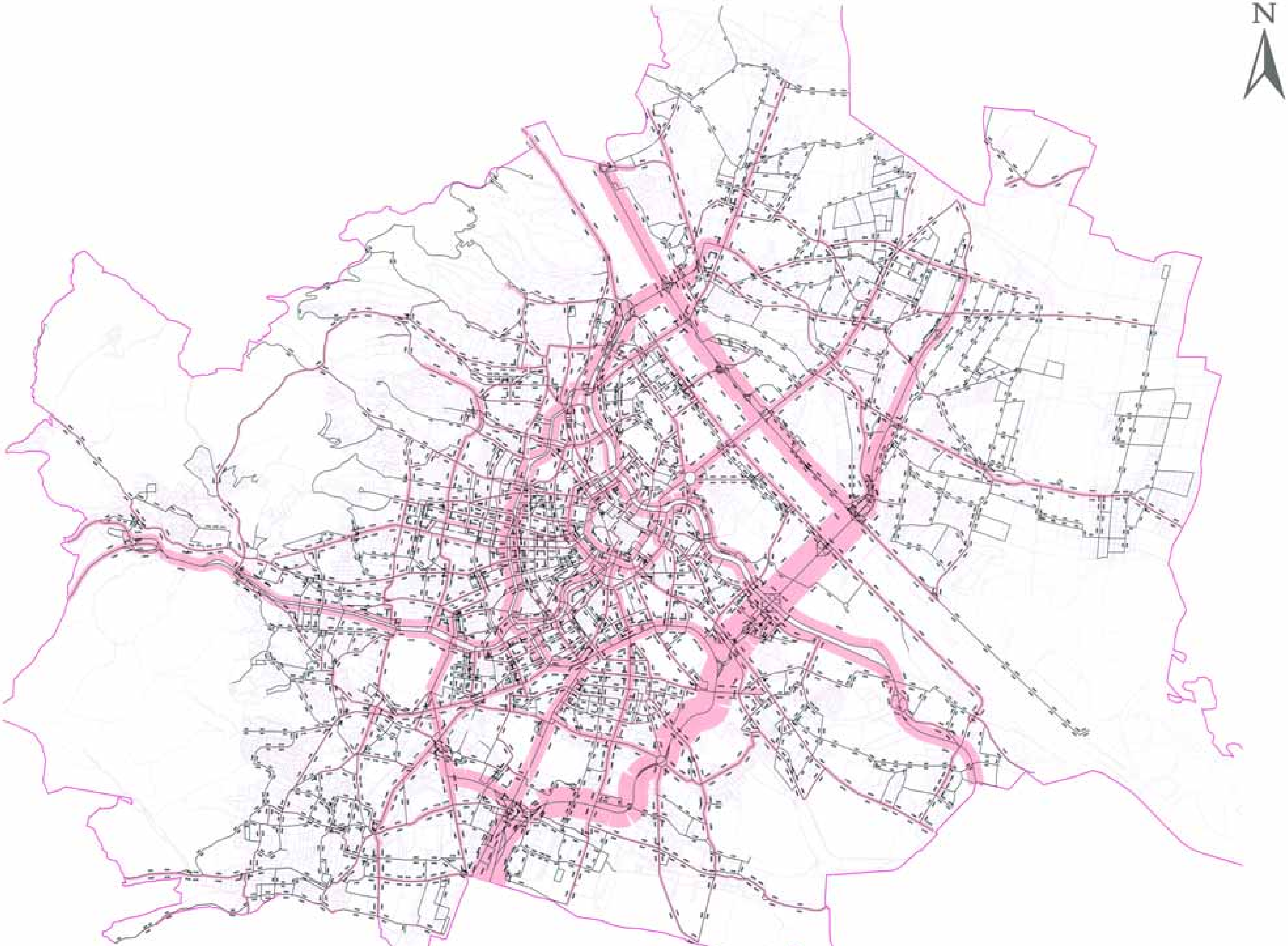


Correlation Analysis - main street network, Vienna 2006

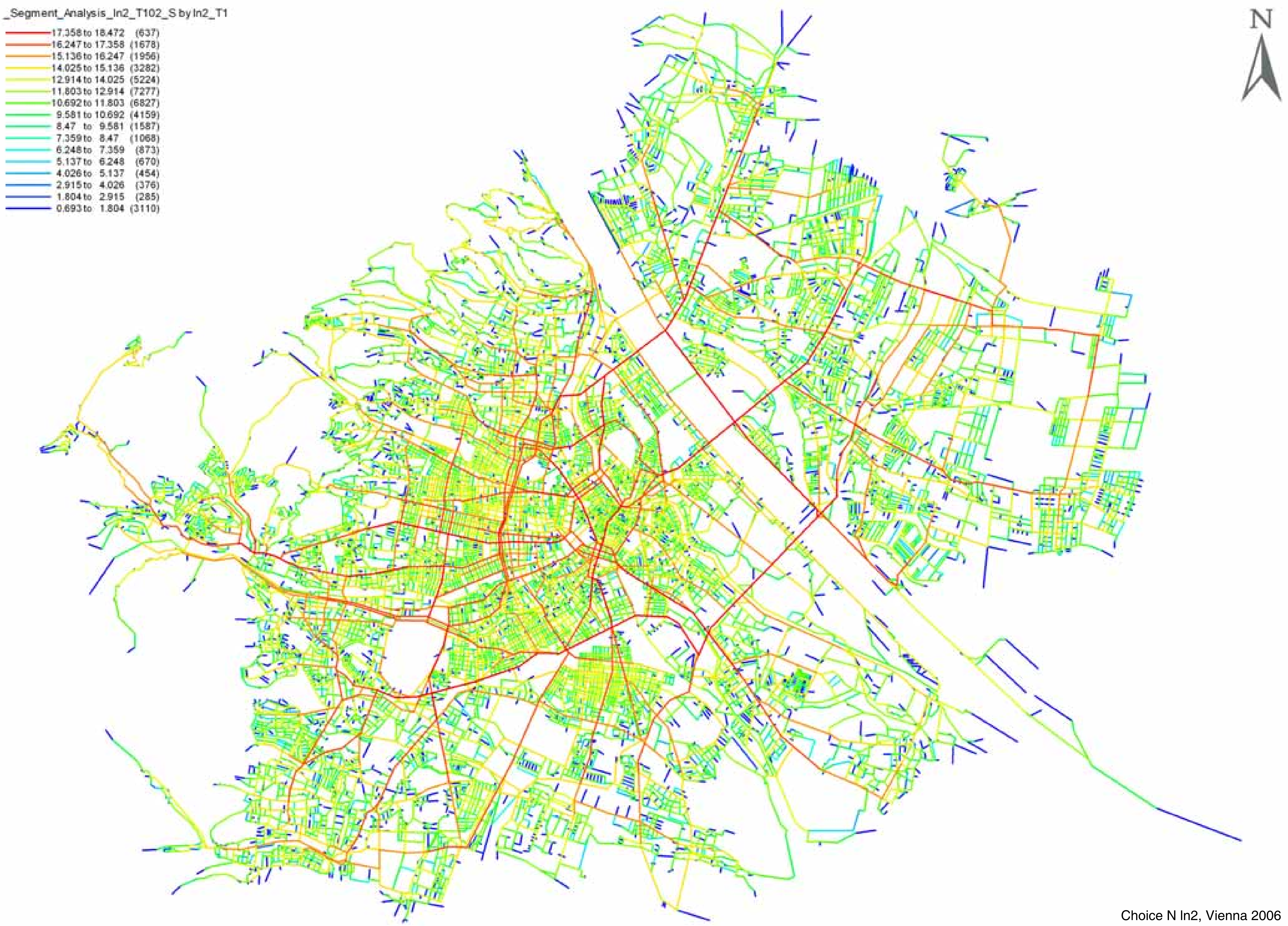


Correlation Analysis - whole street network, Vienna 2006

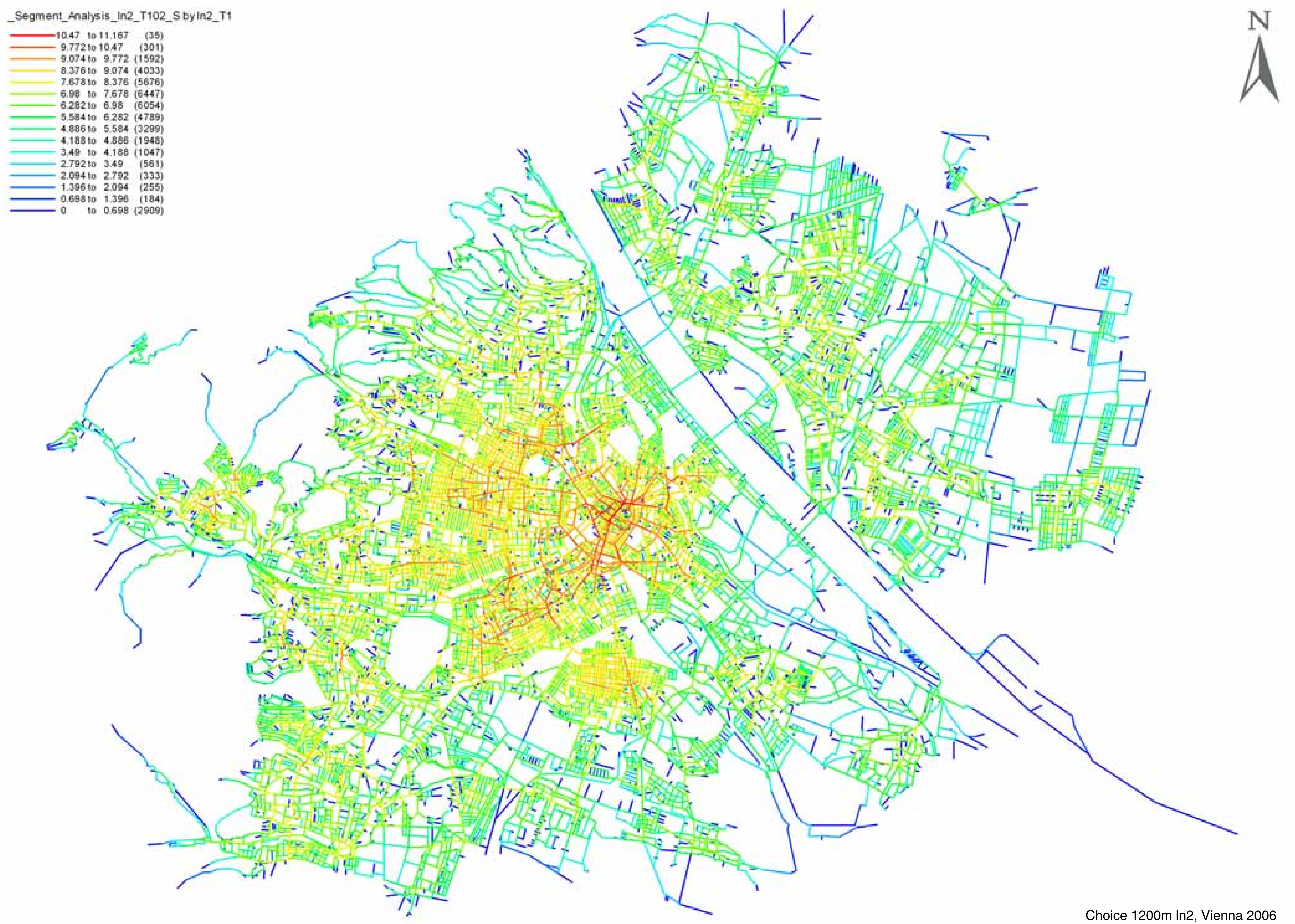

inner city highway & freeway
main road B
main road A
side street
residential area
pedestrian
N



Traffic Census 2000, administrative department MA 18, Vienna 2006



Choice N In2, Vienna 2006



Choice 1200m ln2, Vienna 2006