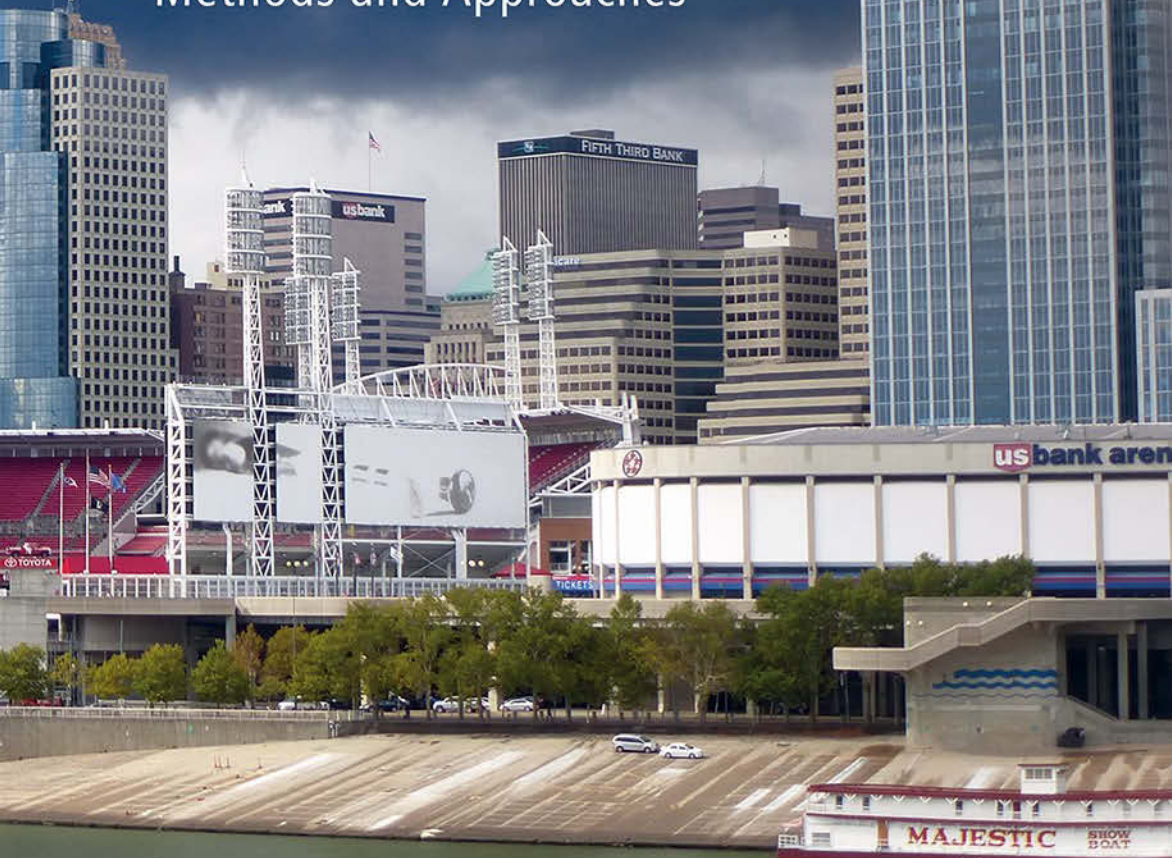
Jens Martin Gurr,
Rolf Parr, Dennis Hardt (eds.)

METRO-POLITAN RESEARCH

Methods and Approaches



[transcript] UrbanStudies

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Metropolitan Research

Urban Studies

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Contents

Introduction

Jens Martin Gurr/Rolf Parr/Dennis Hardt

This collection results from work in the research field "Methodologies in Metropolitan Research" within the Competence Field Metropolitan Research (KoMet; see https://metropolenforschung.uaruhr.de). *KoMet* was established as a joint competence field by the three universities in the University Alliance Ruhr (University of Duisburg-Essen, Ruhr University Bochum and TU Dortmund University) in 2017. It brings together over 120 researchers from a broad range of disciplines engaging with central aspects of metropolitan research. While the Ruhr region with its over 5 million inhabitants and its history of post-industrial transformation is an obvious focus of research, comparative perspectives and research on other metropolitan regions especially in Europe, East Asia and North America are also central to research in KoMet.

In 2018, a broadly cross-disciplinary group of researchers particularly interested in methodological questions in metropolitan research established a sub-research field of its own and launched a series of workshops, in which central methods and approaches from a range of disciplines where presented and points of intersection and processes of transfer where discussed. Here, central questions have been:

- How can quantitative and qualitative research approaches be reasonably combined?
- What are the possibilities and limits of different approaches to modelling complex urban and metropolitan systems, e.g., agent-based modelling, genetic algorithms, stochastic optimization, cartographic visualization, verbal models, everyday models and mental maps – and to what degree are these models complementary?
- Which methods can be used to model and to seek to manage such complex systems – and at what cost?
- How do differing approaches – both theoretical and practical – measure up and where are the boundaries?
- How can inter- and transdisciplinary metropolitan research be organized around paradigmatic concepts such as 'complexity', 'transformation', 'polycentricity', 'narratives'?

In the winter term of 2020/21, members of the research field also convened and contributed to the long-established "Ruhr Lecture: Key Issues in Metropolitan Research", an interdisciplinary lecture series which, in each winter term, features one of the research fields in KoMet. In the course of this semester, the idea for the present collection of essays emerged.

The volume is conceived as complementary to a range of encyclopedias, handbooks, companions and readers in the fields of urban and metropolitan research: It neither seeks to replace (1) *the voluminous (and costly) encyclopedias and handbooks on the city or on urban research*, such as Anthony M. Orum's 4000-page *Encyclopedia of Urban and Regional Studies* (2019) or Hutchison's two-volume *Encyclopedia of Urban Studies* (2009) with their entries on scholars, individual cities, thematic issues, key concepts or historical development, nor (2) *the established or the recent readers and companions in the field of urban studies and city research* such as Bridge and Watson's *New Blackwell Companion to the City* (2013), LeGates and Stout's *City Reader* (^{7}2020) or Orum, Ruiz-Tagle and Vicari Haddock's *Companion to Urban and Regional Studie*s (2021). Nor does it compete with (3) the *classic one-volume reference works* such as Caves's *Encyclopedia of the City* (2005/2013) or Gottdiener and Budd's *Key Concepts in Urban Studies* (2005) or with (4) *the enormous range of both introductions to and in-depth discussions of methods in urban analysis for virtually any discipline or circumscribed group of disciplines engaging in urban research* – and, as Frank Eckardt (2009) has argued, in an urbanized world, there is hardly a discipline that does not. Nor, finally, does it form part of the (5) *numerous studies engaging more specifically with urban complexity, urban systems analysis and urban modelling as a multi-, inter-, and transdisciplinary endeavour* (Albeverio 2009; Portugali et al. 2012; Batty 2013; Walloth/Gurr/Schmidt 2014; Liu 2020). What is largely missing in this wealth of publications, we find, is a survey of methods and approaches in metropolitan research across a range of disciplines (one of the few publications addressing this need is Verloo and Bertolini's 2020 collection *Seeing the City: Interdisciplinary Perspectives on the Study of the Urban*).

Thus, without any claim to being exhaustive, what this collection therefore seeks to provide is an overview of key methods and approaches to metropolitan research that is both scholarly *and* accessible to a wider audience. The disciplines represented in this collection include architectural history, art history and the study of the built environment, geoinformatics and spatial analysis, cultural heritage preservation and cultural memory studies, literary and cultural studies, spatial planning and planning theory, urban sociology, economic geography, technology studies, transport planning, urban economics and operations research, aquatic ecosystem research, as well as urban epidemiology. This scope, as far as we can see, is unique in one-volume works, and so is the focus on methods and approaches. Moreover, while, admittedly, most contributions themselves are still largely disciplinary, and the volume as a whole is thus more multi- rather than fully interdisciplinary,[1] both the individual articles as well as the collection in its entirety seek to contribute to and to further interdisciplinary urban research in that they are written so as to be accessible to metropolitan researchers from other fields and that they formulate interfaces, points of contact and overlaps with other disciplines. Moreover, the volume is organized not primarily by disciplines but thematically, so as

1 For detailed discussions of the rewards, challenges and pitfalls of interdisciplinary collaboration, see the collections by Frickel/Albert/Prainsack 2017; Frodeman 2017; Menken/Keestra 2016; for a brief discussion of conceptual as well as practical challenges, cf. Gurr/Kluwick 2021.

to highlight the way in which metropolitan research lends itself to and frequently even requires interdisciplinary collaboration in order fully to do justice to the complexities of metropolitan regions.

Section I, *Metropolitan Space and the Built Environment*, assembles essays on different approaches to urban form, ranging from architectural history and the study of urban typology, morphology and iconography via geoinformatics and the statistical analysis of spatial structures to questions of urban art history, architectural history and historic preservation. With a sequence of essays on different approaches to the quantitative and qualitative analysis of metropolitan space, this section thus also initiates the conversation on convergences, divergences and complementarities between quantitative and qualitative approaches.

Section II includes articles presenting central methods in the analysis of *Metropolitan Functions and Infrastructures*, surveying research on central places, on the analysis of economic clusters, on the modelling of infrastructure systems and on methods in urban transportation research. Though primarily quantitative in orientation, the essays in this section nonetheless continue the conversation on the intersections between quantitative and qualitative metropolitan research.

With articles on disaster risk and climate impact research from a spatial planning perspective, on the use of social media data for sustainability research, on biodiversity research in urban water bodies by means of DNA analysis in water samples all the way to key concepts and methods in urban public health research, section III on *Metropolitan Resilience, Sustainability, and Health* includes a similarly broad range of disciplines and methods. Here, too, rather than following a *disciplinary* logic, the essays *thematically* focus on key urban challenges.

Section IV, *Metropolitan Culture(s)*, is predominantly qualitative and brings together analyses of the forms and functions of storytelling, on the analysis of narratives and on the theory and analysis of collective symbols. The essays centrally engage with the 'story turn in planning' and the strong interest in questions of metropolitan (self-)representations and thus contribute to the flourishing field of literary and cultural urban studies. Given the underlying question about the potential role of the humanities in interdisciplinary urban research, this section, too, engages with some of the central challenges of interdisciplinary urban and metropolitan studies.

Key questions and issues of inter- and transdisciplinary metropolitan research, for instance concerning the role of comparative analyses or the convergences and complementarities of quantitative and qualitative approaches, are then explicitly addressed in the final section on *Interdisciplinary and Mixed-Methods Approaches to Urban Complexity*. This includes contributions on comparative approaches, on quantitative and qualitative approaches to urban modelling, on the typification of urban neighbourhoods, and on the long-term mixed-methods monitoring of large-scale urban development projects.

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I Metropolitan Space and the Built Environment

Urban Typology, Morphology, Iconography

Wolfgang Sonne

Urban typology, morphology and iconography are methods of analysing, interpreting and developing the shape of the city. They consider the built, i.e. materially realised form of the city in its historical context, but differ in their focus, which results from the different origins of the methods: typology has a long tradition in architecture; morphology is mainly shaped by geography; iconography developed in art history. While *iconography* analyses the actual visible forms of the city as well as the visual representations of cities, *typology* and *morphology* mainly deal with the shapes and structures which are physically existent but not directly visible such as the footprint of the city and represent them with maps or plans like black plans (showing building footprints), floor plans (showing building ground floor plans), or lot plans (showing boundaries of urban lots). However, urban typology and morphology are not restricted to the analysis of the city plan, but can also include the analysis of urban spaces, silhouettes or building facades, thus overlapping with urban iconography.

1. Typology

Among these, typology has the longest history as a method for analysing the built environment. It was developed and used in the field of architecture not only for analysing but also for producing buildings. The most basic distinction since Renaissance architectural theories is between building types for public and private buildings. Architectural handbooks by Sebastiano Serlio in the 16th century (1966), Pierre Le Muet (1623), or Leonhard Christoph Sturm (1715) developed a highly differentiated typology for private urban houses, giving examples from the most humble house of an artisan to the most exuberant palace of a nobleman. These house-types are represented by floor plans and facade views, thus combining typological and iconographic aspects. A first step to enlarge the architectural typology into the urban scale was undertaken by Giambattista Nolli, who introduced the floor plan of public buildings like churches into his urban map of Rome in 1748.

The concept of architectural typology was refined in the age of Enlightenment in France. Jean-Nicolas-Louis Durand presented a system for designing buildings for different public building types, a task which had become prominent especially after the French Revolution (1801). Antoine Chrysostome Quatremère de Quincy specified the understanding of the type by elaborating the differentiation between type and model (Quatremère de Quincy 1825). While the model is repeated exactly 1:1 in each exemplar, the exemplars of the type all differ slightly. Thus, the type only is the ideal form which is in the minds of the producers, while the actual buildings following this type can differ among each other in many aspects. As an abstract ideal, the type can never be concretely built. On the other hand, this concept offers the possibility that within the built examples of a type a certain variety can emerge in contrast to the model where every example is identical.

Fig. 1: Saverio Muratori, typological plan of Venice, Quartiere di S. Zulian, phase IV: present state (1959)

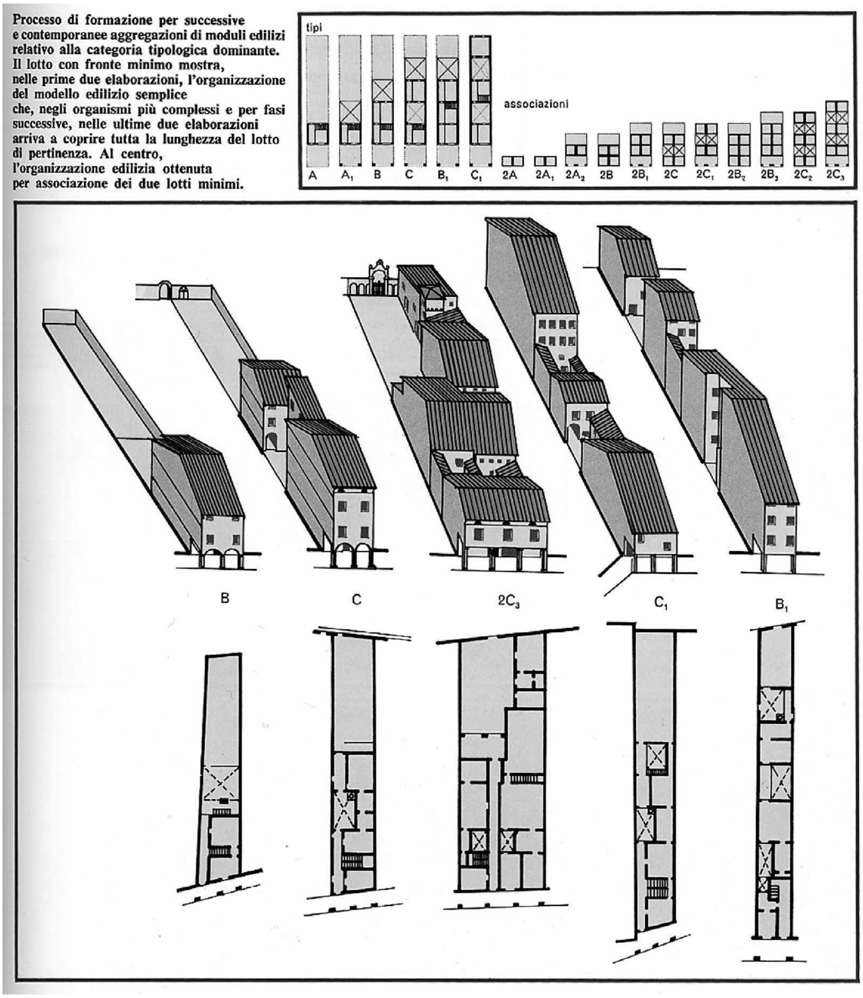
Fig. 2: Aldo Rossi, "zuammenhängende Grundrissaufnahme" (continuous floor mapping), Zurich, 1973 (gta Archive, ETH Zurich)

In the following times, the concept of typology was used both for the analysis and production of architecture. Within this concept it is useful to distinguish between the type (the existent group of similar buildings), typology (the method of arranging these similar buildings to a group and interpreting them as a type), and typological design (the method of developing a design for a building according to the rules of a presumed type). Another useful distinction is between the building type and the building task. A functionalist approach such as Nikolaus Pevsner's *History of Building Types* ignored this differentiation as it was based on the assumption that the architectural form directly followed from the function of the building (1976). Thus, he structured his book according to building tasks such as churches, town halls or hospitals, which in fact had been designed according to quite different building types.

Architectural and urban typology were merged in the studies by Saverio Muratori in Italy. His "storia operante" especially of Venice but also Rome included the floor plans of private buildings into the town plan, thus bringing the structure of the city into directly visible connection with the structures of its buildings (Muratori 1959; 1963; see fig. 1).

Again, his method had two goals: the analysis of the built environment of the city according to its historical development, including the reconstruction of lost phases by

Fig. 3: Development of house types in Bologna (Cervellati/Scannavini/De Angelis 1977)



applying the rules of types on the one hand, and the design of appropriately fitting new urban areas and buildings according to the existing types of urban structures and buildings.

The notion of type was fundamental to Aldo Rossi in his influential book *The Architecture of the City* (1966). In contradiction to the contemporary strand of functionalist urban planning with its assumption that the form of the city just followed the actual practical needs, Rossi considered the urban fabric as a long-lasting entity which offered opportunities for different functions over time. The form of the urban fabric did not follow functions, but form. Within the built urban fabric, he distinguished two different categories of buildings: the monuments which remained constant also in their materiality over time (such as antique amphitheatres, which could become urban neighbourhoods

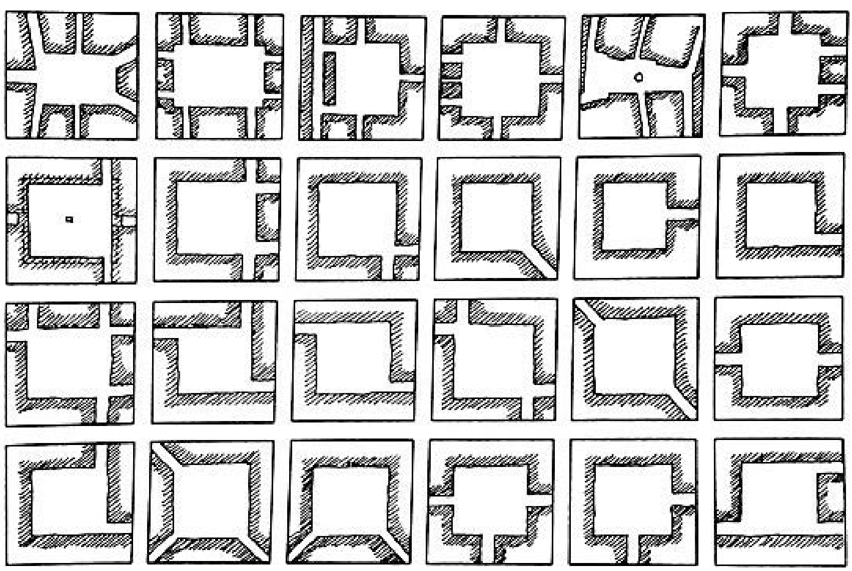
Fig. 4: Josef Paul Kleihues, Berlin-Atlas, plan showing blocks, buildings and entrance situations in Charlottenburg (Kleihues 1973b)

in medieval times) and the town houses of everyday life, where the material structure changed over time but the type remained constant.

The appropriate method of understanding the city as a built environment with its necessarily long-lasting forms therefore was an accurate mapping of the city with the floor plans of the buildings. Such a city floor plan included both the plans of the lasting monuments as well as the plans of the town houses following the long-lasting types. A

Fig. 5: Hans Koepf, facade view of a street showing a specific building type, Schärding (1972)

Fig. 6: Rob Krier, Stadtraum in Theorie und Praxis, typological plate showing examples of rectangular squares (1975)



starting point for a series of so called "zuammenhängende Grundrissaufnahmen" (continuous floor mapping) became the plan of the inner city of Zurich, which Rossi realised with students at the ETH Zurich in 1973 (see fig. 2).

This approach of typological studies by using architectural and structural mapping was continued, enlarged and refined by Gianfranco Caniggia with his studies on Como and Florence (1963; Caniggia/Malfroy 1986; Caniggia/Maffei 2001) and with the research project on Turin by Augusto Cavallari Murat (1968). This typological approach was then applied for the restauration of a historic town in the case of Bologna from 1969 onwards. Under the direction of Pier Luigi Cervellati, the city centre was protected and renovated according to different classes of buildings reaching from monuments, which should be maintained in their original materiality, to ordinary town houses, which could be renovated or even rebuilt – but according to their historic types (see fig. 3; Cervellati/Scannavini/De Angelis 1977).

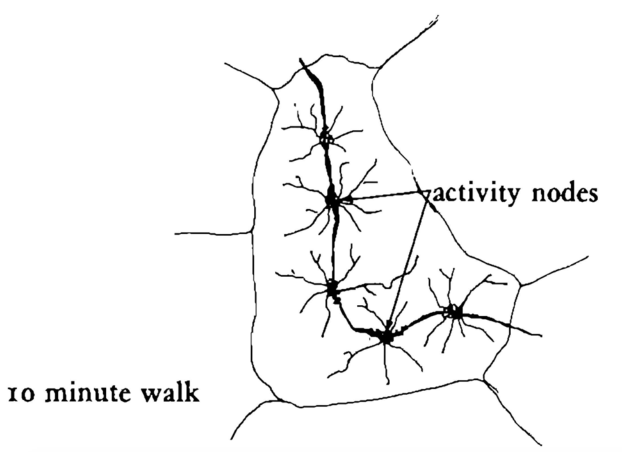
In France a similar approach of typological analysis was practised by Jean Castex and Philippe Panerai in their study on Versailles (Castex/Céleste/Panerai (1980). They also presented a broad research on the typology and development of the urban block (Panerai/Castex/Depaule 1980).

With inspirations from the Italian culture, Josef Paul Kleihues produced two model studies on urban neighbourhoods in Berlin in 1973 (1973a and b). In his *Berlin-Atlas*, he analysed the structure of the urban fabric according to different aspects such as block forms, lot divisions, house units, entrance situations, definition of public space and sorts of use. These aspects were represented in a series of maps which, put together, offered a holistic image of the urban neighbourhood (see fig. 4). This sort of typological analysis then became the basis for the development of Berlin during the International Building Exhibition (IBA 1984/87), which Kleihues organised according to his method of "critical reconstruction".

In his studies on Austrian cities, Hans Koepf complemented the continuous representation of floor plans with the continuous representation of facades. His books, starting with *Stadtbaukunst in Österreich* (Koepf 1972), included redrawn facade views of entire streets, thus offering both the understanding of the house type with its similarities and its diversities in each exemplar as well as the image of the entire street (see fig. 5). Thus, his approach can also be seen as a combination of urban typology and urban iconography.

A more abstract typology of urban spaces is offered by Rob Krier's *Stadtraum in Theorie und Praxis* (1975). He arranges urban squares according to geometric figures and presents them in typological plates (see fig. 6). His analysis is mostly intended to create a tool for future design.

Fig. 7: Christopher Alexander, A Pattern Language, pattern no. 31 Promenade (1977)



Christopher Alexander's "Pattern Language" (1977) can be interpreted as a kind of universal typology of the built environment. He defines 253 patterns of different scales from regions, cities and buildings down to building details, represented in the book by different means such as drawings, sketches, diagrams, maps or photographs (see fig. 7). Based on mathematical and linguistic theories, these patterns are co- and subordinated in web structures.

Like a type, a pattern forms an ideal principle, which in reality can emerge in an infinite number of forms. Meant to be both, an analytical tool for interpreting the built environment and a toolbox for design, Alexander's pattern language has been too complex to be applied for practical design and teaching. However, it has strongly influenced the understanding of cities as non-hierarchical but complex entities, an approach already pursued in his anti-functionalist essay "A City is not a Tree" in 1965. Alexander's theories became especially influential in the post-functionalist understanding of cities in the New Urbanism.

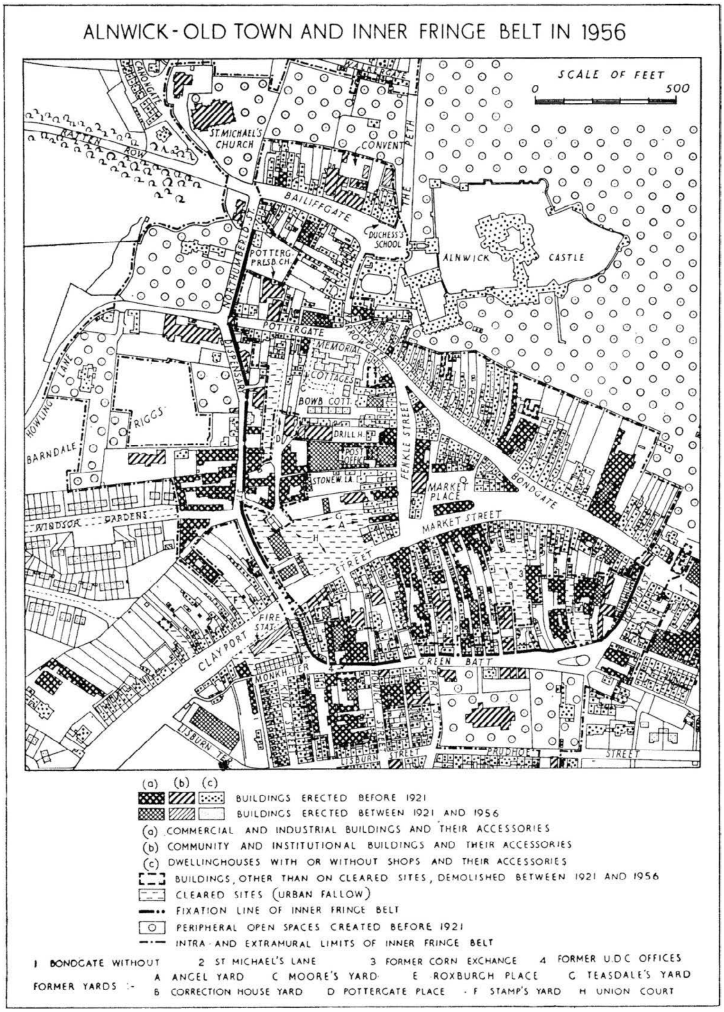
2. Morphology

There is no strict separation between urban typology and urban morphology, and both methods have shared traditions by referring to the same authors. To express this commonality, sometimes also the term "typo-morphology" is used. Morphology developed during the Enlightenment and starts from the assumption that the explanation of a phenomenon can be found within the physical shape of this phenomenon. Johann Wolfgang Goethe used this term to describe the structure and genesis of plants, developing from an "Urpflanze" into the variety of present plants. From there on, morphology was mostly used in biology.

A seminal step towards urban morphology was the shift from biology to historiography in the late 19th century, when a distinction of two different forms of cities was introduced: the 'planned' city with an overall regular plan, and the 'grown' city with an irregular shape. While the 'planned' city was obviously a result of a deliberate cultural action, the 'grown' city seemed to follow a biological paradigm of growth, thus combining the descriptive and evolutionary aspects of the concept of morphology. This distinction of planned and grown cities for example forms the structure of Joseph Gantner's general history of urban design in *Grundformen der europäischen Stadt* (1928).

In the early 20th century, the analysis of the urban form also became a prominent field in German geography. Trained in Berlin and having emigrated to Great Britain in 1933, the German geographer M.R.G. Conzen refined and spread urban morphology in the English-speaking scientific community. His morphological analysis of the small town of Alnwick in north-east England, published in 1960, became the basic reference for the then developing tradition of urban morphology (Conzen 1960). His analysis of the urban form focused on the town plan, in which he identified three basic elements: the streets, the lots and the buildings. His plans represented these elements, but the buildings were only shown in the general footprint without the floor plans as in the urban typology tradition (see fig. 8). Characteristic for his approach was also a dynamic understanding of urban form: He introduced the concept of building and re-building cycles within the street and lot pattern and also used the concept of the fringe belt as zone of urban development. Even though he presented his method with the example of a small town, especially these concepts of change and development were easily applicable to the analysis of a metropolis.

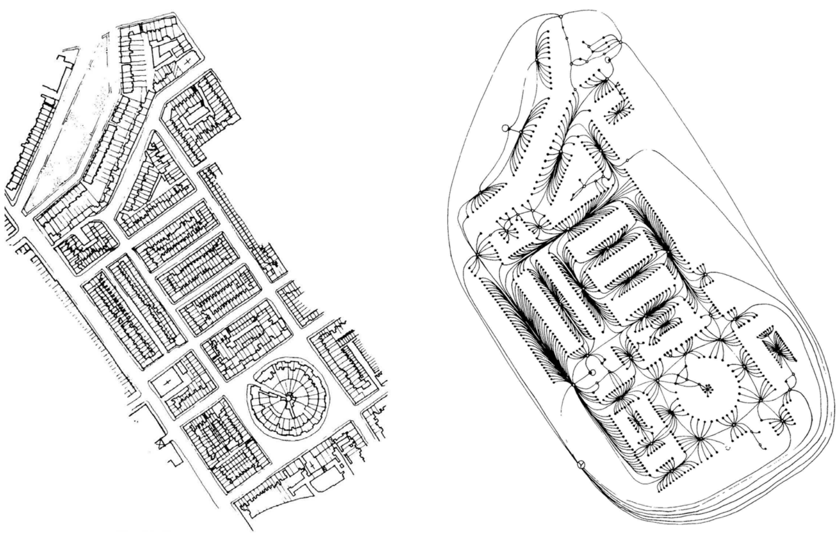
Fig. 8: M.R.G. Conzen, morphological plan, Alnwick, old town and inner fringe belt in 1956 (1960)



After Conzen, the tradition of urban morphology in British geography became institutionalised by Jeremy Whitehand, founding the Urban Morphology Research Group (UMRG) in Birmingham in 1974. Morphological research here ranged from the analysis of medieval small towns to modern metropoles. With strong participation of the UMRG, in 1994 the International Seminar on Urban Form (ISUF) was founded, now including researchers from different European countries, a variety of disciplines such as architects, town planners, geographers, archaeologists, art historians as well as historians, and including typological and morphological approaches. Since 1997, the group has published the journal *Urban Morphology* as the main international platform of urban morphological and typological research (Moudon 1997).

A specific method of analysing urban space was developed by Bill Hillier as "Space Syntax" in the 1970s and then published together with Julienne Hanson as *The Social Logic of Space* in 1984. Space Syntax analyses the built spaces in correlation with their social uses, especially movements (see fig. 9). Space Syntax research includes two approaches: an inductive method of analysing existing cities and a deductive method of generating space patterns from mathematical algorithms. The first method mostly uses urban maps with indications of people's movement; the second mostly uses geometric diagrams for showing possible spatial combinations. Central categories are convex spaces (such as squares) and axial spaces (such as streets). Within the analysis of the street network, aspects of hierarchy and connectivity are crucial, as already observed by Jane Jacobs. Space Syntax became institutionalised at the Bartlett School of Architecture in London with the founding of the Space Syntax Laboratory, which since 2010 has also published the *Journal of Space Syntax* (JOSS) (van Nes/Yamu 2021).

Fig. 9a/b: Bill Hillier, Julienne Hanson, space syntax, interface map showing possible movements in a neighbourhood, Somerstown, London (1984)



A phenomenological approach to mapping urban spaces has recently been developed by Uwe Schröder at the RWTH Aachen (2015a; 2015b). The differentiation between inner and outer spaces is represented on a map in red and blue, using the association of warm and cold. In these red-blue plans ("Rotblauplan") not only spaces within buildings, but also enclosed urban spaces are represented in red (see fig. 10). Thus, this method is able to analyse the combination of open and enclosed spaces within cities, not only analysing the actual situation, but also the historic development. Compared to the figure-ground plan or black plan ("Schwarzplan"), the red-blue plan offers a range of interpretation as the definition of inner and outer spaces is dependent on the feeling of a person perceiving this space. However, it picks up Camillo Sitte's method of analysing enclosed urban spaces and enlarges it from the analysis of urban squares to entire cities and metropoles.

Fig. 10: Uwe Schröder, "Rotblauplan" (red-blue plan) indicating enclosed and open urban spaces, Bologna (der architect 6 (2020))

Urban morphology and urban typology are not different methods, but only show different ways and scales of representation in dependence from their historic development. While urban typology has mostly evolved from an architectural discourse, it also includes the floorplans of buildings. Urban morphology developed more from a historical and geographical background; typical maps of morphological research therefore show lots or building footprints (figure-ground plans). Fundamental for both methods is the pictorial representation of the shape of the city or metropolis, as these pictorial representations show a form which cannot be perceived in the city itself: the plan. As the plan of the built city includes all scales from public spaces to lots, building footprints and building floor plans, for a comprehensive analysis of the urban form, it is more useful to combine the approaches of typology and morphology than to separate them. Both approaches also have in common that they are developed and used for both analysis as well as planning.

3. Iconography

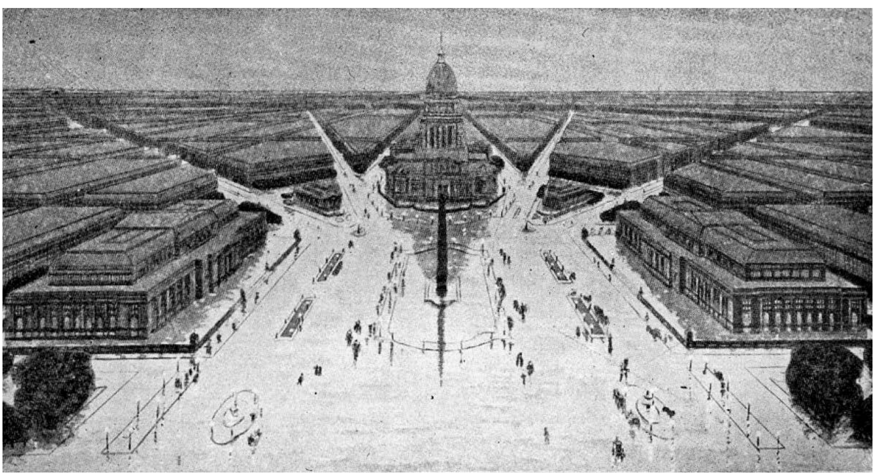
Iconography explores the meaning of images. It is an established method in art history and has been developed in addition to formal and stylistic analysis. It started with the analysis of religious images ('Christian iconography') and allegorical representations. Two techniques are fundamental for an iconographic analysis: the combination of similar motives and the combination of these motives with exploring texts. Especially the interpretation of images by combining them with texts which establish the meaning of the images is a central characteristic of iconography.

As a method in 20th-century art history, iconography has been strongly inspired by Aby Warburg and his research on the survival and revival of antique "pathos formulas", presented in his *Mnemosyne Atlas* on large plates with sequences of similar motives. The method was refined by Erwin Panofsky, who introduced the distinction between iconography and iconology in his book *Studies in Iconology* (1939). He defined iconography as the identification of the theme of an image while iconology explores the meaning of the image in a broader cultural context and historic development. Even if iconology is an old term, going back to Cesare Ripa's "Iconologia" in 1593, Panofsky's distinction never became fully established in scientific and public discourses, and the term mostly used for the interpretation of the meaning of images is iconography.

In the following times, iconography also became a method not only to research the meaning of images but also of architecture. E. Baldwin Smith's study on *The Dome* (1950) focused on the meaning of a specific architectural element. Günter Bandmann's book *Mittelalterliche Architektur als Bedeutungsträger* (medieval architecture as a bearer of meaning) (1951) explored the meaning of entire buildings. The more specific but highly controversial aspect of political meaning in architecture was the topic of Stanislaus von Moos' study *Turm und Bollwerk* (1974). Here, he was able to show that specific architectural motives in Italian Renaissance architecture had been less influenced by functional or constructional needs, but more by symbolic intentions. Thus, these buildings could be interpreted as means of communication which could be understood by iconographic research.

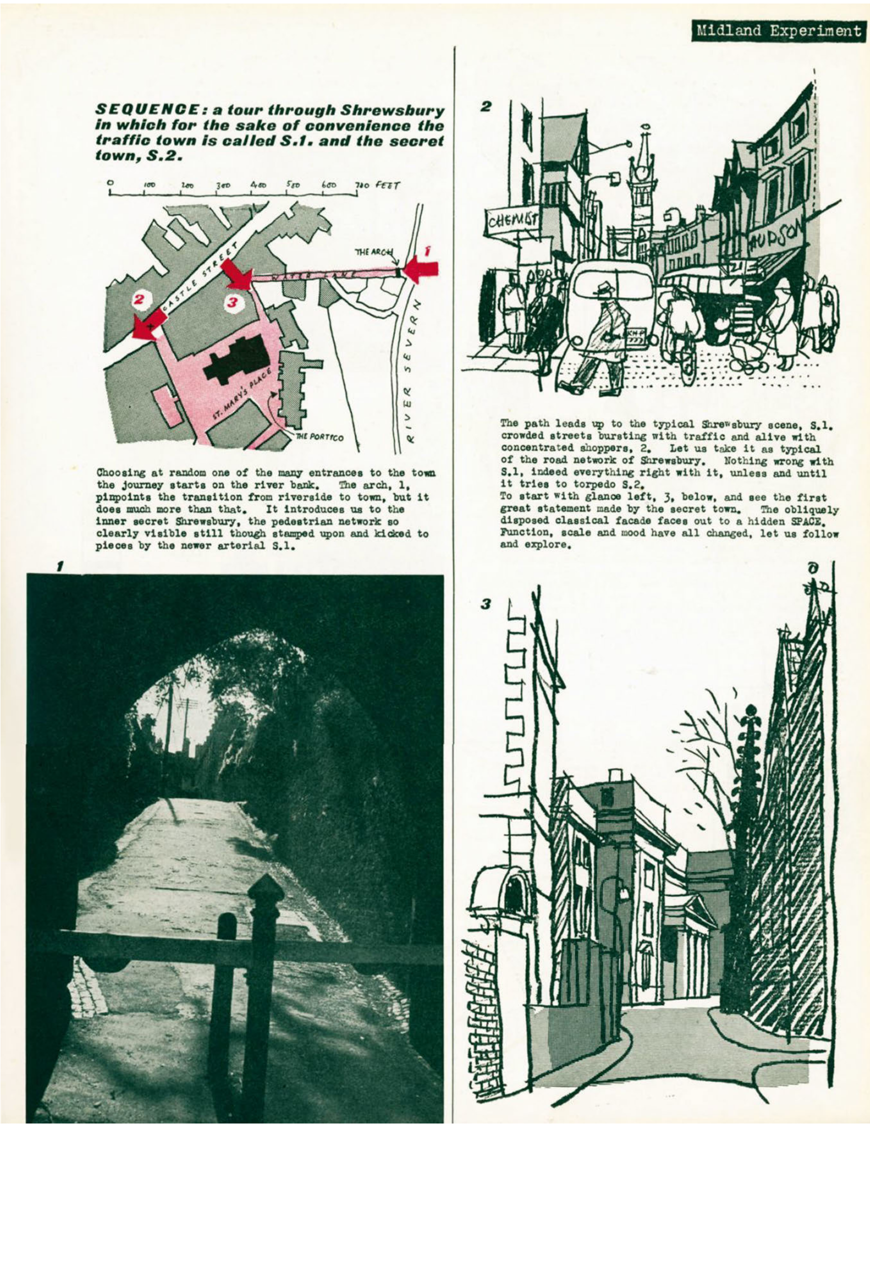
Martin Warnke established the theme of political iconography with several studies. His volume *Politische Architektur in Europa vom Mittelalter bis heute* (Political architecture in Europe from the Middle Ages to the present day) gave a broad overview with the presentation of several case studies of buildings and their political meaning, while his essay *Politische Landschaft* (Warnke 1992) enlarged the field to the interpretation of entire areas. Within this art-historical tradition, the field had already been widened to the city by Wolfgang Braunfels in his book *Abendländische Stadtbaukunst* (1976). In Wolfgang Sonne's study *Representing the State* (2001; 2003), the political iconography of cities was examined with examples of capital cities from the early twentieth century. Here he distinguished several levels or scales of urban design which could be used for messages: the entire city with a potentially significant plan; urban elements such as squares, streets or ensembles; building types and elements such as temples, towers or domes; and architectural styles. As these forms had been used even in the same period for different political messages, the form itself does not convey the meaning. Crucial for the reconstruction of meaning of cities and buildings is the close examination of the historical context and the combination of urban and architectural forms with contemporary texts stating their possible meaning.

Fig. 11: Robert Breuer, political iconography of cities, Plan of Chicago from 1909 described as "monumental expression of a ruling strong capitalism and the sober pathos of a free people" (1911)



When it comes to urban iconography, a fundamental distinction has to be made: just as architectural iconography deals with the meaning of architecture, urban iconography deals with the meaning of the city, i.e. the three-dimensional material urban fabric and its spaces. However, quite often the term is also used when pictorial representations of cities are examined. But as these two media strongly differ in their qualities (the two-dimensional picture against the three-dimensional object with spaces), they should not be mixed. On the other hand, there is a strong relation between the city and its pictorial representation. The produced image of the city can strongly influence the way the city itself is perceived. Thus, in urban iconography the pictorial representation of a city can be used to analyse and interpret the city in a similar way as the map or plan of a city is used in urban typology and morphology. The difference, however, is that in urban iconography the images and the city are both actually visible (and therefore so easily become mixed), while in urban typology and morphology the maps and plans visualise a physically existent but invisible part of the city. Early examples of creating images of entire cities for both understanding and representing come in two major genres: the bird's eye view, for instance with Jacopo de Barbari's incredibly accurate representation of Venice in 1500, and the view showing the silhouette of the city, for instance with Frans Hogenberg and Georg Braun's *Civitates Orbis Terrarum* (1572–1618) or Matthäus Merian's *Topographia Germaniae* (1642–1654).

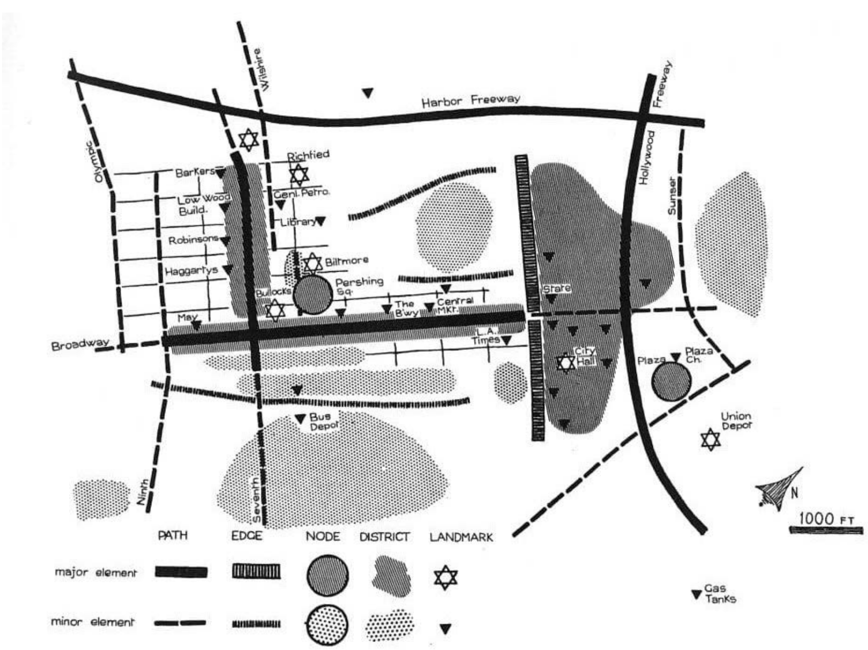
Fig. 12: Gordon Cullen, visual sequence of urban spaces, Shrewsbury (The Architectural Review 116 (1954))



Comparable to urban typology and morphology, urban iconography in the 20th century has not only been used to analyse urban phenomena, but also to design and produce cities. Within the context of architectural and urban design, Robert Breuer presented an iconography of politically motivated urban forms in an article (Breuer 1911). His text was accompanied by a series of illustrations, showing specific urban forms and assigning them to political systems in the explanatory captions (see fig. 11). The market square in Nuremberg was interpreted as "the architectonic form of the reserve that characterises the German bourgeoisie. The entrances are hardly noticeable. The square is experienced as a space that is hemmed in on all sides." Versailles, as another example, is presented as follows: "The spaciousness of the square and the representative axial disposition are the architectonic form of the Sun King's monarchy." Thus, specific urban forms and spatial arrangements were loaded with specific political meaning.

A meaningful arrangement of cities and metropoles also was intended by Bruno Taut in his book Die *Stadtkrone* (1919). Here he presented a broad collection of monumental buildings which dominated the city. The examples range from antiquity to modern times and from Asia to America and Europe. With these "City Crowns" for religious and social gatherings, the respective cities gained a higher meaning as places of spiritual communities. In his own design of an ideal city, such a "City Crown" also dominated the town and its image.

Fig. 13: Kevin Lynch, mapping of "paths", "edges", "districts", "nodes" and "landmarks", Los Angeles (1960)



In the UK, architect Gordon Cullen developed the analysis of urban spaces which had started with Camillo Sitte and his book *Der Städtebau nach seinen künstlerischen Grundsätzen* (1889). While Sitte presented his spatial analysis and spatial principles only with small plans, Cullen explored urban spaces with series of sketched perspective views, thus establishing an iconography of urban spaces (see fig. 12). Some of his presentations even show a series of views according to the way of the pedestrian through town like film stills, thus including movement into the analysis. He started his research with articles in the magazine *The Architectural Review* in 1949 and finally published it in his book *Townscape* (Cullen 1961).

In the USA, architect Kevin Lynch examined how people oriented themselves within cities. By observing and experimenting with groups of people in downtown Boston, he investigated the perception of urban space by pedestrians, publishing his results under the title *The Image of the City* (1960). His central result was that orientation in the city was focused especially on the recognition of the five elements "paths", "edges", "districts", "nodes" and "landmarks". These five elements were noted in diagrammatic "mental maps" and explained with pictograms, establishing an annotation system for the visual perception of urban spaces – an urban iconography which could be used for both analysing and planning cities and metropoles (see fig. 13).

4. Conclusion

Urban typology, morphology and iconography are established methods which offer a rich variety of ways of analysing the built environment of cities and metropoles. Having developed in different research fields and disciplines, they differ in focus and approach, but share some basic assumptions and intentions: They all focus on the built city with its forms, realised materially in three dimensions. They all see the shape of the built city in relation to its historic development. They all present their findings not only with texts but also with images: typology and morphology mostly with plans which visualise the invisible of the built city, iconography sometimes with views which represent the visible city. And they are all not only restricted to scholarly observation, but can also include planning intentions.

These methods do not reduce the built city to traces of other aspects, but see it as a valuable object of investigations. They also do not see the built city as an autonomous phenomenon, but understand it in relation to other aspects of the city such as society, politics, economy, or culture, which can have an influence, but also be influenced by the form of the built city. As every city always also forms a built entity with a specific shape, the use and further development of urban typology, morphology and iconography will be indispensable for the comprehensive understanding and planning of cities and metropoles.

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Exploratory Statistical Analysis of Spatial Structures in Urban Datasets

René Westerholt

1. Introduction

Metropolitan phenomena are often characterised by spatial structuring and arrangement. The term 'urban', understood as a "fabric in which [...] sociocultural and political-economic relations [...] are enmeshed" (Brenner/Schmid 2014, 751) and where collective action "comes from a plurality of sources" (Castells 1985, 3), implies a complex assemblage of social and physical processes that co-occur in nearby locations. This simultaneity of processes not found in the same way in rural areas makes urban phenomena interesting objects of study. Simultaneity and nearness in space and time are hence reflected in different forms throughout the entire volume at hand. Urban epidemiological incidents, as discussed in the chapter by Moebus, gain traction when spatial conditions facilitate contagion. Urban narratives embedded in the confluence of different ideas and conceptualisations, as discussed in the chapters by Sattler and Parr, have a spatial structure, either explicit (through the use of place names) or implicit (through spatial language). Methodological workflows in metropolitan research often reflect the spatial nature of urban phenomena through the presentation of maps, the explicit consideration of spatiality, and through the attribution of analytical results to different places. The elaborated literal 'throwntogetherness' (Massey 2005, 140) of metropolitan areas, combined with contextual geographical variation, almost inevitably leads to identifiable spatial structures, both observed in situ and reflected in data.

Understanding systematic spatial structuring is the core of statistical spatial analysis. In the context of geographic information systems (GISs), the term 'spatial analysis' is often used as a catch-all term for any kind of methods that involve space. In statistical analysis, however, the term has a stricter and narrower meaning and refers to the identification and characterisation of (possibly non-random) spatial structures (Fischer/Getis 2010). The core idea of this subfield in the nexus of geography, (analytical) cartography, statistics, economics (through regional science and econometrics), and (more recently) computer science (Brachman 2020; Singleton/Arribas-Bel 2021) is the application of a statistical epistemology to the analysis of spatial arrangements. The latter implies that spatial analysis falls within the realm of the sciences, as it attempts in a nomothetic way to derive law-like statements from observed recurring regularities. The focus of spatial analysis is on the 'in-between', that is, on the interconnectedness of spatial units, which can stand for places, cities, regions, or any other kind of spatial entity (Fischer 2005). The perspective taken is a holistic one. The whole arrangement, manifested in map patterns, is considered together and at once rather than looking at individual places in isolation. The fundamental task at the heart of spatial analysis, thus, is to explore systematic geographical arrangements.

This chapter provides an accessible introduction to statistical spatial analysis aimed at interdisciplinary metropolitan researchers. It combines an applied approach with a rigorous, sufficiently technical consideration. This way, the reader is empowered in terms of establishing a solid basis for further engagement with spatial-statistical analysis. The following Section 2 is devoted to application examples from metropolitan research motivating the methodology introduced in the subsequent sections. Section 3 then discusses a number of concepts and presumptions on which spatial analysis is based. These are important for understanding the principles and contexts of application in which spatial analysis can and may be used. In a second step, in Section 4, Moran's I, a widely used measure of spatial autocorrelation, is explained in detail. This method has been researched for decades and serves here as a prototypical example for the nature and application of methods in spatial analysis. Section 5 introduces both additional established and novel techniques from the spatial statistical toolkit that are useful in different, selected application contexts. These include measures and tests for spatial configurations in numerical, categorical, vector, and multivariate variables.

2. Urban Applications

The methods introduced in this chapter are widely being applied in the context of metropolitan research. Three popular areas of application that have recently gained interest are exemplified below.

2.1 Census Analyses

Censuses have long been a rich source of information for metropolitan research. Among other things, they enable the study of population dynamics, socioeconomic characteristics, and demographic features. Spatial statistical methods play a central role in many census analyses. Using spatial regression models and autocorrelation methods, Manley et al. (2006) identify different scales and associated processes in British census variables. Spatial statistics here enable the distinction of finely graded sub-regions. In the same vein, census studies have been conducted with spatial statistics on topics such as employment (Martín-Román et al. 2020; Fingleton et al. 2020), housing (Barreca et al. 2018; Lin et al. 2014), and socioeconomic disadvantage (Andrews et al. 2020; Cebrecos et al. 2018), to name but a few. A young but active area of research is geodemography, the explicitly spatial study of demographic characteristics. Largely accelerated by increased data accessibility, studies have been conducted on the geography of surnames (van Dijk/

Longley 2020a; 2020b; Kandt/Longley 2018), small area characterisations (Yazgi Walsh et al. 2021; Singleton et al. 2020), and links between geodemographics and other domains (Kim et al. 2021; Liu/Cheng 2020). Although much spatial statistical work has been done in the field of census analysis, methodological concerns continue to be raised. For example, using the American Community Survey, Jung et al. (2019a) criticise the inappropriate use of spatial statistics, particularly in the context of rates, an issue discussed in Section 5.1. Yet, explicitly spatial techniques are increasingly being used but are still not as widespread as they probably should be, given the spatial nature of census data.

2.2 Urban Infrastructures

The analysis of urban infrastructures and their use is also a research area that makes frequent use of spatial statistics. In particular, mobility and transport infrastructure research make extensive use of spatial autocorrelation and regression, which are used to assess the spatial configuration of deployed infrastructures including their possible impacts on economic, social, and other characteristics (Wang et al. 2020; Potoglou et al. 2019; X. Gao et al. 2019). In addition, the utilisation of transport infrastructure, and human mobility in general, have been extensively researched using spatial analysis methods (Y. Gao et al. 2019; Boss et al. 2018; Blazquez et al. 2018; Steiger et al. 2016). Similarly, green infrastructures, that is, those concerning the strategic deployment of urban greenery, have also been studied in terms of spatial statistics. Examples include studies on the influence of urban green on residential property values (Mei et al. 2018; Conway et al. 2010), accessibility of green spaces (Pearsall/Eller 2020; Dai 2011), and associations of urban green with mental well-being (Houlden et al. 2019; 2018). Also in focus, but less frequently studied with the methods presented in this chapter, are electricity and water supply infrastructures. For example, Ceci et al. (2019) exploit spatial autocorrelation to better understand the spatial properties of a network of photovoltaic plants. On a larger scale, Hong et al. (2020) use spatial regression models to investigate regional spillover effects in energy consumption. In terms of water supply, Zamenian et al. (2017) use hotspot statistics to reveal spatial clusters in certain characteristics of water pipes, while Abokifa and Sela (2019) disclose spatial patterns in pipe failures with Moran's I. These and other examples demonstrate the usefulness of spatial analysis in both infrastructure research as well as infrastructure management and monitoring.

2.3 Geosocial Media Analytics

A newer field of metropolitan research is the analysis of geosocial media. Despite concerns about skewed demographics of social media users (Jiang et al. 2019), these types of user-generated geographic information have been used in numerous fields, particularly in the social sciences. One such field that also ties in with Section 2.1 is using social media analytics as a proxy for geodemography. Spatial statistics have been used to construct daytime counterparts to the census, for example, in terms of peoples' whereabouts (Steiger et al. 2015), the ethnic composition of neighbourhoods (Longley/Adnan 2016; Longley et al. 2015), and for age and gender profiling (Lansley/Longley 2016). Another area of geosocial media analytics is the study of urban emotions. Frank et al. (2013) apply Geary's c and Moran's I to examine patterns of 'happiness' in tweets from across the US. Similarly, Rybarczyk et al. (2018) use exploratory spatial analysis and regression to establish links between tweet sentiments and travel modes. Examples of the use of spatial analysis of social media data in the field of crime research can be found in Ristea et al. (2020) and Kounadi et al. (2018). This selection shows the breadth of topics for which social media data has been spatially analysed, and numerous others exist (for overviews, see Steiger/Westerholt/Zipf 2016; Steiger et al. 2015). Methodological concerns have been raised about using established methods in the context of geosocial media analytics. Social media differs from scientific data in that it is generated without adherence to scientific protocols (Westerholt 2019a; 2019b). Studies have shown that using methods like Moran's I with these datasets can lead to variance inflation (due to mixtures of different phenomena, see Section 4.4) and scale-related problems (Westerholt et al. 2016). Accordingly, methods tailored to the spatial analysis of this type of data have been proposed (e.g., Westerholt 2021a; Westerholt et al. 2015).

3. Presumptions and Principles of Spatial Analysis

The application of spatial analysis methods is characterised and constrained by a number of principles and presumptions. These rest on two main circumstances: the georeferenced nature of spatial datasets and the fact that these are not independent samples. This section briefly presents some of the main resulting specificities with the aim of making the reader interested in applications aware of them when using spatial statistics. Easy-to-understand explanations, often in the form of footnotes, are given throughout to support the reader's rigorous understanding.

3.1 Spatial Processes

The primary goal of using spatial statistical measures is to understand the interaction behaviour of geographical phenomena. Making geographical phenomena including their spatial structure available to statistical analysis requires a formalisation,[1] which can be achieved via spatial processes (Cressie 1993, 8f.) of the form

$$\mathcal{Y} = \{Y_s : Y \in \Omega, s \in \mathcal{S} \subset \mathbb{R}^n\}, \tag{1}$$

where the Y denote random variables indexed over spatial units s (e.g. points, lines, or polygons). Set Ω is the sample space containing all possible outcomes of Y (e.g. $\mathbb{R}_{\geq 0}$ in case of precipitation or $\{1, 2, 3, 4, 5, 6\}$ when rolling a dice). This very general notion of a spatially indexed set of random variables can be endowed with various properties that lead to three specialisations of $\mathcal{Y}$. If we assume $\mathcal{S}$ to be fixed and with cardinality

1 In terms of notation, for this chapter, upper-case symbols mean random variables and lower-case symbols denote associated realisations of these in terms of concrete data, unless otherwise stated. Furthermore, bold upper-case letters stand for vectors or matrices. Superscript $\top$ is the vector or matrix transpose. Set-builder notation is used when introducing sets.

$|\mathcal{S}| = \infty$, we arrive at the notion of a geostatistical process that is used to analyse spatially continuous phenomena like precipitation or soil properties. These are defined at every location in a given study area, and thus at an infinite number of coordinates (e.g. by considering ever more precise decimal places of numeric coordinates). If we instead consider $\mathcal{S}$ as a finite but stochastic set of geometries, we can derive the notion of a point process. Here, not only the attributes but also the geometries are considered random, as is the case with locations of trees or crime sites. In other words, both the 'where' and the 'what' in these cases are subject to a certain degree of randomness. The notion used in exploratory spatial data analysis and spatial econometrics is the lattice (regular or irregular) based on a deterministic and finite set of locations with $|\mathcal{S}| < \infty$. Census variables are a common example of lattices, for which variables such as income or household sizes are only defined for the census units and any attempt to interpolate in between would be invalid. The remainder of this chapter will focus on the latter type of lattice processes and thus on the analysis of spatial structure in attributes mapped over fixed locations.

3.2 Stationarity Assumptions

Many statistical techniques rely on homogeneity assumptions. To ensure valid results and conclusions, it is often necessary that certain properties of the distribution of observations are constant. This property, called stationarity, is particularly challenging when geographical processes are involved. Geographical space is inherently heterogeneous, rendering the latter a candidate for a 'second law of geography' (Goodchild 2004). In less technical terms, this often observed lack of homogeneity in space means that there is no such thing as an average place on the Earth's surface (Goodchild 2009). Nevertheless, for technical reasons, many techniques of spatial analysis are bound to certain somewhat relaxed but still rigid stationarity assumptions. The strongest statistical homogeneity concept is that of strict stationarity. This concept implies that all properties of distributions remain constant regardless of where and when respective phenomena are observed. White noise is a non-spatial example of strict stationarity with mean $\mu = 0$ and a fixed variance σ^2, but this concept would be too restrictive and unrealistic to apply in geographical contexts. A slightly less strict form of stationarity is second-order or weak stationarity (Oliver 2010, 320f.). Here, the mean and the variance are assumed to be constant, while no assumptions are made for higher-order moments. Weak stationarity is the form of homogeneity required for many spatial analysis procedures. As a corollary, the properties of weak stationarity imply constant covariance. This is advantageous because it means that the spatial behaviour of the random variables under consideration is assumed as equally characterised everywhere on the map. We are therefore only dealing with one spatial process, not with a potentially complex mixture. One disadvantage is that strict conditions are still imposed that are not always fulfilled in practice.

3.3 Spatial Weights

A common way to incorporate spatial associations explicitly in statistical routines is to construct a spatial weights matrix. There are various forms of spatial weights for different purposes (Bavaud 2014; Harris et al. 2011), but all of them formalise the potential for either proactive interaction or passive relatedness between spatial units (Dray 2011). For example, if the process under study is based on physical contact or direct exchange as in the case of contagious diseases, the weights may be based on spatial contiguity (e.g., through immediate physical adjacency or flight connections facilitating movement). When distance plays a role, as is the case with the propagation of noise in cities, the weights pairwise connect locations based on some function of their joint physical distance. These examples illustrate two important classes of spatial weights: topological and distance-based (Getis 2009). A third way to construct weights is to derive them empirically from a given dataset, which can be helpful when no prior knowledge is available about the nature of the spatial mechanism under study. However, empirical weights carry a risk of introducing circular logic by deriving weights from the same dataset to which they are then applied, hence lowering the explanatory power of analyses. In still other cases, a third attribute can serve as a useful spatial proxy for connectedness. An example of this would be the study of the spread of invasive species using the global trade network as a proxy for their exchange.

Regardless of the underlying semantics of spatial weights, they have a profound technical impact on the results of spatial-statistical methods. Spatial weights matrices are composed of positive coefficients whereby, by convention, the diagonal is filled with zeros (Bavaud 1998). Self-interactions are thus deliberately ignored (though they would technically be includable in many cases) in order to concentrate on spatial effects between units. In addition, the weights are used to adjust the geographical scale of an analysis. Scale is an important characteristic because geographical phenomena typically operate at specific scale ranges (Dungan et al. 2002). Incorrect scale adjustment through spatial weights is a common source of error. This can have far-reaching effects on the validity of obtained results, including difficult interpretation and, in the worst case, wrong conclusions on which further theory-building could then in turn be based. Another reason why spatial weights are important for spatial analysis is a more technical and less obvious one. Many spatial statistics are given as so-called ratios of quadratic forms[2] $\boldsymbol{Y}^{\top}\boldsymbol{W}\boldsymbol{Y}$, with $\boldsymbol{Y}$ being a sample of n observed values for Y, and $\boldsymbol{W}$ denoting a spatial weights matrix. The range and shape of the distributions of such statistics are determined by the eigenvalue spectrum of the (in this case) spatial weights matrix (de Jong et al. 1984), a property explained in more detail in Section 4. Spatial weights therefore determine, to some extent, how we should correctly interpret spatial-statistical results.

2 Quadratic forms are polynomials in n variables with terms whose sum of powers is not greater than two (Lam 2005, 1). $f(X_1, X_2) = a_1 X_1^2 + a_2 X_2^2 + X_1 X_2$ is an example.

3.4 Modifiable Areal Unit Problem

Metropolitan research often involves the analysis of secondary data. These have most likely been collected for purposes other than studying the process we, as analysts, want to study. Furthermore, many such datasets, including census data, information divided into raster cells, or anonymised datasets to preserve geoprivacy, involve the use of aggregation units. This frequently results in the so-called Modifiable Areal Unit Problem (MAUP, Bluemke et al. 2017; Openshaw 1983), which is caused by an at least partial arbitrariness of the location, shape, and scale of aggregation units used. A consequence can then be a wrongly specified scale leading to a possible discrepancy between the scale of the process under investigation and that of the data collected. The phenomenon of interest may then not be optimally represented in the data. One problem with arbitrarily shaped aggregation units is that they may combine smaller-scale units that should possibly not be combined from a geographical point of view and with regard to the stationarity assumptions discussed above. Another concern can be the creation of possibly meaningless boundaries, which then lead to problematic spatial weights. Furthermore, the position of the aggregation units is beyond our control when using secondary data, which adds to the uncontrolled geographical mixing effects. A common example of the occurrence of the MAUP is the use of polygonal census units. These are intended for demographic purposes, but not necessarily for other types of geographical study. Another typical example of MAUP occurs in the use of grid cells. While convenient to use, these often do not reflect well underlying spatial structures. Unfortunately, the MAUP remains unsolved and challenging, mainly because it is a theoretical rather than an empirical problem (Wolf et al. 2020). It is therefore essential for any spatial analyst to be cautious when interpreting results obtained from secondary data.

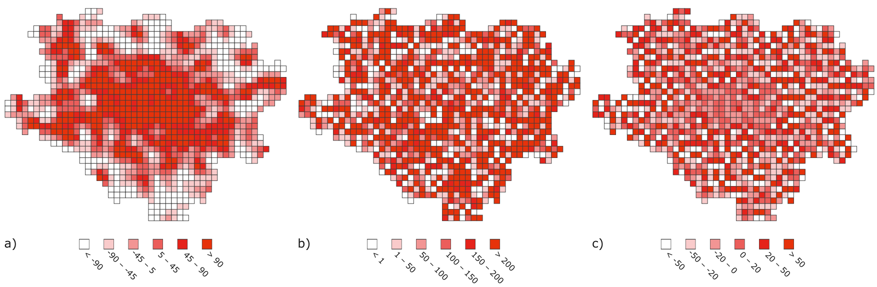
4. Spatial Autocorrelation and Moran's I

A very essential part of the statistical analysis of spatial structures deals with the estimation of spatial autocorrelation (see fig. 1). In this section, this concept is first discussed in general before the estimator Moran's I is considered in detail. An overview of other measures is given in Section 5.

4.1 Conceptual Remarks

The so-called First Law of Geography, which states that "everything is related to everything else, but near things are more related than distant things" (Tobler 1970, 236) is one of the major conceptual underpinnings of spatial analysis. Spatial autocorrelation is a way to formalise and quantify this idea in statistical terms. It describes the tendency of mapped attributes to be significantly spatially clustered (positive), dispersed (negative), or random (no significant spatial autocorrelation). Fig. 1 illustrates all three characteristics using a population grid from Dortmund, Germany. Fig. 1a shows a positively autocorrelated version of the population data resulting in more similar values occurring together than by chance. Fig. 1c shows a negatively spatially autocorrelated

Fig. 1: Illustration of positive and negative spatial autocorrelation as well as spatial randomness based on a 500-m population grid from Dortmund, Germany. Partial graphics a) and c) are based on spatially filtered variables using the method presented in Westerholt (2021a). a) Positive spatial autocorrelation; b) spatial randomness; c) negative spatial autocorrelation. The maps are based on data from the 2011 German Census.



counterpart with fewer similar values sticking together than would be expected at random. Fig. 1b shows a randomised version of the original population data with clustered areas being compensated by negatively autocorrelated parts of the map. Measures of spatial autocorrelation are thus a way to characterise different types of spatial structures in datasets.

Spatial autocorrelation is encountered in a number of situations and is often methodologically useful. Geostatistics, for example, is based on assuming positive spatial autocorrelation (Getis 2008). Natural phenomena such as precipitation and temperatures do not normally show sudden jumps in neighbouring areas unless barriers like rivers or rock walls are present. Data about such phenomena exhibit smooth spatial variation that is exploited in geostatistics for Kriging, a statistical interpolation procedure that takes into account the spatial correlations estimated from data (Calder/Cressie 2009). Exploratory spatial data analysis uses spatial autocorrelation to explore the *a priori* unknown spatial nature of phenomena and generate hypotheses. Inferences from measurements of spatial autocorrelation combined with different spatial weights, each reflecting different possible spatial interaction mechanisms, are then a way to investigate possible spatial functioning mechanisms and geographical relationships. Spatial autocorrelation also gives rise to specific forms of spatial regression modelling including the spatial autoregressive (long-range spatial effects; global spillovers) and the spatial error model (small-scale, limited spatial effects; local spillovers) (LeSage/Pace 2014; Anselin 2003). Further uses of the concept of spatial autocorrelation include testing for model misspecification, testing spatial stationarity assumptions, uncovering spatial relationships, examining the influences of geometric units and aggregation, revealing the roles of time and space, and supporting the study of spatial outliers (Getis 2007).

4.2 Definition of Moran's I

Particular attention has been given to estimators of spatial autocorrelation for interval-scaled random variables. Due to its widespread availability in software packages and statistical computing environments, Moran's I is one of the most widely used such methods. Other popular methods include the G-statistics (Ord/Getis 2001; 1995) for hotspots and Geary's c (Cliff/Ord 1981; Geary 1954), but Moran's I was shown to be better behaved than c with respect to statistical power[3] and sensitivity to spatial weights (Chun/Griffith 2013). Another reason for its popularity may be that Moran's I resembles the non-spatial Pearson correlation coefficient r. This similarity is appealing, but it may also tempt researchers to misinterpret Moran's I in spirit of Pearson's r, which is sometimes justified but much more often is not. Global and local Moran's I are given as

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(y_i - \bar{y})(y_j - \bar{y})}{\sum_{i=1}^{n}(y_i - \bar{y})^2}, \tag{2a}$$

$$I_i = \frac{y_i - \bar{y}}{\frac{1}{n}\sum_{j=1}^{n}(y_j - \bar{y})^2} \sum_{j=1}^{n} w_{ij}(y_j - \bar{y}), \tag{2b}$$

whereby the w_{ij} terms denote spatial weights connecting locations i and j, and y_i are n numeric variates with mean $\bar{y}$. Note that alternative notions of I exist for the analysis of regression residuals that account for the additional exogenous variation contributed by regressors (Tiefelsdorf 2000).

4.3 Interpretation

Interpreting Moran's I is more complex than interpreting Pearson's r. Pearson's r has a straightforward interpretation where values on $[-1, 0)$ indicate a negative and values on $(0, 1]$ indicate a positive correlation, and where the mean 0 signifies decorrelation. Significance of r depends on whether r is far away enough from 0, and on sample distribution and size. The mean of Moran's I also goes towards 0 as n increases but is generally given by $-1/(n-1)$ (Cliff/Ord 1981, 44), whose deviation from 0 is important especially for smaller samples. For better understanding the feasible range of Moran's I, it is useful to first look at Pearson's r. Let $\boldsymbol{E} = (e_{ij})$ be the $n \times n$ identity matrix.[4]

3 The ability of a statistical test to successfully identify significant effects when they are present.

4 Identity matrices have ones on the diagonal and zeros elsewhere. They are the neutral element for vectors and matrices, since multiplication with them leaves the latter unchanged. Thus, identity matrices are the vector and matrix equivalent of the scalar 1.

Instead of using the usual expression, we can write r as:

$$r = \frac{n}{\sum\limits_{i=1}^{n}\sum\limits_{j=1}^{n} e_{ij}} \frac{\sum\limits_{i=1}^{n}\sum\limits_{j=1}^{n} e_{ij}(x_i - \bar{x})(y_j - \bar{y})}{\sqrt{\sum\limits_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum\limits_{i=1}^{n}(y_i - \bar{y})^2}}. \tag{3}$$

The left-hand summation over elements e_{ij} evaluates to n and the double sum in the numerator on the right-hand side adds a number of zero terms, since all off-diagonal elements of $\boldsymbol{E}$ are zero (since Pearson's r does not contain pair-wise weights). Mathematically, nothing has changed by this more complicated notation. Writing r this way, however, one can see the structural similarity to Moran's I including the ranges of the two statistics. Determined by the only non-zero eigenvalue of $\boldsymbol{E}$, which is $\lambda = 1$, Pearson's r ranges on $[-\lambda, \lambda]$ and thus on $[-1, 1]$. This range no longer holds if we replace $\boldsymbol{E}$ by some spatial weights matrix $\boldsymbol{W}$ with a different eigenvalue spectrum.

It is possible to substitute $\boldsymbol{W}$ in Equations 2a and 2b by its eigenvalue representation[5] $\boldsymbol{HWH} = \boldsymbol{U\Lambda U}^\top$ with $\boldsymbol{H}$ being the centring operator[6] (Dray 2011; Dray et al. 2006). Here, $\boldsymbol{\Lambda}$ is a diagonal matrix of eigenvalues associated with eigenvectors in the columns of $\boldsymbol{U}$. It can be shown that for symmetric[7] matrices $\boldsymbol{W}$, the feasible domain of Moran's I is given as $[a \cdot \lambda_{\text{min}},\ a \cdot \lambda_{\text{max}}]$ with $a = n/\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}$ and $\lambda_{\text{min}}, \lambda_{\text{max}}$ denoting the smallest and largest eigenvalues of $\boldsymbol{HWH}$ (de Jong et al. 1984). This shows that for quadratic forms such as Pearson's r and Moran's I there is a close relationship between the eigenvalues of (implicit or explicit) weighting structures and the feasible value ranges of the corresponding statistical measures.

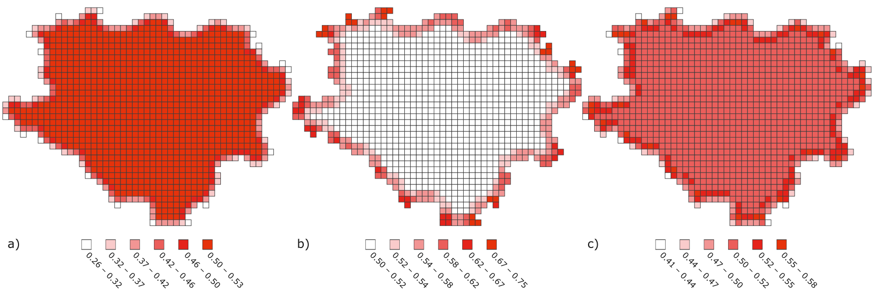
Not only the bounds of I depend on the eigenvalues of $\boldsymbol{HWH}$, but also the shape of the distribution and resulting map patterns. The locations of the eigenvalues on the spectrum are important for the shape of I's distribution, and some eigenvalues can mark inflection points (Tiefelsdorf/Boots 1995) especially for smaller lattices (for large-sample asymptotics, see Section 4.4). In addition, the spatial weights are sometimes normalised, for example, to make them comparable across different study areas. Common normalisations include the W-coding (each row sums to 1), and the C-coding scheme (each weight represents its global share; for an overview, see Bavaud 2014). However, these normalisation schemes affect the topology-induced variance and change the influence of spatial units on a spatial analysis. The W-coding scheme gives excessive weight to low-connected units (see fig. 2b) that are typically found along the boundary of a study area, but can also occur elsewhere, for example, when spatial units vary strongly in size. In contrast, the C-coding scheme favours highly connected units (fig. 2a). Tiefelsdorf et al. (1999) have presented the S-coding scheme to balance the

5 An eigenvalue representation of the spatial weights matrix can intuitively be thought of as a decomposition and reorganisation of the initial matrix into all possible spatial substructures represented by the weights. The eigenvalues then reflect the strengths of these substructures.

6 A centring operator is a matrix that subtracts the mean value either by column or by row.

7 The symmetric part $1/2\left(\boldsymbol{W} + \boldsymbol{W}^\top\right)$ of $\boldsymbol{W}$ can safely be computed in the present case of Moran's I since the antisymmetric part leads to quadratic forms evaluating to zero.

Fig. 2: Effect of different kinds of normalisations of spatial weights represented by the eigenvalues of local spatial weights matrices. a) C-coding scheme. b) W-coding scheme. c) S-coding scheme. The maps are based on data from the 2011 German Census.



effects of C and W-coding (fig. 2c). Shortridge (2007) has further found for grid configurations that both positive and negative autocorrelation are overestimated when using rook[8] instead of queen[9] weights, an effect that is more pronounced in the case of negative spatial autocorrelation. In summary, interpreting Moran's I and related measures depends strongly on the spatial weights and the way neighbourhood relations are specified. Reporting results without elaborating on the spatial weighting scheme used is therefore of limited informative value.

A useful graphical tool to understand Moran's I results beyond distributional concerns is the Moran scatterplot (Anselin 1996). The plot maps the standardised[10] attribute values y_i on the x-axis against their also standardised[11] spatial lags $\sum_j w_{ij} y_j$ (i.e. the spatially weighted sum of neighbours) on the y-axis. This shows the relationship of Moran's I to the regression of the lags on the variates. Fig. 3a shows an example of a Moran scatterplot for the filtered population data used in fig. 1a. The data are strongly positively autocorrelated, which is manifested in the diagram by the clustering of data points in the first (high values surrounded by other high values) and third quadrants (low values surrounded by other low values) and by a positively sloping trendline. In contrast, the negatively spatially autocorrelated data from fig. 1c result in an arrangement centred in the second and fourth quadrants (fig. 3c). Spatial randomness is characterised by the absence of a discernible trend as visualised in fig. 3b. The plot can be used to examine different features of the spatial autocorrelation structure present in a dataset. For example, it is possible to identify deviant data points that exhibit unusual behaviour. These are often of particular geographical interest because they do not fit into their spatial surroundings. In addition, the scatterplot can be used to identify structural breaks, that is, possible non-stationarities with respect to the spatial process.

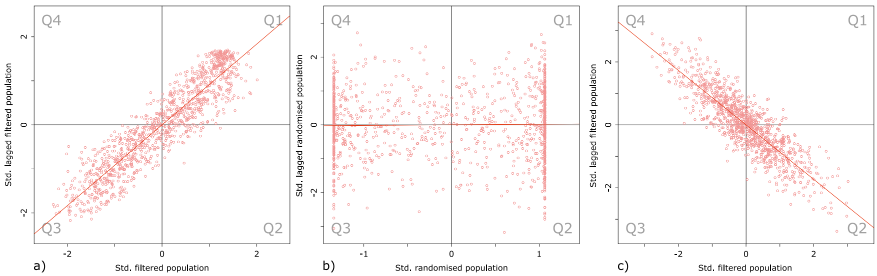
8 Rook weights connect grid cells along the four cardinal directions.

9 Queen weights connect grid cells along the four cardinal directions and the diagonals.

10 Standardisation means to centre the variables by subtracting their mean and then dividing by their standard deviation.

11 Standardisation means to centre the variables by subtracting their mean and then dividing by their standard deviation.

Fig. 3: Moran scatterplots for the positively and negatively spatially autocorrelated population variable from fig. 1 and for its spatially randomised version. Q1–Q4 denote quadrants 1 to 4 as defined by the dashed lines. The red trend lines indicate the regressions of the lags on the standardised variables. Moran scatterplots for a) a positively spatially autocorrelated variable; b) a spatially randomised variable; and c) a negatively spatially autocorrelated variable.



The Moran scatterplot is thus a very helpful tool especially for the initial exploration of spatial structures.

The main takeaway from these technical considerations is that the range of possible values for Moran's I and its distribution depend strongly on the spatial weights. This is analogously the case with Pearson's r but is not of practical relevance there, since the (implicit) weighting structure is always the same. Very similar results apply for other spatial measures like Geary's c, which also depend on given exogenous spatial linkages. Moreover, the spatial weights determine to some extent how much influence individual spatial units exert on the overall spatial analysis; a property that can sometimes affect analyses in unexpected ways, for example, when normalisations are involved. Empirical researchers should be mindful of these aspects and take them into account when interpreting corresponding results.

4.4 Asymptotic Distribution of Moran's I

Drawing inferences about Moran's I requires knowledge of the null distribution assuming no spatial autocorrelation. This knowledge allows to assess how likely or unlikely an observed I value would occur by chance given the connectivity defined by the spatial weights. Resorting to a Monte Carlo-style approach with estimation of an empirical null distribution is possible but may sometimes be impractical, for example, if the sample size is large. Moran's I can also be evaluated analytically by approximating its asymptotic distribution in two different ways. One possible approach uses a randomisation argument implying a conditional viewpoint holding the observed values fixed. The null hypothesis then assumes that the observed values could occur randomly anywhere on the lattice with equal chance (Besag/Newell 1991). An alternative approach is based on the assumption that the observed values were drawn from a joint normal distribution and is thus not limited to certain already observed values. In this case, the distribution of I in the null hypothesis corresponds to repeated and independent sampling from a normal distribution for each spatial unit. Both approaches allow testing for complete spatial randomness using normal approximations. Which of these viewpoints to adopt depends largely on the nature of the process under investigation.

Approximating the null distribution of I using normal distributions is possible for both inference approaches outlined above. They are subject to only mild regularity conditions (Cliff/Ord 1981, 46ff.). One condition is a sufficiently large dataset. Cliff and Ord (1972) suggest using a Beta approximation for small samples. A second condition is that the number of non-zero connections per spatial unit and established through the weights is not a function of the size of the lattice. A third condition is that no geographical subregion should dominate the lattice too much. Indeed, unfavourable spatial configurations exist that may prohibit the use of the normal approximation, but in many practical cases the latter will be possible. Normal approximation requires estimates of the mean and variance of I. The mean is given in Section 4.3 and does not differ between the two types of null hypotheses concerned. The variance terms for the two cases, however, are not identical and, due to the complex weighting structures involved, are quite cumbersome. For the latter reason, I refrain from replicating these terms here and refer the reader to Cliff and Ord (1981) and Griffith (2010). The analyst may sometimes encounter underlying, exogenous spatial processes that interfere with the analysis. Also, as described in Section 4.3, spatial configurations may impact the null distribution. Both situations can result in skewness invalidating the normal approximation. Tiefelsdorf (2002) suggests using a saddlepoint approximation in these cases that can accommodate such circumstances better than the normal approximation.

Data in metropolitan research often come in the form of counts, rates, or other forms of non-normal observations. It is therefore of practical interest to consider inferences about Moran's I with non-normally distributed samples. Griffith (2010) has shown that the normal approximations introduced above can be extended to a range of random variables that mimic the normal distribution. This is the case, for example, for counts drawn from a Poisson distribution, provided their mean is sufficiently large. A similar argument applies to binomial variables under the restriction of a large number of trials. For these types of variables, the equation for the mean of I holds if the random variables are reasonably symmetric about their mean. In the cases of skewness or non-symmetry, the mean estimator will be asymptotically valid if n is large enough. The term for the variance of Moran's I under the normality assumption is asymptotically valid as long as independence and identical distribution hold, and when n is roughly larger than 25. These encouraging results allow the extension of the normal approximation to a number of distributions. To some extent, this even applies to mixtures of differently distributed random variables, although this would require even larger sample sizes. For the latter case, however, it has been shown that the spatial arrangement of the random variables involved has an influence on both the mean and the variance of I, especially when the underlying means and variances of the distributions that enter mixtures differ greatly (Westerholt 2018; Westerholt et al. 2016). Therefore, caution is still required when drawing conclusions about Moran's I using non-normal data.

5. Specialised Measures of Spatial Association

In metropolitan research, non-interval scaled variables are often considered. Specialised estimators have been developed, of which the following subsections provide an overview.

5.1 Rate Variables

Rates like disease incidences and unemployment shares often violate the stationarity assumptions of spatial-statistical tests. High rates are more likely to occur when the underlying base population is small. Depending on the composition of the underlying populations, the resulting heteroscedasticity leads to either Type-I (false positive) or Type-II (false negative) error inflation (Walter 1992a; 1992b). Various approaches have been proposed to deal with rate variables. Acknowledging that the variance of normal variables depends on the sample size, Waldhör (1996) proposes to use inverse local population sizes as approximators of the local variances in the estimator for the variance of I. Oden (1995) instead traces regional rates back to individual cases. This, however, would incur a high downstream computational effort. The analysis is thus brought back to spatial units by using global comparison values based on the same base population everywhere. Assuncao and Reis (1999) propose an empirical Bayesian solution considering rates as conditional on local propensities. Rates are standardised with a constant global mean estimated from raw counts (instead of averaging the rates) and a variance estimate taking into account local numbers of cases. A similar but improved method has been proposed recently by Jung et al. (2019b). Jackson et al. (2010) propose to include the spatial weights matrix in the variance estimator used in the denominator of Moran's I. In this way, explanatory power is borrowed from exploiting spatial redundancy in nearby populations. In a similar vein, Bucher et al. (2020) incorporate additional uncertainty weights in I in a mobile sensor measurement context. Zhang and Lin (2016) develop an adjustment factor to account for heteroscedasticity as well as spatial structure in the variance. This factor can be used in the variance estimator for the randomisation-based hypothesis testing framework. The range of approaches introduced shows that heteroscedasticity has received considerable attention.

5.2 Categorical Variables

Categorical variables can mean either the analysis of binary outcomes like the presence or absence of a species, or multi-categorical data such as the Index of Multiple Deprivation in the UK censuses. The traditional and still widely used methods for assessing spatial structure in these types of variables are the join-count statistics, either in a binary way (Cliff/Ord 1981; Moran 1948; 1947) or for so-called k-colour maps (Cliff/Ord 1981; Krishna Iyer 1949). These measures count the numbers of ties of certain, spatially neighboured attribute values. In addition to using a Monte Carlo permutation approach, two different types of analytical evaluation based on normal approximations are available. These are in principle analogous to the normal and randomisation assumptions for the evaluation of I: free sampling with replacement and unfree sampling. Boots (2003) develops local tests for categorical value clustering. These tests are conditional on local compositions of classes and thus address the problem that the spatial configuration of categorical variables is not independent of their class composition. To address this compositional issue, Ruiz et al. (2010), Matilla-García et al. (2012), and Farber et al. (2015) develop global tests based on the entropy of the different locally occurring attribute value compositions. These ideas are taken further towards local testing by Naimi et al. (2019). Also focusing on local tests, Anselin and Li (2019) and Anselin (2019b) have proposed categorical counterparts to local Moran's I, which are an amalgamation of the latter with the join count statistics.

5.3 Vectors and Flows

Many phenomena including traffic flows, commuter patterns, and migration can be represented in networks or origin–destination matrices. Analysing these is possible from various perspectives (Chun 2008): spatial dependence in the origins, clustering of destinations, or combinations of these. Additional modelling steps are thus required for the spatial weights in addition to adapted models. Liu et al. (2015) have modified Moran's I towards considering origin and destination geometries as attribute values. Tao and Thill (2020) have extended this geometric idea to include attribute values (e.g. exchange intensity) and bivariate cases (in their example taxi trips and use of ride-hailing services). Analogous approaches exist for the analysis of the tails of a distribution (hotspot analysis). Berglund and Karlström (1999) have presented an approach to the G-statistics that allows clusters of high and low fluxes to be identified, again taking into account different perspectives through respectively modelled spatial weights. Another approach to hotspot analysis is developed by Tao and Thill (2019b). They extend an incremental method called AMOEBA (Aldstadt/Getis 2006), which grows spatially connected clusters from the bottom up, towards detecting coherent 'ecotopes' of flows. Another perspective on flows is a geometric one in the sense of unmarked point pattern analysis. Tao and Thill (2016) introduce a method based on the widely used K-function that considers flows in a joint four-dimensional space, and thus without separating the origin and destination geometries. This idea was later extended to the multivariate case (Tao/Thill 2019a). Similarly, Shu et al. (2021) present an analogous technique based on the L-function, a variance-stabilised version of K.

5.4 Multivariate Analysis

Sometimes it is of interest to analyse joint spatial patterns and linkages between different processes. The use of standard correlation measures like Pearson's r with spatially autocorrelated variables is problematic due to Type-I error inflation (Dutilleul/Legendre 1993; Clifford et al. 1989; Bivand 1980). A number of alternative approaches have been discussed. Wartenberg (1985) proposes to expand data vectors to matrices with different variables per spatial unit. These $n \times m$ matrices can be used in a cross product with the spatial weights matrix, and the eigenvectors of the resulting matrix can then be evaluated in the sense of a principal component analysis. A local version of this method has recently been proposed (Lin 2020). The relationship between spatial and non-spatial correlation is not unique, however, and different spatial configurations can be found producing the same Pearson's r values. Lee (2001) therefore combines Pearson's r and Moran's I into a common measure that captures point-to-point and spatial correlations. The latter proved to be more suitable for small sample sizes than the Wartenberg (1985) approach (Khamis et al. 2010). Anselin et al. (2002) focus solely on spatial arrangement and present a multivariate version of local Moran's I, including a generalised Moran scatterplot, in which the spatial lag of one variable is regressed on observations of another. In the same vein, Anselin (2019a) extends Geary's c for multivariate datasets and points out that for the multivariate case, measures like Geary's c based on differences in attribute space offer conceptual advantages over cross products of mean deviations such as Moran's I. Also modifying Geary's c and Moran's I, Eckardt and Mateu (2021) propose partial versions of these statistics.

5.5 Spatial Heterogeneity

Spatial heterogeneity describes geographical instabilities of statistical parameters (Dutilleul/Legendre 1993). This property can be caused either by endogenous non-stationarity or by exogenous contextual variation. Often regarded as a nuisance, spatial heterogeneity can be an interesting feature for scientific enquiry. One way to investigate heterogeneity is to use local statistics such as the local version of Moran's I (see equation 2b) or other so-called Local Indicators of Spatial Association (Anselin 1995). Mapping such measures and inspecting visualisations like the Moran scatterplot enables the exploration of local pockets of heterogeneity. More recently, specialised measures of spatial heterogeneity have been developed. Ord and Getis (2001) propose a measure of spatial concentration and thus of spatially varying means, whereby the method controls for possibly interfering global autocorrelation structures. Focusing on variance, Ord and Getis (2012) propose a measure of spatial heteroscedasticity. This method called LOSH (*Local Spatial Heteroscedasticity*) calculates variances about locally estimated means and allows for the detection of irregular clusters and spatial boundaries. Xu et al. (2014) have investigated the distributional properties of LOSH and recommend a Monte Carlo strategy for inference instead of the parametric chi-square test originally proposed. Based on LOSH, Westerholt et al. (2018) develop a test for strictly local spatial heteroscedasticity to characterise spatial variance in subregions regardless of other locations. Background is the detection of pronounced variances that may only stand out within small subregions but not in a global comparison. On a more practical note, Aldstadt et al. (2012) have suggested using LOSH and the G-statistics in tandem to investigate internal cluster heterogeneity. An alternative approach to this with improved discriminability between cluster boundaries and interiors is to use a spatial filtering approach (Westerholt 2021a; 2021b).

6. Summary and Outlook

In this chapter, basic principles and methods of statistical spatial analysis were presented. The topic was motivated through outlining selected application areas. These give the reader an impression of the breadth of metropolitan research for which spatial analysis has been applied. Presumptions and possible pitfalls were then outlined before Moran's *I* was presented in detail. The latter included not only the definition and interpretation of the measure, but also associated inference mechanisms. After the main methodological part, further spatial statistical estimators were discussed. However, this chapter is not exhaustive. Many of the principles presented do also apply to the various spatial regression approaches. Examples include spatial error and spatial lag models (Anselin 2001), geographically weighted regression (Wheeler/Páez 2010), and spatial filtering (Getis/Griffith 2002; Griffith 2000). Another area that is largely left out in the chapter is the topic of spatiotemporal analysis. Whilst broadly similar to what is discussed in this chapter, the latter differs conceptually, particularly in terms of modelling spatial weights (e.g., Gao 2015). In terms of future trends, one current research direction is towards a deeper integration of spatial analysis with computer science, leading to the notion of 'spatial' or 'geographical' data science (Bacao et al. 2020; Singleton/Arribas-Bel 2021). A related direction deals with a stronger integration of spatial analysis and machine learning (Klemmer/Neill 2020; Klemmer et al. 2019). Another current trend is the deeper integration of spatial analysis with human geography, manifesting itself in human-centred, place-based approaches (Westerholt et al. 2020; Purves et al. 2019). These areas will complement the traditional directions of spatial statistics in interesting ways and open up new pathways, both theoretically and in terms of practical integration with new fields of application in metropolitan research.

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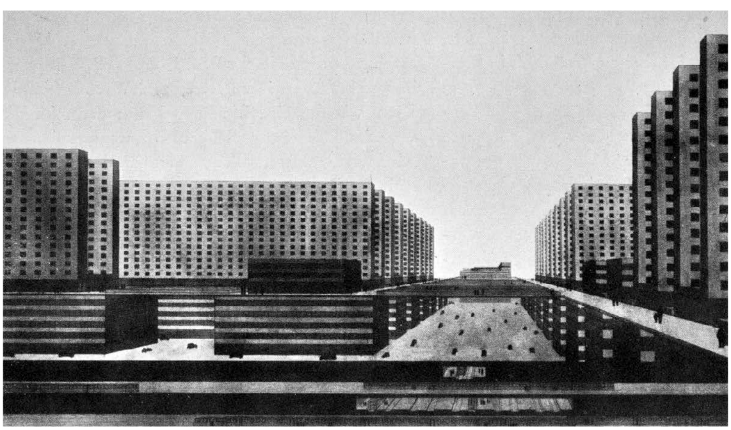
Spatial Analysis as a Tool for Architectural and Urban Historians

Cornelia Jöchner

1. Preliminary Remarks

The view that urban spaces are experienced while in motion emerged long before the modernist urban visions of someone like Ludwig Hilberseimer, who in 1927 suggested separating pedestrian from motorized traffic (Hilberseimer 1998, 17).

Fig. 1: Ludwig Hilberseimer, high-rise city, 1927. Source: Hilberseimer 1998, Fig. 24



His proposal to place walkways far above roads (fig. 1) was analogous to calls for cities to be divided into different functional areas. Similarly, movement was considered a key way of experiencing cities long before promenading and hiking became fashionable in the late eighteenth century. In Karl Philipp Moritz's novel *Anton Reiser* (1785–1790), walking through and around the city is a way for the protagonist to consider his own past and future (Moritz 1996, 82–83). At the dawn of the early modern period, the city was already regarded as an entity experienced in motion, an aspect that needed to be reflected in its architecture. In his architectural treatise about the planning of curved streets in cities, Leon Battista Alberti wrote: “Moreover, this winding of the streets will make the passenger at every step discover a new structure, and the front and door of every house will directly face the middle of the street” (Alberti 1975, 201). Alberti’s recommendation that urban streets, instead of being straight, should be “winding about several ways, backwards and forwards, like the course of a river” was based on the experience of the human body in motion: walking along a sinuous street (he explained) was the only way to confirm that the façades continued to follow one after the other.

But how can such idiosyncrasies be included in academic analysis of the city? Below, I attempt to address characteristics of the city that are primarily of interest to architectural and urban historians. The aim is not to provide formulae, but to explore how questions about certain problems of the city can be asked in a meaningful way.

2. *Longue durée* as a Methodological Challenge for Urban Analysis

In my introduction, I mentioned a few key points about the fundamental importance of motion to experiencing the city. In addition, for architectural and urban historians, there is a second, pivotal condition of the city which any analytical study needs to deal with from the outset – the fact that the city is a complex system characterized above all by change. According to urban historian Spiro Kostof, urban development is a process that encompasses the many ways in which the built whole of the city is adapted to changing conditions and requirements (Kostof 1992, 8).

The transformation to which the city is permanently exposed also engenders the challenge of incorporating it methodologically. And it may sound paradoxical at first, but this is particularly necessary when it comes to the ‘immovable property’ of the city, its real estate. After all, given their materiality and their particular involvement in the processes of life, architectural and immovable artifacts are plainly constituted by temporal relations of ‘before’ and ‘after’. In the case of the city, this means not only buildings, but also especially long-lived spatial structures, such as parcelling, site constancy, and historical watersheds.

This specific *longue durée* of the city is known to art and architecture researchers as a methodological problem (Jöchner 2010). Very often, however, they translate this fundamental condition into chronologies instead of searching for the constitutive ‘construction factors’ of spatial situations. The combination of chronologies, however, derives from ideal cases of architecture. By contrast, acknowledging – including methodologically – the permanent pressure on the city to change is a far more realistic view. And this means that the continued interpretation of the city’s topology and buildings against the background of conversions and new buildings, urban planning schemes and repurposing, is analytically assumed from the outset.

Suitable tools here include morphogenetic methods (cf. the article by Wolfgang Sonne) from both urbanistics (Malfroy/Caniggia 2018) and urban geography (Conzen 1990). Urbanistic approaches with a dual focus on both long-lived structures and historical watersheds are helpful in grasping the development of urban texture in its interrelations with specific buildings (Jöchner 2015). Such an approach is particularly apt for modern metropolises with specific, highly dense growth structures such as London, Paris and Naples, or even modern metropolitan regions, which often lack clear boundaries.

Accordingly, urban analysis that includes the two fundamental constituents of the city – motion and processuality – clearly operates on the level of space. This latter concept has by no means only been considered by research into architectural and urban history since the spatial turn; on the contrary, it is no exaggeration to say that a spatial approach to architecture and the city was first tried out on the example of the square (Jöchner 2010) and thus contributed to making it useful for art history. *Vice versa*, the concept of space was crucial to the fact that around the turn of the twentieth century, the city was for the first time systematically studied within the history of art and architecture.

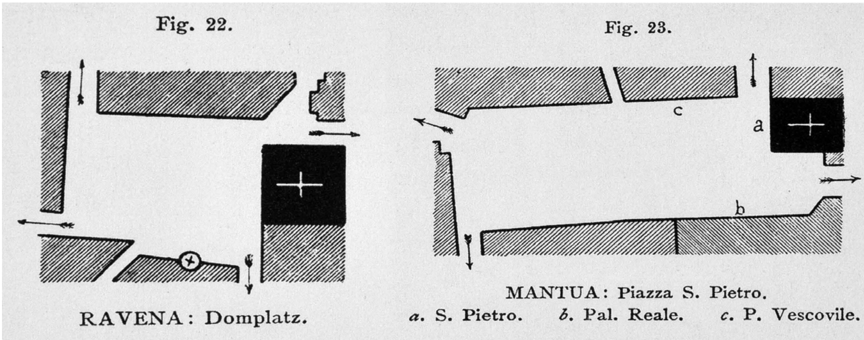
3. The Square as an Object of Research

"This work is devoted to an area that has received little attention from either art history or aesthetics. The manuals of architecture doubtless record the tiniest detail. Urban construction as a whole, which is the culmination of architectural design, has been almost ignored." (Brinckmann 2000, V) This was how Albert Erich Brinckmann introduced his book *Platz und Monument. Untersuchungen zur Geschichte und Ästhetik der Stadtbaukunst in neuerer Zeit* ('Square and monument. Studies on the history and aesthetics of urban architecture in recent times', 1908). When describing the state of art history with regard to the study of the city, Brinckmann negated the preceding, intensive examination of the city by Camillo Sitte, then a teacher at Staatsgewerbeschule in Vienna. *Der Städtebau nach seinen künstlerischen Grundsätzen* ('Urban planning according to its artistic principles') was the title of his book, which was first published in 1889 and republished several times. He developed a new way of studying the city which Brinckmann adopted, whether intentionally or not.

Sitte's 'art-technical' analysis, as he called his approach (Sitte 1983, 2), was prompted by the situation of the city at the time, which was growing beyond its previous borders in response to considerable urban expansion. For Sitte, these expansions were characterized by large unplanned areas. He wrote that people always lived "under the mad delusion of always having to be able to see everything" and that the only acceptable approach was the monotonous spatial emptiness around them. He added that the fact that this intrinsically boring spatial emptiness destroyed any diversity of effect was unheeded (Sitte 1983, 35). Starting from this criticism of contemporary urban design, he developed his analysis of historical cities with particular emphasis on squares and their irregularity. He examined cities' design principles and systematically translated them into simple black-and-white drawings (fig. 2): empty spaces such as squares and streets were left white, religious buildings rendered in black, and other built-up areas hatched in grey.

These plans resembled the figure-ground representations that had become widespread since the mid-eighteenth century. Such illustrations accompanying Sitte's writing were a striking element of his highly successful book: an unswerving

Fig. 2: Ravenna, the cathedral square (left); Mantua, Piazza San Pietro. Source: Sitte 1983, 40



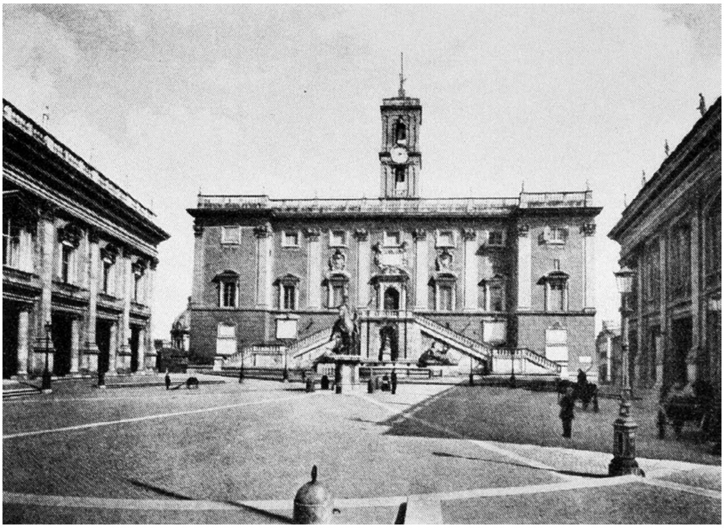
analysis of built structures, especially squares. He was particularly interested in the spatial unity of historical squares. The examples of Piazza Duomo in Ravenna and Piazza San Pietro in Mantua (fig. 2) show that the streets usually led into the square at the corners. The square thus appeared closed like an interior space. The lines of sight that Sitte drew into the plans were intended to emphasize that from the sides of the square, there was always only one view into a street, ensuring the square's spatial unity. Other examples showed groups of squares, the erection of monuments at functionally prominent points, and the wide range of urban planning methods that are effective in squares: from fixed barriers and optical openings to covered passageways.

With his view that the square was like a furnished room, i.e. a more or less enclosed interior space in the city, Sitte took his cue from the theory of architecture developed by Gottfried Semper, who was the first to point out the space-creating role of the wall. In contrast, the above-mentioned Albert Erich Brinckmann was partly influenced by Heinrich Wölfflin and his idea of architecture as a 'plastic mass', yet also by August Schmarsow's idea of the history of architecture as a history of the sense of space (Schmarsow 1894). When it came to analysis of the square, a key innovation by Brinckmann was his recognition of the space-forming significance of the monument, especially for the early modern plazas of Italy and France (Brinckmann 2000).

The constellation of square and monument explored by Brinckmann has also been dealt with by current research. In addition, Brinckmann attributed a more independent role than Sitte to the square (which he also placed in relation to the rest of the city). He wrote of the square as a 'spatial object' (*Raumkörper*), citing the example of Piazza del Campidoglio (Capitoline Hill) in Rome (fig. 3). The equestrian statue of Marcus Aurelius riding out of the centre and the square's loosely placed architecture create spatial depth, giving the square an independent quality (Jöchner 2010).

However, especially in the late eighteenth and early nineteenth centuries, the fact that recently built squares were opened up to nature and the landscape was something that Sitte and Brinckmann failed to see, for they refused to accept 'urban greenery' as a contemporary tool of urban design. Both authors rebuffed such parks and gardens, which were often laid out on the contemporaneous outskirts and acted as new 'gate-

Fig. 3: Michelangelo Buonarotti, Piazza del Campidoglio, Rome. Source: Brinckmann 2000, 45



ways' to the city. Such 'entrance squares' have since been identified as a hybrid spatial type (Jöchner 2014; 2015), which opened up the previously fortified, now more open city in a novel way, yet also connected it to the surrounding political territory, the former 'outside' (fig. 4). With these squares associated with times when the fortified city was opened up, the above-mentioned processuality of the city (i.e. the gradual construction of spatial structures) emerged as an important constituent of new spaces (Jöchner 2015).

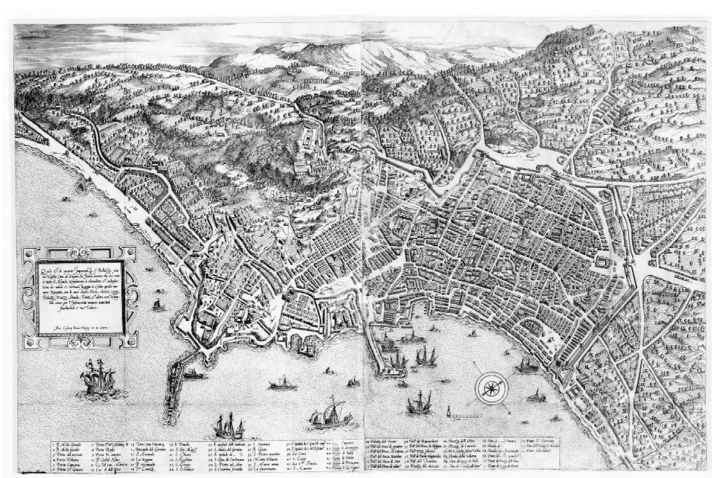
4. The Cityscape and Urban Spaces

The example of the 'entrance square' granting symbolically broad access to a now more open city emphasizes that spatial and architectural arrangements of the city also have inherent illustrative values: they produce 'images'. Traditionally, the city is one of those social spaces known for the high production of images. In the Middle Ages, for example, drawings on walls depicting the legal space of the city (which was usually autonomous at that time) were common. The question of what information these half-pictorial, half-cartographic views of early modern cities contain takes researchers back to the concept of ancient chorography – the arrangement of action-related places in an abstract classification system such as cartographic descriptions or visual maps. The visual classification of such cartographic representations can thus also be understood as a historical image of a city (fig. 5).

The art-historical study of the cityscape began from a different angle: the built city rather than the depicted city. Interest in visual qualities of the built city was particularly

Fig. 4: Giuseppe Frizzi, Piazza Vittorio Emanuele (since renamed Piazza Vittorio Veneto), 1825–30, Turin. © Uwe Rüdenburg, Berlin

Fig. 5: Antonio Lafreri, after Etienne Dupérac: Quale e di quanta, importanza e Bellezza sia la nobile Cita di Napole … Map of Naples and its surroundings, 1566. Source: Michalsky 2008, 269



evident in the 1920s, when the concept of architecture as a structural body became widespread. Most authors regarded architecture as a cubic form and thus supported Wölfflin's idea of architecture as a plastically formed mass. This drew attention to the outdoor area of the city shaped by various buildings, and which came to be regarded as a continuous space.

One such author was Paul Zucker, who in 1929 published his book *Entwicklung des Stadtbildes. Die Stadt als Form* ('Development of the cityscape: The city as form'). Zucker explored the "form of the city", namely the city shaped by a certain topography, which in turn leaves its mark on the topography by means of its buildings (Zucker 1986 (fig. 6). The geographical capacity characterizing Zucker's approach (which is still worth reading) is one of the instruments of heritage conservation today: its range of criteria would be unimaginable without the fact that the external form of a city, the cityscape, is individually shaped by its buildings and topography.

Fig. 6: Tripoli. Source: Zucker 1986, 149

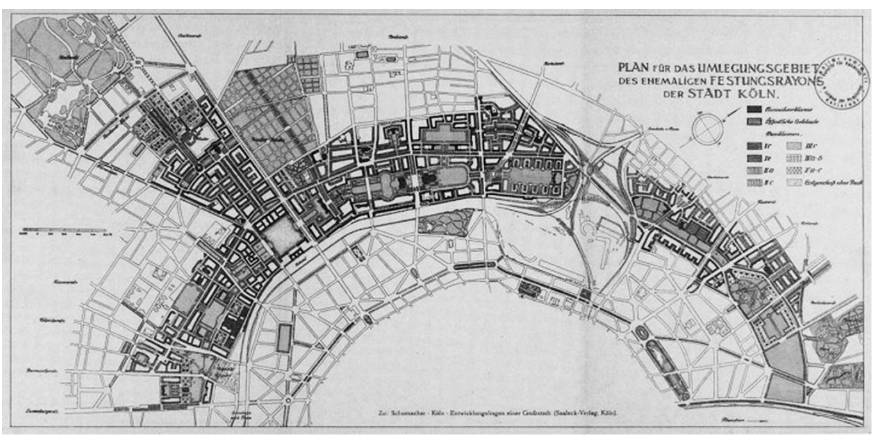
Formalist analyses of urban space, which include the city-related chapters in Herman Sörgel's *Architekturästhetik* (Sörgel 1998), were typical of the 1920s with their object-space thinking. The fact that the spatial formation of architecture takes place both inwardly *and* outwardly was demonstrated by Sörgel and Schumacher in somewhat different ways. While Sörgel formalistically defined the quality of architecture as the concavity of inside and outside, Schumacher understood architecture as a *means* of overarching spatial design:

> Only when we see in architecture the art of *spatial design* through *object design* do we bring the two factors into a more suitable relationship. Spatial design is the dominant goal, object design the serving means. […] Architecture is the fulfilment of concave intentions through convex formation. In this sentence, the use of 'intention' in the plural and 'formation' in the singular is no accident; it indicates […] that architectural physicality is a dual spatial generator. This physical appearance acts as a spatially limiting element in two ways, namely in *indoor* space and *outdoor* space. (Schumacher 1991, 36)

Only Fritz Schumacher included the *dual* spatial function of architecture to create a media theory of architecture (Jöchner 2015, 59–60; 2017). If architecture makes use of shielding and opening simultaneously, by means of this special mediality it also forms 'in the same breath' a place and object of social action. By applying Schumacher's media theory of architecture, the analysis of the city can be extrapolated into an analysis of social spaces. It could also help us to see through the current trend towards an image-oriented, market-driven production of the old town. The fact that Schumacher's reflections on the *two* spaces of architecture are not included in today's overview works on outdoor space may be due to their theoretical nature, which requires clarification. On the other hand, historiographical endeavours can easily lose sight of the task of analysing urban phenomena in concrete terms.

In particular, Zucker's book *Entwicklung des Stadtbildes* reveals just how influential the idea of a unity of the city was in the 1920s. Nothing shaped it as much as the previous city walls, which had reinforced the visual depictions of the once autonomous legal space of the city. The fringe belt developments, to which Fritz Schumacher for example contributed in Cologne in 1923 with his modern intertwining of city and country, contain traces of that past unity – traces which were now to be displayed in an expanding city (Jöchner 2017; fig. 7).

Fig. 7: Fritz Schumacher, plan for the redevelopment of the fortified belt once surrounding the city of Cologne, 1923. Source: Schumacher 1923, 258



At the same time, the modern city had provided an approach that understood the city as a social entity. At the first German exhibition dedicated to cities (held in Dresden in 1903), where Fritz Schumacher spoke about the architectural tasks of cities (Schumacher 1903), the sociologist Georg Simmel delivered his famous lecture *The Metropolis and Mental Life* (Simmel 1903). Simmel's topic was the pace and the "multiplicity of economic, occupational and social life" that creates conditions with "each crossing of the street" and which he calls "psychological": the pace, the diversity, the hustle and bustle of the big city. Five years later, he developed from this his sociology of space. Rejecting all formalistic conceptions of space, the focus was instead on social interaction. Every kind of spatial constellation, according to Simmel, came about in the interrelationship between different social carriers, their respective demands determining the way in which space was filled (Simmel 1992, 689). In other words, space is not given, but created.

This made it possible, for example, to determine the much-invoked unity of the city as a historical expression of legal circumstances. Simmel emphasized this using the example of the medieval cities of Flanders. This was probably due in part to his experience of the fragmented modern city, something that was represented by contemporaneous artistic projects. From his structural analysis, it emerged that the medieval city had also consisted of multiple legal spaces with different affiliations that overlapped one another: instead of focusing on the *one* holistic space, Simmel emphasized the plurality of *spaces* of the city.

5. The User's Perspective and the Urban 'In-Between'

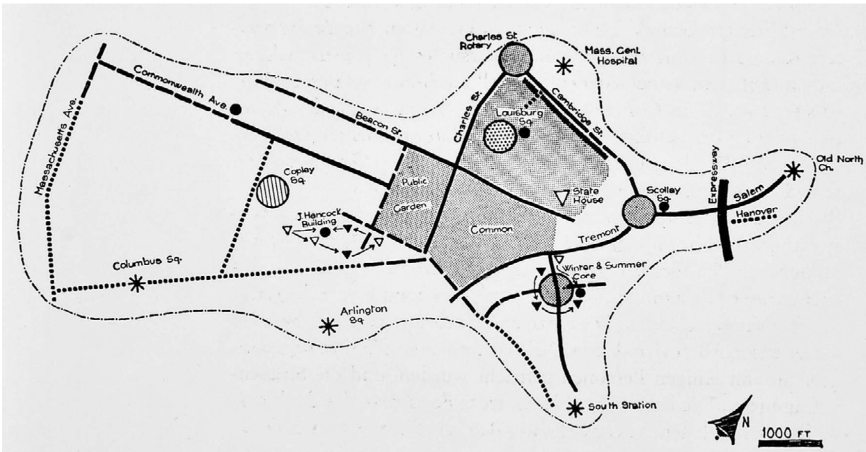
It was precisely this density of the modern city as well as the experience of it that put motion as a mode of reception back on the agenda – with great urgency. Experiencing the city through the movement of one's own body underwent a novel formulation in the literary figure of the flâneur strolling through nineteenth-century Paris apparently aimlessly with the sole purpose of absorbing the diverse visual and also commercial charms of the modern city (Benjamin 1982). The flâneur's urban equivalent was the boulevard and the covered street shops (*passages*), both of which shaped the public space of the time (cf. Barbara Welzel's essay in this volume).

A shared interest in the perception of the city leads to Kevin Lynch's book *The Image of the City* (Lynch 1960). It explores visual depictions of the city, albeit not those discussed above produced by experts. Lynch's starting point is that a user's view of the city looks completely different from that of professional planners. In the studies he developed together with György Kepes, urban inhabitants were asked about their personal observations of the city, their mental images of it. The basis for such images was always five certain fundamental spatial structures of their cities, namely landmark, node, district, edge, path. Translating these very different design elements of each city into simple graphic signets resulted in its users' "mental maps" (fig. 8) (cf. also Wolfgang Sonne's essay in this volume).

Lynch's book marked a turnaround in urban studies by refocusing attention on the user. This participatory approach was one of the reasons why, in the second half of the twentieth century, urban planning no longer necessarily relied on the masterplan. Modern cartographic research raises similar questions about the information content of urban maps on the one hand and the perceptions of the urban spaces they show on the other. This is based on the postmodern notion that although at first sight maps seem to be objective, they are in fact subject to an interest-driven construct of reality.

A more recent field of research is also based on the user's perspective: the question of the 'in-between' in the spatial structure of the city. Structurally, this concerns the historical public buildings of the city, many of which have elements serving as a transition to the interior such as porticoes, staircases, ramps and balconies. In the Middle Ages and the early modern period, building elements that projected into or overlapped with public space were sometimes also legal spaces, one example being the *Gerichtslaube* (a porch adjoining a town hall which was open at the sides and used as a court of law where proceedings could be viewed by the general public), which in the modern period

Fig. 8: The mental map of Boston compiled from surveys conducted among passers-by. Source: Lynch 1960, Fig. 10



sometimes contained a suitably deterrent iconography of punishment or references to the city's legal system. With reference to cultural theory, such transitory elements are understood as 'threshold spaces'. They mark a border which can be crossed in order to enter another space. As in most studies addressing the social spaces of the city, analysis of the form of the city is associated here with social actions (de Certeau 1984). Since the 'in-between' is virtually a characteristic of urban spaces, this current question can be seen as a continuation and application of Simmel's spatial theory. Furthermore, it directs our attention to urban spatial phenomena extending beyond a single, self-contained work. Accordingly, the urban ensemble can now be explored again using additional spatial questions, for instance with respect to social demarcations and how they can be overcome.

Translation: Chris Abbey

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Historic Preservation as Change Management: Methods in Context

Ingrid Scheurmann

The city of the future in Europe is currently – and in contrast to the expanding Arab and Asian cities – being imagined less in images of futuristic architecture, but rather as a compact agglomeration of short distances in a high-quality green environment, with intelligent mobility concepts, a pronounced sharing culture and a resource-saving new construction practice. This is all the more true for the high-density metropolises. In view of the man-made climate crisis, the motto here must be: the city of the future has already been built. Therefore, it is important to orient visions to the existing building stock and to a culture of further building ["Weiterbauen"], repairing, repurposing, questioning needs, upgrading and maintaining. New neighborhood or commons projects are already shaping urban neighborhoods and are increasingly being used as living labs, future workshops or fields of experimentation. Participation and knowledge transfer are important prerequisites for this. Within the sustainable development of metropolises, monuments play an important role as symbolic proofs of duration and identity, as does historic preservation with its expertise in the care and preservation of existing buildings and structures.[1]

It is no coincidence that some of their central concepts have found their way into the current discourse on architecture and urban development, which gives priority to 'building without new construction' (Bund Deutscher Architektinnen und Architekten 2019, para. III: "Respect for the Stock").

1. Substance and Process Values

Metropolises are not original objects of historic preservation. Having originated as an object-oriented discipline concentrating on selected testimonies of high culture, the

1 The understanding of sustainability in this paper refers to the Brundtland Report, see United Nations (1987, ch. 3 "III. Enabling Sustainable Development", Art. 27–30) and the linking of intergenerational and international social justice, economic growth, participation and ecology.

subject has continuously expanded its field of activity in relation to the societal development of the last 200 years and has reached its maximum spatial expansion in the period following the Second World War with the care of monuments in large cities on the one hand and the care of cultural landscapes on the other. Both of these special concerns are not regulated in Germany by the laws of the federal states on historic preservation, but they are taken into account in conjunction with regional planning and building law and with nature and landscape protection, respectively.

Thinking about historic preservation in big cities was developed in the context of the reconstruction debates after the Second World War and was discussed within the discipline for the first time in the period around 1960. Here, the example of the Hanseatic city of Hamburg, which had been severely destroyed during the war, was seminal: dealing with the growing uniformity of the buildings, the orientation toward traffic flows, city formation, and the significance of high-rise buildings (Grundmann 1962).[2]

Thereafter, metropolitan historic preservation played an important role within the framework of the *European Year of Monument Preservation* in 1975 with the model city project West Berlin (rehabilitation of the tenement city; see fig. 1) and, following on from this, in the context of the *International Building Exhibition* in Berlin in 1987 with concepts of Hardt-Waltherr Hämer for careful, socially compatible urban renewal (Hardt-Waltherr Hämer; Cutolo 2015; Bodenschatz et al. 2012).

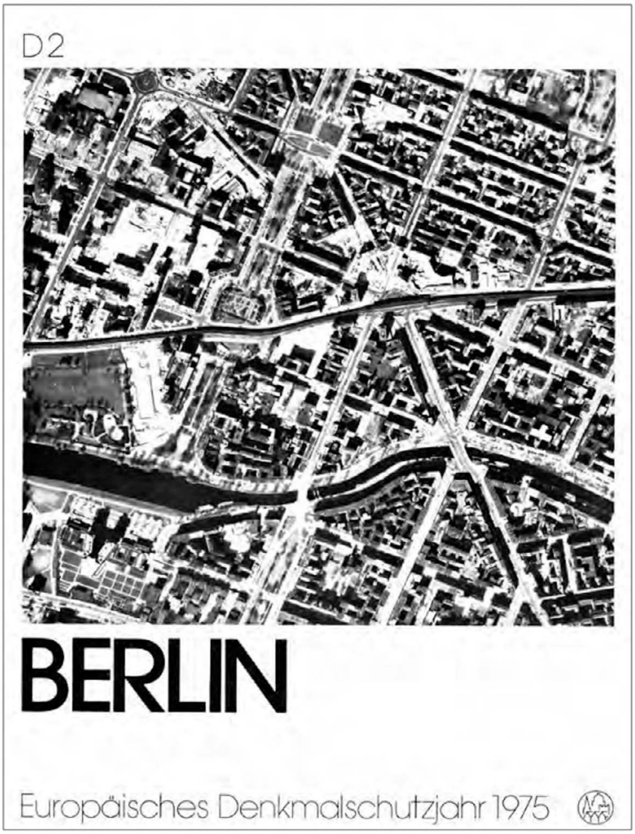
Cultural landscape thinking, on the other hand, dates back to the late 1970s and 1980s and responds to a new understanding of historic preservation as an "environmental therapy" or "environmental ethics" (Petzet, 1975; 1988; my translation) or – critically turned – as "monumental ecology" (Sauerländer 1993; my translation), i.e., to the environmental awareness that has been gaining strength since the 1970s. Only then are the landscape contexts of a monument perceived as integral components of the monument's character, and formative cultural landscape elements identified as worthy of protection.

Finally, in 1994, the monument theorist Wilfried Lipp described the preservation of large cities and cultural landscapes as new 'areas of hope' or 'areas of expectation for monuments' for his discipline and emphasized the necessarily associated methodological shifts: both metropolitan as well as cultural landscape require "an expanded concept of monument, namely a fluid, to a certain extent 'strolling' concept of monument" (1994, 11; my translation). According to Lipp, in the metropolis, the question of "preserving change" arises in a similar way as in the case of the *per se* non-static cultural landscapes – only thinking in terms of process values, which are adequate to the change, can do justice to the new tasks (1994, 11; my translation).

Beyond this, the accelerated innovation processes, especially in metropolitan areas, and, as a consequence, the continuous rejuvenation and multiplication of 'cultural heritage' raises fundamental epistemic questions. They concern not least the floating role

2 See also Vancsa (1989), who takes the example of the metropolis of Vienna, which remained largely undestroyed in the Second World War, and discusses it as a historically evolved work of art/monument. See also Architektenkammer Berlin 2019 and Lipp 2008, 340f.

Fig. 1: Cover of the Publication Model City Berlin 1975



of the professional actors between participation in and observation of processes ("Are we actors or witnesses?"; Bradley et al. 2004, 5).[3]

Precisely because of their peculiar link between preservation and change, the preservation of monuments in large cities and the preservation of cultural landscapes offer a variety of starting points for the sustainable development of large areas, since it is not only significant individual monuments or ensembles (town halls, churches, historic town and village centers) that are important here, landscape contexts (green belts, road networks, settlement structures) and large spatial figures (production sites, infrastructures, high-rise dominants, shopping centers, campus universities, airports) that are to be protected, but also the multicultural migrant heritage associated with specific places of memory, as well as experiences of foreignness and identity conflicts. This is about places or spaces of belonging but just as much about diverse cultural practices and immaterial layers of meaning. In this respect, it is precisely what Lipp designates as the

3 Vinken (2010, 14) points out that big cities in the 19th century were often perceived as "chaos" and triggered a sense of the disintegration of conventional orders.

future areas of historic preservation that are linked to a shift in priorities from object values to historically grounded process values.

In English-speaking discourse, the concept of 'change management', adapted from the economic sciences, has been in use for some years now. It does not only address the natural aging, but also action on and with the monument and responds to the adaptation processes that are becoming necessary at ever shorter intervals. This involves controlled change, however "neither the preservation of form nor of substance alone, but the preservation of the monument characteristics of a processual object" (L. Schmidt 2011, 52; my translation; see also, e.g., Teutonico/Matero 2003).

Together with the concept of 'change management', and motivating the thinking in processes of change, the concept of cultural heritage has conquered Western European discourses and with it the focus on social processes of meaning-making that "interpret[s] and make[s] usable the past with regard to our present and future" (Herold 2018, 39; my translation). They go hand in hand with the multiplication, internationalization and regionalization of monument values and authenticity concepts.[4]

2. Living and Dead Monuments

Under a different perspective and in connection with other objectives, the concept of *change management* is also at home in the Western European object-oriented discourse on monuments. Already in the heyday of the debate about material substance and historical testimonial values around 1900, the Belgian architect Louis Cloquet proposed a differentiation between living (*monuments vivants*) and dead monuments (*monuments morts*), in order to propagate a pragmatic path between substance protection and modernization for the mass of living monuments which are in use. This proposal was acceptable for the contemporary architects and subsequently incorporated into an agreement of the International Congress of Architects in 1904 ("Recommendations" 1904).

Cloquet and – with reference to him – the Belgian politician and urbanist Charles Buls recommended the strict preservation of time layers ("conserve, not restore", my translation) only for selected musealized buildings (of high culture) and emphasized for all other the possibility of greater adaptations to changing urban and landscape contexts (Scheurmann 2018, 304–308).

Especially after the First World War, this idea experienced a strong reception with reference to the "living" of cultural heritage, and at the same time a tendential reinterpretation towards a predominantly aesthetically argued understanding of historic preservation. The Austrian art historian Hans Tietze, for example, postulated in 1921 a "new interlocking" (1921, 197; my translation) of historic preservation with life, and the Rhenish Provincial Conservator Franz von Wolff-Metternich advocated a "living historic preservation" (1931, 231; my translation). Other examples could be added. Indirectly, they questioned the substance orientation of their profession with the accusation of "museification" (Wolff-Metternich; my translation) and wanted to remove monuments from

4 *The Nara Document on Authenticity* was groundbreaking in this regard, see ICOMOS 1994.

the "cultural protection park[s] of untouchedness" (Tietze 1921, 197; my translation; cf. also Scheurmann 2018, 309–314; 2019.).

Even though these statements did not explicitly speak of a controlled process of change in historic preservation, the idea of development instead of the notion of a document nevertheless already played a decisive role. This also applies to the pioneer of historic preservation at that time and the first Austrian General Conservator Alois Riegl, who already wanted his innovative 'age value' ["Alterswert"] to be understood as a "development value" (1995, 65; my translation).

In contrast to these positions, today's thinking about process values and *change management* (in the sense of a targeted, value-based management of change processes) reflects a strongly changed approach to the landscape of monuments and historic preservation compared to the early 20th century. This concerns the diversity, the contemporaneity as well as the dimensions of the objects of protection, but also the plurality of values, the globality of interdependencies and the spectrum of the new stakeholders. According to these shifts and the climate crisis, thinking about conservation issues has become an essential common concern of contemporary societies. Questions of the differentiation of cultural heritage, respectively the significance of its layers, continue to play an essential role.

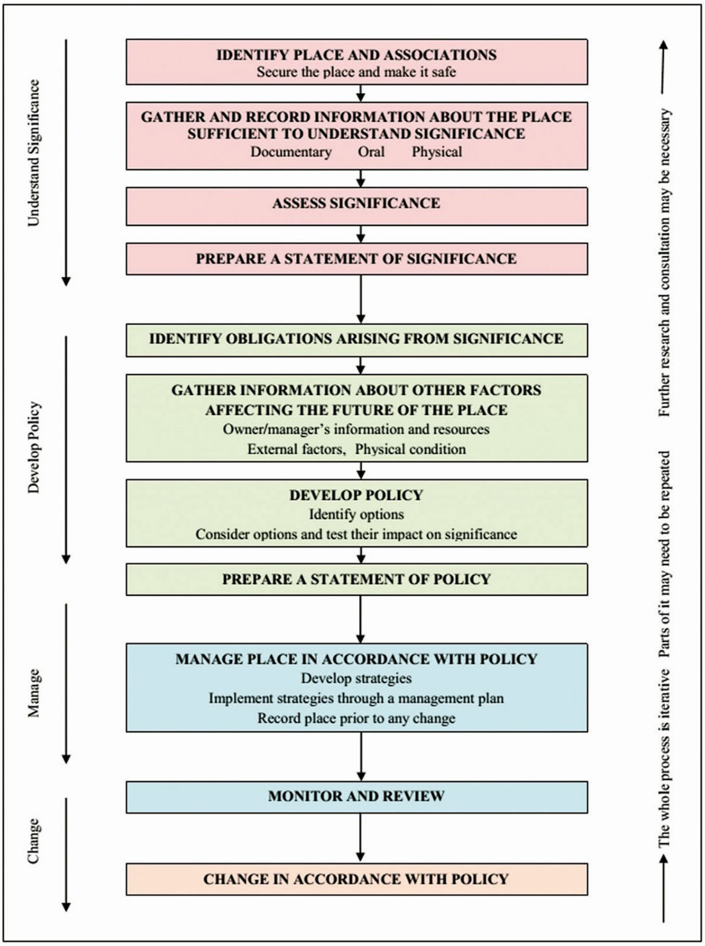
3. Actor Orientation and Participation

The term "change management" first found its way into an official document of historic preservation in 1999, the so-called *Burra Charter* (first version 1979). This is a position statement of Australia ICOMOS, published in 1979 and updated twice since then, which, among other things, strives for a balanced relationship between *change* and *maintenance* (2000, 6, Art. 15 and 16). The fact that both strategies for dealing with cultural heritage are classified under the title of "Conservation Principles" indicates that the central concept of *Cultural Significance* is based on various tangible and intangible values ("aesthetic, historic, scientific, social or spiritual value[s]", 2000, 2, Art. 1.2), which find correspondingly diverse forms of expression within the cultural heritage ("*fabric, use, associations* and *meanings*", 2000, 8, Art. 27.2; original emphasis).

It is furthermore clear that the idea of change and its conservational moderation are closely linked to the concept of cultural diversity – understood as diversity of values, but also of the stakeholders representing them. In this respect, the Australian "Conservation Principles" are quite adaptable for historic preservation in socially and culturally heterogeneous metropolises. Even more: the acceptance of change – a reaction to the 'cultural turn' of the 1990s – implies a focus on the attribution of meaning instead of supposedly ontological values and cultural norms and in this respect also responds to the social and cultural preconditions in multi-ethnic and migrant communities – the "'home[s]' of the postmodern global society" (Lipp 1994, 11; my translation).

A further consequence of *change management* – not least in view of the plural needs of identity and memories of the population in large cities and metropolises – is the establishment of forms of participation. In this regard, the 1999 version of the *Burra Charter* underlines the right to "participation of people for whom the place has special *associations* and *meanings*, or who have social, spiritual or other cultural responsibilities for the place" (Australia ICOMOS 2000, 5, Art. 12; original emphasis) and links it within the framework of the so-called *Burra Charter Process* with procedures, including management plans, supervision and monitoring (see fig. 2).

Fig. 2: Schematic representation of the Burra Charter Process



Source: Adopted from the Burra Charter (1999).

A similar change in the relationship between experts and laypeople is also reflected in the Faro Convention of the Council of Europe (*Convention on the Value of Cultural Heritage for Society*) from 2005.[5] Here, too, it is about the right to cultural participation and

5 The convention has not yet been ratified by Germany, England and France, see www.coe.int/en/web/conventions/full-list/-/conventions/treaty/199/signatures199

the protection of cultural diversity ("every person has a right to engage with the cultural heritage of their choice"; Council of Europe 2005, preamble). The aim of the Faro Convention is not only to promote dialogue between cultures and religions (Council of Europe 2005, preamble), but also to share the responsibility for the cultural heritage and establish forms of participation (Council of Europe 2005, "Section III – Shared responsibility for cultural heritage and public participation").

In its emphasis, the *Faro Convention* – similar to the *Burra Charter* – responds to the changed cultural constitution of modern societies and promotes a democratization not only of access to cultural heritage, but also of its "management". Historically, this was the Council of Europe's reaction to the so-called ethnic cleansing during the Balkan wars of the 1990s. Under the changed stakeholder-based perspective, it opened the understanding of cultural heritage to heterogeneous meanings of heritage, memory and monument. The postmodern openness to emotional values and show values ["Gefühlswerte", "Schauwerte"], as opposed to substance values, has also emphasized the increasing acceptance of plural values (Meier/Scheurmann/Sonne 2013).

It becomes clear that contemporary societies are undergoing multilayered transformations and are increasingly determined by economic, ecological and cultural interdependencies. This has resulted in adaptation processes with regard to cultural heritage, its definition, preservation and maintenance as well as the practices associated with it, and has caused developments and processes as well as targeted management of this change to take the place of a fixed catalog of historic preservation values. However, the change in practice does not make experts superfluous, but it does assign them new tasks – including the areas of communication and moderation.

Above all, these adaptation processes respond to the increased importance of sustainability thinking, which necessitates "the active protection of urban heritage and its sustainable management" (preamble) and underlies UNESCO's 2011 *Recommendation on the Historic Urban Landscape*, which is important for the development of metropolitan areas. This document also relegates the object- or substance-related values of historic preservation to the background in favor of the perception of diverse cultural and natural layers of significance as well as a value context that takes ecological, societal and economic aspects into account.[6]

At the same time, the recommendation emphasizes the value of the historic especially in dynamic urban spaces ("the most abundant and diverse manifestations of our common cultural heritage"; UNESCO 2011, preamble) and stresses the need to no longer separate preservation, sustainability, and planning concerns from one another. It becomes clear that monument and ensemble protection have changed under the

6 Article 9 of the document defines the understanding of the term *historic urban landscape*: "This wider context includes notably the site's topography, geomorphology, hydrology and natural features, its built environment, both historic and contemporary, its infrastructures above and below ground, its open spaces and gardens, its land use patterns and spatial organization, perceptions and visual relationships, as well as all other elements of the urban structure. It also includes social and cultural practices and values, economic processes and the intangible dimensions of heritage as related to diversity and identity" (UNESCO 2011).

premises of current processes of social transformation and the imperative of sustainability "[f]rom an approach where change was at all costs to be avoided" to an "approach where change is to be managed" (Pereira Roders/Veldpaus 2013, 17).

This also concerns the stakeholders. In view of the complexity of evaluation processes, the art historian Hans-Rudolf Meier suggests that monument conservators should become process managers who justify their decisions, communicate them, and thus make them comprehensible and open to discussion (2013, 14).

Such a *management of change* is by no means to be understood as license for arbitrary changes to the monument or to historical sites. It does, however, concede that any measure taken on the monument "changes its status materially and aesthetically" (2019, 102; my translation). Even a "decision for a *non toccare* ['do not touch']" according to monument conservator Bernd Euler-Rolle, "represents a step in the object biography" (2019, 102; my translation).

The commitment to *change management* therefore means a change only insofar as it makes transparent the processes that take place at the monument, in the cultural landscape or in the metropolis, justifies them and moderates among the stakeholders involved.

4. Repair and Sustainability

In Europe, most progress in the opening of historic preservation institutions to the concept of *change management* can be witnessed in England (Historic England 2008).

For some years, however, similar tendencies have also become noticeable in Switzerland and are linked on the one hand to pleas for stronger participatory structures (*Nike-Bulletin* 2020), and on the other hand to a concept of building culture ["Baukultur"] that encompasses monuments, existing buildings and new buildings alike (e.g., Eidgenössisches Departement des Inneren 2017; Bundesstiftung Baukultur 2018).

The common reference in both cases is the idea of sustainability and its implementation in the context of projects of sustainable urban and landscape development. Monuments as well as cultural heritage in its entirety play an essential role as parts of the building culture, providing historical orientation.

For a development of metropolitan regions that bundles sustainable, economic, ecological, social and cultural aspects, the concept of 'change management' respectively the focus on process values offer important links, not least because of their integration into long-term repair strategies. This also applies to the definition and determination of concrete goals for action. What Wilfried Lipp called the exit from "modernity's compulsion to complete" (1994, 10; my translation) is understood as the priority of age and use values over novelty and aesthetic values, or as the acceptance of temporality and traces of age, or also: that old things really look old, or are allowed to look old. "Tolerance for change" is demanded of the institutions, while they should define the "limits of acceptable change" in a comprehensible manner and take into account the significance of the historic for the individual as well as for society as a whole (Pereira Roders/Veldpaus 2013, 17; see also Euler-Rolle 2019, 103).

As a proof of duration and longevity, cultural heritage guarantees diverse possibilities of orientation and identification, which are essential and rare especially for residents of rapidly transforming urban regions such as the Ruhr area. In this respect, the historic is to be regarded as similarly scarce and therefore worthy of protection in a similar sense as nature. "[I]f our conservation and management policies are to be sustainable", according to the English monuments administration English Heritage in the year 2004, "they must allow change to continue, rather than wipe the sheet clean every generation. Our decisions about what to lose, what to retain, and what to build anew, will be better, if they are informed by careful understanding" (Bradley et al. 2004, 1).

Particularly in view of climate change and sustainability thinking, it becomes relevant to link the practice of *change management* with an understanding of repair or reconstruction culture that focuses on avoidance (avoiding waste, saving resources) on the one hand and on social as well as individual responsibility (sustainable living, intergenerational justice, respect for what exists) on the other and promotes an "ethics of conservation, preservation and prevention" in the sense of philosopher Hans Jonas (2003, 249; my translation).

In the context of historic preservation, the topic of repair or repair society was focused for the first time in the context of the annual conference of the Bavarian State Office for the Preservation of Historical Monuments in 1993 and thereafter as the title of two symposia of the International Council on Monuments and Sites (ICOMOS) in 1995 and 1996. This involved the "search for a guiding principle" that considers all building development from the perspective of "conservation of energy, resources and buildings" (Petzet/Hassler 1996, foreword, my translation; see also: Lipp/Petzet 1994; H. Schmidt 2000; Will 2020, 487–504).

The direct reference for the Dortmund conference of 1995 was the ongoing transformation of the metropolitan region of the Ruhr area and questions of how to deal appropriately with the material relics of the coal and steel era (see figs. 3/4).

Fig. 3 and 4: Hansa coking plant, before and after shut-down[7]

In this respect, not only the sheer mass and landscape-shaping significance of the industrial architectures posed a challenge; given the growing awareness of the global scarcity of resources, the conference also addressed their material (utility) values, beyond any architectural-historical significance, and their significance as energetic resources within material and substance cycles.

In concrete terms, it was a question of strategies for preserving value, a "culture of repair", and this in a more comprehensive sense than that prescribed by the preservation of monuments (Petzet/Hassler 1996, 14; my translation). In a similar context, historic preservationist and building researcher Uta Hassler spoke of "adaptive change" as the necessity "of combining slow and fast processes, aligning short-term and long-term goals" in order to sustainably preserve the value of the building stock (2011, 5; my translation). She positions herself against the "compulsion of constant renewal" in building and the planning of buildings as "short-term products" (8; my translation). In contrast to new construction, historic preservation was "one of the few fields with an established culture of long-term orientation, resource conservation, and reuse" (Hassler 2011, 10; my translation).

If the idea of repair is nevertheless presented not as a description of the present, but as a vision of the future of the preservation profession, this reflects on a practice of restoration which, not least in form of noble restorations, often serves the expectations of the beautiful old and the shining of the historic in the much-cited new splendor. In contrast, the discussants of the 1990s advocated "delaying time" on a case-by-case basis, granting space to "letting be" and thus enabling new assignments of meaning. Under the primacy of repair – as "part of the spectrum of possibilities in monument preservation" – the focus should be on prevention and care instead of rehabilitation and restoration (Lipp 1994, 10; my translation; see also Petzet/Heilmeyer 2012).

5. Preservation of Monuments or Modification Culture?

In the context of the conference in Dortmund in 1995, the industrial analyst Walter R. Stahel summed up what since then has shaped the discourse on monuments as well as architecture in one way or another: "The most efficient protection is prevention" (1996, 52; my translation).

Care and repair strategies – such as the Dutch concept of *Monumentenwacht* or the Leipzig initiative *Haus-Halten* – have since then not only found their way into thinking about historic preservation; in connection with the growing awareness of the consequences of the climate crisis, the discourse on architecture and urban development has also opened up in this direction. Repair, building in the existing stock, avoiding new construction and life cycle analyses are the associated keywords; locality, reuse

7 Fig 3: *Das Denkmal als Altlast? Auf dem Weg in die Reparaturgesellschaft*. Munich: Lipp, 1996. 6 (Lehrstuhl für Denkmalpflege und Bauforschung, Universität Dortmund, Elmar Wiedenhöver). – Fig. 4: *Kokerei Hansa Dortmund-Huckarde*. Blick vom Deusenberg, 2018. Foto: Lucas Kaufmann, CC BY SA 4.0.

and durability of building materials are the concrete strategies, along with waste avoidance and resource conservation. In a policy paper, the Association of German Architects (BDA) took a stand on this in 2019 with *Positions for Climate-friendly Architecture in Cities and Rural Areas*. With its high consumption of energy and resources, construction – and this is now considered indisputable – is one of the main drivers of climate change. It is obvious that the "increasing heat load, extreme precipitation, flooding along coasts and rivers, landslides, air pollution, drought, and water scarcity" pose considerable dangers, especially for metropolises in poorer countries, and exacerbate existing social problems (*Klimawandel* 2017; my translation).

The short-term orientation toward depreciation cycles, materials that are difficult to dispose of, and generally toward expanding, land-sealing new construction is seen as partly responsible for this and calls for course corrections or a climate-friendly architecture and planning practice. Building must "increasingly do without new construction", according to the Association of German Architects in 2019, and "priority is given to the preservation and the material as well as constructive further building ["Weiterbauen"] of that which exists already, and not to its frivolous demolition" (Bund Deutscher Architektinnen und Architekten 2019, Prolog; Postulate III; my translation).

Thus, also in architecture the focus is more strongly than before shifting to the processes associated with building processes (life cycle analysis), including the materials and technologies employed. Here, too, *change management* becomes decisive, and it is precisely at this point that historic preservation becomes a method and knowledge potential for sustainable architecture and urban development. Overall, a change in values is emerging in the building sector that no longer and not *per se* dubs the existing as obsolete, outdated and thus dispensable, but rather appreciates it as a basis for creative ideas and as a material value. In this context, building in the existing stock or building further ["Weiterbauen"] can also adopt the idea of deferring time from the discourse on monuments and make unfinished buildings that are capable of further development available for a growing spectrum of do-it-yourself initiatives. Examples of this include the half-finished residential buildings of the Chilean architect Alejandro Aravena, which were erected in the 2000s as social housing according to the motto "[y]ou provide the frame, and from then on, families take over" (Aravena 2014). One can also refer to the Leipzig project of the 'Guardian Houses' ["Wächterhäuser"], which after the political turnaround of 1989/90 continued to use buildings whose ownership was still unclear, whose redevelopment was seemingly utopian, and whose use was uncertain. With the aim of "keeping the house", temporary craft, artistic or social uses or even stores were brought into the buildings, the substance was secured and successfully saved from demolition – this with the aim of viewing vacancy as a potential for innovation and at the same time securing the historic stock. The association offers further perspectives with so-called extension houses, which are extended by the tenants themselves at low rents and renovated in the long term (http://www.haushalten.org/de/waechterhaeuser_modell.asp).

These and comparable projects in other large cities do not only rely on the idea of repair, but also on active citizen participation and a growing sharing culture in dealing with the architectural heritage. In most cases, the interventions in the historic substance are considerably less extensive and thus more gentle on the substance than in renovation projects. In addition, they offer scope for multi-perspective assignments of meaning, diverse forms of cultural practice and preserve historic ensembles as attractive living and identification spaces.

6. Summary

As has been demonstrated, the thinking about *change management* in the debate about monuments and cultural heritage has several causes and historical roots. On the one hand, it is related to the erosion of the Western European concept of monuments in the course of the progressive internationalization of discourses. Not only did the global diversity of cultural heritage thus receive greater attention, but the diversity of authenticity concepts and preservation practices has also been changing professional discourses ever since. On the other hand, climate change has updated issues of preservation of what exists and brought monuments – like the old building stock as a whole – increasingly into focus as material and cultural resources, illuminating and enhancing the value of diversity from an ecological perspective. Particularly with respect to climate change and the sustainability paradigm, the boundaries between the building stock and historic testimonies singled out by law have tended to level out. From this perspective, aesthetic and historical testimonial values are losing significance. Currently, the discussion about building culture ["Baukultur"], which can be observed in several countries since the Davos Declaration of the European Ministers of Culture in 2018, testifies to this shift (Déclaration de Davos 2018).

Furthermore, thinking about transformation processes – as these tendencies also show – is changing the 'classic' relationship between experts and laypeople in favor of participatory and do-it-yourself strategies. In historic preservation, the processes have progressed to different degrees. The political appeal to citizens to take into account the scenarios of change through sustainable personal lifestyles and to develop an ethics of frugality is nevertheless leading to corresponding shifts and new values worldwide – also for cultural heritage. Within the urban and architectural discourse, similar changes can be observed, which, under the primacy of largely avoiding new construction, lead to a pioneering approach to heritage conservation practices and, from this broader perspective, prove the discourse participants of the 1990s right, who wanted to recognize areas of hope for heritage conservation in the view of large landscape and urban structures.

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Urban Art History: Cultural Heritage, Flâneurs, and Points of Presence

Barbara Welzel

1. Art History and Cultural Heritage

Separated only by a building joint, two materials and layers of time clash sharply: the sandstone from which the medieval church nave was built in the thirteenth century and the exposed concrete, complete with the surface structure of the wood planking mould, on the ground floor of the tower dating from the post-World-War-II reconstruction (fig. 1; von Möllendorff 2016; Ruppio 2021).

From the west, the view opens onto the church interior with its unadulterated medieval aura: an Early Gothic three-aisled nave and a choir elevated by a few steps, the latter dating from the first half of the fifteenth century. The space owes its impact in great part to the stained-glass windows and the light atmosphere they create. It was not until the 1960s that they replaced the provisional white emergency glazing installed after the destruction of the medieval stained-glass windows during World War II. On closer inspection, the windows of non-representational design prove to be works of the mid-twentieth century, inscribing themselves into their context with deliberate respect. At the west end of the nave, just a few steps from the abovementioned construction joint, usually in the shadows and thus inconspicuous in the overall context, the damages caused to the clustered pillars by the aerial attacks of the years 1943–1945 have been left unmended (fig. 2).

In the choir as well, the pieces that broke off the baldachins over the apostle figures during the bombing were in some cases never replaced, in others with a stone of a considerably lighter shade. A look back towards the nave from the choir reveals the building joint of the choir extension – the base of the original vault, which was bevelled in the fifteenth century to accommodate a higher structural element. This detail (to change the perspective) has likewise remained visible to this day as a visual exclamation mark calling attention to the building's enlargement and an important source for present-day research. Eye work and narrative could easily continue, but these few sentences on Dortmund's Main City Church of St Reinold (Sonne, Welzel 2016) shall be deemed to suffice as an overture to and signet of disciplinary and methodological localization.

Fig, 1: Church of St Reinold, Dortmund, reconstruction by Herwarth Schulte, view from west to east (2021 during organ reconstruction phase); photo: Detlef Podehl, TU Dortmund University

The aim of this contribution is to propose art history as an object-based discipline to metropolitan research. The reference here is to an art history that questions the historiographic paradigm reducing an object to its value as a witness only to the era of its origins and thus, in a sense, leaving it in the past. An art history that, on the contrary, takes the objects' present state as its point of departure and examines them from the perspective of *lieux de mémoires*, or places of remembrance, and cultural heritage, ultimately with the aim of reintroducing them to the debates of the present as places of the future. Seen from this perspective, a building such as the Church of St Reinold is more than merely a medieval work of architecture and an object of a concluded past, but rather a structure in the present that goes back to the Middles Ages and can serve as a reference in the discourse on cultural heritage (Welzel 2016). We can interrogate the building about the various medieval phases of its origins, but it also provides information about all other eras since, and, to this day, marks the centre of the city of Dortmund as well as the highest elevation in that centre.

More often than they like, practitioners of art history find themselves confronted with an image of their discipline as one frozen into information plaques on the walls of buildings and conventional guided tours of cities – and compelled to defend itself

Fig. 2: Church of St Reinold, Dortmund, clustered pillars in front of western nave wall; traces of wartime destruction left as a reminder; photo: Allegra Höltge, Department of Fine Arts, TU Dortmund University

against the accusation of elitism and out-of-touchness with reality, even in school textbooks and teaching materials. Again and again, historical-stylistic categorizations are still undertaken for the purpose of formally classifying the individual structural elements. And this exercise is accompanied, typically, by an evaluation of the objects' innovativeness in an imaginary evolution of architectural forms, as well as insights into how they derive from more famous examples. To this end, the building is conceptually disassembled, the construction phases broken down into their relative chronology and, where possible, reconstructed in terms of absolute dates (Horn 2015; 2017). In the process – taking the Church of St Reinold in Dortmund as a case in point – the nave is left in the thirteenth century, being considered a testimony solely to the time of its construction, while the choir, for its part, is conceived of as a document of the fifteenth century. In castles, tours by guides wearing historical garb round out this narrative, while evening guided tours of cities make use of night-watchman costumes. The buildings are thus degraded to time capsules of earlier epochs; they are pushed out of the present. "Why should I go inside the Church of St Reinold? That's the Middle Ages and I live in the present!" is how one student summed up the implications of this stylistic-historical, historiographic paradigm. Or, phrased more generally from the perspective of the sociology of science – and in a manner that has far-reaching historiographic and methodological implications for the Ruhr Metropolis in particular, as a place whose overwriting by industrialization borders on the falsification of history:

> The moderns have a peculiar propensity for understanding time that passes as if it were really abolishing the past behind it. […] They do not feel that they are removed from the Middle Ages by a certain number of centuries, but that they are separated by Copernican revolutions, epistemological breaks, epistemic ruptures so radical that nothing of that past survives in them – nothing of that past ought to survive in them. (Latour 1993, 68)

We could cite numerous publications that simply overlook or disregard the material testimonies of the Ruhr district which originated before the industrial age and have borne an impact on the region through the ages to this very day, again and again embodying a localization of the respective present. By way of example, let us merely cite two very different publications: the monumental compendium *Zeit-Räume Ruhr* of 2019 (Berger et al., 2019) and the essay *Das Ruhrgebiet: Versuch einer Liebeserklärung* (The Ruhr district: Attempt at a Declaration of Love) by Wolfram Eilenberger (2021). Works like these could almost be thought of as an epistemic sieve through which the region loses its history, its age, and its character as a European cultural landscape and premodern (pre-1800) economic region (keywords: Hansa, Silk Road).

The example given above by way of introduction responds with an art-historical approach that – hardened argumentatively through numerous discussions, in particular with students (see Franke/Welzel 2011) – does not cut time off but inquires after the objects' multifaceted biographies (Kopytoff 2011) over the course of time to the present. Rather than continuing a narrative progressing historically from past to future, it undertakes a fundamental reversal of perspectives. It is an approach in which the tradition of the place (Horn 2015; 2017) comes into its own. And it enables the inscription of the place in history in its historically substantiated meaning, the reading of its outward form within those coordinates, and the analysis of the process by which it endows meaning – even if the individual artistic solutions were and are not considered worthy of discussion or mention, and thus of admittance into the canon, by the autonomized history of art as developed in the nineteenth century (Niehr 1999; Locher 2001; Karge 2006). A leading paradigm is thus "cultural heritage": the transmission of cultural manifestations in the present, as well as their maintenance and preservation.

> Cultural heritage is a group of resources inherited from the past which people identify, independently of ownership, as a reflection and expression of their constantly evolving values, beliefs, knowledge and traditions. It includes all aspects of the environment resulting from the interaction between people and places through time. (Faro Convention 2005)

And the text continues: "A heritage community consists of people who value specific aspects of cultural heritage which they wish, within the framework of public action, to sustain and transmit to future generations."

This paradigm thus encompasses normative dimensions in addition to its discursive coordinates. And it by all means gives rise to the tensions of the "empirical-normative divide" characterizing political science and democratic theory. Nevertheless, documents like the European Council's 2005 Faro Convention, which sets forth the right to participation in cultural heritage enshrined in the Universal Declaration of Human Rights, should be part of the discursive framework (Dolff-Bonekämper 2009; 2020).

The scientific references accordingly also include the wide spectrum of research on "*lieux de mémoires*" (Nora 1984–1992; François, Schulze 2001; Oexle 2009, to name just a few examples) that inquires after the embedment of "places" – in the sense of topoi, commonplaces – in the cultural memory. For the Ruhr Metropolis, that paradigm was played out in the recent publication *Zeit-Räume Ruhr* (Berger et al. 2019). To an even greater degree than the compendium *Deutsche Erinnerungsorte* (François, Schulze 2001), this work relies on examining historical, social, and cultural phenomena under headings like "Landscape and City", "People and Types", "Industry and Work", and "Culture and Recreation" with entries on topics such as "steel", "miners", "football", and the *Steigerlied* (a German mining song). An art-historical perspective that could have introduced specific places and objects – now in the literal material sense – as characteristic of the region does not come to bear in this context. For example, the book contains an important (!) contribution on the Ruhr Diocese ("Ruhrbistum"; Gawlitta 2019), but nothing at all on Essen Cathedral and its treasure chamber (see "Essener Dom und Schatzkammer", Falk 2009) or the Parish Church of St Suitbertus with its sophisticated modern design (cornerstone ceremony 1964) as a programmatic example of a "Pantoffelkirche" ("slipper church") – that is, a church within easy reach of the miner families' residences (see "Kirche St. Suitbert in Essen", Kloke 2021). What is more, the main contribution, "Industriekultur" (Berger 2019), focusses more on "historical culture" than on presenting specific sites along the "Route Industriekultur" (or those ignored by that project; see, for example, Welzel 2009a; 2009b) as places of remembrance (*Route der Industriekultur*).

It is intrinsic to the conception of an object-based art history partaking of the discourse on cultural heritage that it has an eye on issues of monument preservation (for an overview of that discourse, see Scheurmann 2018 and her contribution to this volume) and hence on the very specific material preservation of its objects. Here as well, the discourses are reflected in international conventions such as the UN's *New Urban Agenda*, which states in Section 38:

> We commit ourselves to the sustainable leveraging of natural and cultural heritage, both tangible and intangible, in cities and human settlements, as appropriate, through integrated urban and territorial policies and adequate investments at the national, subnational and local levels, to safeguard and promote cultural infrastructures and sites, museums, indigenous cultures and languages, as well as traditional knowledge and the arts, highlighting the role that these play in rehabilitating and revitalizing urban areas and in strengthening social participation and the exercise of citizenship. (New Urban Agenda 2016)

In view of the necessity to clarify the scope of scientific discourses on the one hand and of political conventions on the other, we must therefore ask if there are epistemes that – if unconsciously for the most part – are in a sense a stab in the discipline's back.

One such episteme, for instance, is the tendency to cling to an art historiography that subscribes one-sidedly to a historical past-to-future perspective and the accompanying disregard for the material presence of cultural heritage in the present. The concept of cultural heritage as "points of presence" offers an alternative that is also justifiable by the standards of the ethics of the discipline.

2. Points of Presence and Flâneurs

Since the summer of 2015, the Dortmund art history team (TU Dortmund University) has been inviting school classes with refugee children to places of cultural remembrance in Dortmund, thus participating in the culture of welcoming refugees to their new homes. In the process, they have not only visited venues such as the "Dortmund U" and the Church of St Reinold, but have also taken joint excursions with university and school students to the Essen Cathedral and Cathedral Treasury (Schüppel 2016). To this day, the treasure chamber has in its holdings outstanding objects amassed by the prominent Essener Frauenstift (Essen Women's Collegiate Foundation; Falk 2009) and dating back as far as the Early Middle Ages. What we have in these objects, however, are not time capsules of a past age in which connections to the Ottonian imperial dynasty made this city a cultural centre. On the contrary, several of the items are still in liturgical use today. They are dual-coded: in the religious coordinates of God's history with humankind, and at the same time in the secular coordinates of (art-) scholarly research and cultural heritage with its obligation to make its objects generally accessible (Welzel 2017). What is more, while the treasure has suffered losses over the course of the centuries, it has also been expanded continually by the addition of new objects to the very present, especially in connection with the founding of the Ruhr Diocese in 1958 (Falk 2009).

An arm reliquary (fig. 3) considered art-historically unique in terms of both size (height: 72 cm) and design dates from around 1300 and, as verified by an inscription on the object itself, was commissioned by Abbess Beatrix von Holte (Prange 2009). In the eminently complex iconographic design of this partially gilded work of wrought silver, the abbess is rendered eternally present by way of an effigy and, in an interactive appeal, commended to the intercessory prayer of all who see this effigy, as well as to the angels believed present in the church interior. At the same time, in the tower, architectural forms of the period from which the reliquary dates (the tower itself is to be understood as a miniature of the Essen church building) make reference to the role of Beatrix von Holte as the driving force behind the reconstruction of the collegiate church (the present-day cathedral). The object holds the foundation's most precious relics: particles of the bones of Sts Cosmas and Damian. The two physicians of Late Antiquity are the patron saints of European cities, for example Florence and Essen, to this day. Their cult has its origins in their place of burial in or near the ancient city of Cyrrhus. Iconographic and historical reference works (Artelt 1974; Anonymous 2003) neglect to localize the narrative in the present-day topography. Whereas Gerhard Mercator (b. Rupelmonde, Flanders in 1512, d. Duisburg in 1594) still conceived of the topography of his own time as the stage of history and incorporated historical knowledge in his

Fig. 3: Arm reliquary of Beatrix von Holte, Essen Cathedral Treasury, © Essen Cathedral Treasury; photo: Christian Diehl, Dortmund

map of the world as a matter of course (Stercken 2015), the legends around Cosmas and Damian here remain buried in an antiquarian layer of time. During the excursion in the first half of 2016, however, that layer was unearthed, and the archaeological site – the present-day Nebi Huri – catapulted straight to the very Syria from which the refugees had only recently made their way to the Ruhr district via the Balkan route, which is in part identical to the route by which the Cosmas and Damian cult was spread.

This little empirical encounter corresponds to the normative wording in the Faro Convention when it states: "The Parties recognise that everyone, alone or collectively, has the right to benefit from the cultural heritage and to contribute towards its enrichment." (Faro Convention 2005)

"Point of presence" is a borrowed term with origins in computer science. Points of presence are nodal points at which at least two, but often more, communication networks connect. They also connect local points to the World Wide Web. Even more effectively than the related term "node", "point of presence", when applied to art history, allows us to focus the attention on the present as the point of departure for analysis. It also enables us to think of the multiplicity of the object's possible interconnections from a meta-perspective, and to valorize the object, in a sense, as the key orientation for the questions and discourses revolving around it (Welzel 2019). At the same time, this term insists on the complexity of the examined objects, with their various and multifaceted interconnections, and makes an uncircumventable demand on scientific analysis. This strong status is justified by the object's empirical weight, equipped, as it is, with the right of veto in the formation of hypotheses and the incorporation of various narratives and questions.

> If historiography is more than the subjective production of fabricated truths, then it is because of the control by the sources to which every history must subject itself. Every historical theory, every hypothesis or conjecture, must subject itself to scrutiny by what the source says about itself. Sources have the power of veto. The historian cannot claim whatever he wants to, because he bears the burden of proof. He can derive his proof only from the sources, without which he can say a lot, but against which he can say absolutely nothing. The condition of scientific objectivity lies in control by the sources. (Koselleck 2010, 78, trans. JR)

The term "sources' right of veto" was initially coined in the context of historical records in archives. For material culture, the same idea can come to bear as the "objects' right of veto" (König 2012; König 2022). An example: In the Essen Cathedral Treasury there is a processional cross (fig. 4) generally referred to as the *Otto-Mathilda Cross*, which was made in the same period as the *Golden Madonna*, the oldest extant sculpture of the Virgin Mary.

Adorned with precious stones and gems and furnished with a comprehensive iconographic programme, it owes its art-historical designation to an enamel plaque at the lower end of the upright beam (fig. 5; Beuckers 2009; Westermann 2011). An inscription identifies the two persons represented in the image there by name: "MAHTHILD ABB(ATISS)A", Abbess Mathilda (973–1011) and "OTTO DVX", her brother Otto, Duke of Swabia and close companion to Emperor Otto II. The siblings belonged to the Swabian line of the Ottonian imperial house. In the depiction, they hold a processional cross like the one the image decorates: it is a subtle and, in terms of pictorial rhetoric, sophisticated depiction that lodges an appeal against the cross's popular designation. That is because it is Mathilda who comes first in every respect. She is placed to the left of her brother and thus, in the direction of reading from the viewer's perspective, before him. Even more importantly, in the heraldic pictorial logic she stands both to the right of the cross in the enamel image and at the right of the sculptural figure of the Crucified Christ on the processional cross, and thus on the hierarchically higher side. Tested against these empirical findings, the object should by rights be called the *Mathilda-Otto*

Fig 4: Mathilda-Otto Cross, Essen Cathedral Treasury, © Essen Cathedral Treasury; photo: Christian Diehl, Dortmund

Cross (Welzel 2011). The established designation thus projects a male-dominated gender hierarchy onto the object. Nor is the cross, as is regularly implied, about the history of a ruling family and thus a means of integrating that history into the liturgy and representation of the Frauenstift. On the contrary, the *Mathilda-Otto Cross* is a testimony to the self-confident history of the women's collegiate foundation of Essen and its abbesses, who continued to leave their material marks for centuries until the dissolution of the Old Reich in 1802 – marks still visible in many places in the Ruhr Metropolis today (Schilp 2011). The *Mathilda-Otto Cross* ultimately calls attention to a stratum of the region that has largely been ignored. And to splice in another communication network, this circumstance is of interest because the historiography of the region has been reduced for the most part to its industrial production sites and male work environments, with the "Kumpel" (miner) as the central "lieu de mémoire" (Kift 2019; Berger et al. 2019). In the multiplicity of the discourses, the object's veto thus turns the *Mathilda-Otto Cross* into a strong point of presence.

As far as the history of the discipline is concerned, the examination of objects (for instance goldsmith's art from the Essen Cathedral Treasure or buildings such as the Church of St Reinold in Dortmund) with regard to their material constitution and the biographies inscribed in them – that is, two qualities distinguished by a right of veto over historical narratives – has one of its anchor points in a dispute over monument preservation around 1900. The controversy had ignited in connection with Heidelberg Castle and effectively drawn the attention of the public. Should the gaps in the ru-

Fig. 5: Mathilda-Otto Cross, enamel plaque at foot of upright beam, Essen Cathedral Treasury, © Essen Cathedral Treasury; photo: Christian Diehl, Dortmund

ins be filled in by a process inseparably interweaving reconstruction and imagination, or should the remains be stabilized and preserved to ensure the continued authentic transmission of history – that is, a transmission furnished with the power of veto? The "Heidelberg Monument Dispute" ended in favour of preservation, an approach that still shapes the self-conception of the discipline to this day (for example Scheurmann 2018, 147–153). The testability of hypotheses against the individual object which, for its part, must be capable of providing reliable information (hand in hand with reliable documentation of all measures carried out on the object itself, including and especially conservation measures) is considered an indispensable standard, at least ideally. At the same time, especially in popular and popularizing publications, grand narratives retrace more general lines of development, disregarding the specific objects except to cite them as examples of epochs, styles, or zeitgeists of one kind or another, thus assigning them no more than an illustrative function.

In 1970, the art historian Martin Warnke articulated a fundamental critique of this approach, describing it as a "consistent subjection of the individual to the whole, of the specific in favour of the unconditional dominion of the general" (Warnke 1970, 97, trans. JR). At least in retrospect, his analysis is seen to have liberated the discipline from epistemic distortions. “In the popular literature of art scholarship”, Warnke diagnosed an “imagery of power, violence, domination, subordination, coercion, and banishment that rigidifies the relations of the individual to the whole […]” (Warnke 1970, 97, trans. JR). Unsurprisingly, one of the authors whose works were read in the following years and who – at least in the German art history tradition – contributed decisively to bringing about a shift towards the close examination of individual objects was Walter Benjamin. Already in the first issues of the *Kritische Berichte* founded in 1973, a journal intended to serve as a platform for reformed, critical art history (and indeed serving as such), Wolfgang Kemp wrote about “Walter Benjamin und die Kunstwissenschaft” (Walter Benjamin and Art Scholarship, Kemp 1973). It would be another decade before the *Arcades Project*, the work left behind by Benjamin when he died in the attempt to escape the Nazis in 1940, was edited. Only then was it possible to pick up the thread of scientific discussions – with Walter Benjamin as well as with Norbert Elias and Aby Warburg (Franke/Welzel 2005, 59–70) – that, severed by National Socialism, had never taken place. It was the *Arcades Project*, however, that represented the key reference for an exploration of cities and places in the methodological habitus of the flâneur (Benjamin 1982b; Benjamin 1999; now, to a certain extent on a reversed reception under a textual paradigm, Gurr 2021).

> But the great reminiscences, the historical shudder – these are a trumpery which he (the flaneur) leaves to tourists, who think thereby to gain access to the genius loci with a military password. Our friend may well keep silent. At the approach of his footsteps, the place has roused; speechlessly, mindlessly, its mere intimate nearness gives him hints and instructions. He stands before Notre Dame de Lorette, and his soles remember: here is the spot where in former times the cheval de renfort – the spare horse – was harnessed to the omnibus that climbed the Rue des Martyrs toward Montmartre. (Benjamin 1982b, 525; Benjamin 1999, 416)

It is with these words that Benjamin’s text about the “flâneur” begins: with a rejection of the touristic aiming of the gaze to the genius loci and a renunciation of sensation mongering that is on the lookout for the sights to which it can gain access with stereotypical passwords. Instead, as the text goes on to develop, Benjamin proposes mindful rambling that allows itself to be lured by the impressions of the place, that listens and engages with the experiences “under the soles”. “The space winks at the flâneur: What do you think may have gone on here?” (Benjamin 1982b, 527; Benjamin 1999, 417–418; see Welzel 2021).

In the rereading of Walter Benjamin on which Karl Schlögel bases his magnum opus *In Space We Read Time* (Schlögel 2016, trans. JR), he elaborates on the extent to which “eye work” is not only a key method of this “spatial turn” in historical scholarship but also accompanied and driven by work in archives and libraries. The “spot where in former times the […] spare horse was harnessed to the omnibus” reveals itself only to the historically informed flâneur who has looked at historical images and texts about that particular street, the “the Rue des Martyrs toward Montmartre”, and is thus capable of reading it as the way to Montmartre in the “capital of the nineteenth century” (Benjamin 1982c; 1999), and who is moreover familiar with past forms of mobility. In this methodological habitus, Benjamin was able to give the small, individual site a voice as a point of presence.

3. *Flâneurs* in the Ruhr Metropolis

Everything is plural. Points of presence hold a multitude of interfaces at the ready. And therein lies one of the strengths of the concept that grants contemporary access to cultural heritage and participation in it. Objects and places can become an agora in which different discourses, different perspectives, different religions and worldviews, different origins, different experiences, and different bodies of knowledge come together and are negotiated (Bartz et al. 2018). The article of the Faro Convention headed "Cultural heritage and dialogue" formulates the obligation to:

> encourage reflection on the ethics and methods of presentation of the cultural heritage, as well as respect for diversity of interpretations […]; develop knowledge of cultural heritage as a resource to facilitate peaceful co-existence by promoting trust and mutual understanding with a view to resolution and prevention of conflicts. (Faro Convention 2005; for cultural heritage and historic preservation, cf. also Scheurmann in this volume)

In polyphonic and – literally and figuratively – multilingual encounters such as these, (art-)scholarly analysis is assigned at least a dual role. On the one hand, it is responsible for empirical-scientific stocktaking on which it can base the objects' veto where necessary. Yet the right to cultural participation as formulated in the Universal Declaration of Human Rights also encompasses the right to participation in scientific progress: "Everyone has the right freely to participate in the cultural life of the community, to enjoy the arts and to share in scientific advancement and its benefits." (Universal Declaration of Human Rights, Article 27.1) In addition to the abovementioned responsibility for the preservation and maintenance of the objects and places entrusted to its professional custody, a further ethical consequence for the discipline of art history is the obligation to communicate the results but also the methods of art-historical research, and to embed them in social negotiation processes. And this is where the second role of art history – but also, for example, field archaeology – comes into play: they are called upon to share their knowledge of places and objects as well as to call attention to places as points of presence, and to incorporate them in the communication networks of cultural heritage.

What is at issue in this paradigm is an art history on site (Welzel 2019b) that does not conceive of places only as places of origin but, with their cultural heritage, also as places of arrival (Welzel 2020). Texts by Czeslaw Miłosz can serve as an anchor point for these issues. Against the background of his experience of exile, and taking his native Wilna/Vilnius as an example, he writes: "How can one recognize this heritage as one's own, how does one take one's place in the generational chain of this city?" (Miłosz 2001, 53–55, translation JR; see also Miłosz 2005) Rather than falling back on "roots" and "identity" as key concepts, we might here – to activate a further discursive interface –

cite "belonging" as a notion from the field of social anthropology (Pfaff-Czarnecka 2011; 2012).

During a walk through the city with young school-age refugees (in early 2016, exclusively young men), they took selfies at the Church of St Reinold and sent them to the members of their families who had remained behind. They were no longer in a no-man's-land but had arrived in a place with history and culture. And there was a further ring of meaning attached to the point of presence: reports about the destruction of Dortmund during the war and the damages whose traces still characterize the city today – and to which the fire scars left visible in the western pillars of the Church of St Reinold pay sensitive tribute – here encountered persons who had just escaped from their destroyed native towns (Homs, Aleppo, et cetera). They had arrived in a city that, after a destructive war, can once again offer a home and a refuge. They mirrored this change of perspective back to those who were showing them around the city. The presence of the point had changed.

In front of the southern nave wall of the Church of St Urban in the Dortmund district of Huckarde is a small installation evidently only added to the church's furnishings relatively recently (fig. 6). It features a lump of hard coal from the Prosper Haniel mine, which was closed for good on 21 December 2018 in an act marking the end of hard coal mining in Germany (see Farrenkopf 2019; Przigoda 2019). A point of presence already complexly interconnected (Welzel 2009a; 2009b) is thus now linked to a further remembrance and communication network.

In around 870, about a century before the *Mathilda-Otto Cross* was made, King Louis the German donated the Huckarde estate to the Frauenstift Essen, to which the village would then belong until the dissolution of the Old Reich and with it the foundation in 1802 (Schilp 2009). Central monument protection authorities were founded in Prussia in the second half of the nineteenth century. One of their responsibilities was to draw up a basic inventory of all historic buildings and art monuments. For the Prussian province of Westphalia, Albert Ludorff embarked on the monumental publication series *Die Bau- und Kunstdenkmäler von Westfalen* (The Structural and Art Monuments of Westphalia), and in 1895 submitted volume 3: the compendium *Kreis Dortmund-Land* (District of Rural Dortmund). This work contains an entry on the Church of St Urban with its mid-thirteenth-century nave and an extended choir presumably built after the mid-fifteenth century to replace its predecessor, which had been demolished (Ludorff 1895, 43–45, pl. 14–18). Of the building documented here, all that remains today is the nave and its tower. In 1855, the Hansa Mine was established in Huckarde (Lauschke 2009) and was in need of manpower. Industrialization went hand in hand with the universally described rapid population growth, and the Catholic Church of St Urban was soon too small for its parish. To enlarge it, the Late Gothic choir was torn down and replaced by a large nave with a new choir as well as a second, significantly higher tower. The measures were the subject of extensive discussions with the monument preservation authorities and attracted notice even as far away as Berlin. There are few places – points of presence – in the Ruhr district that manifest the dynamics of the industrial age and the accompanying upheavals, for example reliance on tradition and shifts of proportion in the built environment, as directly and concretely as this one. It should be added here that the new building was expressly intended to retain "the style and character of the old Gothic

Fig. 6: Church of St Urban, Dortmund-Huckarde, installation with a lump of hard coal from the Prosper Haniel mine; photo: Allegra Höltge, Department of Fine Arts, TU Dortmund University

church" (in the words of the responsible master cathedral builder of Paderborn, Arnold Güldenpfennig; here quoted in Pieper 2009, 112, trans. JR). That amounts to more than just a decision to build a Neogothic structure. What happened here, rather – as indicated, for example, by the integration of inherited furnishings in the new building, among them the fourteenth-century sculpture of St Urban (Stiegemann 2009) – was an inscription in the tradition of the place.

The Hansa Mine, which was shut down for good in 1980, entered the possession of the Vereinigte Stahlwerke AG in 1926 and in the course of radical rationalization measures the nearby Hansa Grosskokerei (large cokery) gradually replaced its coking plant from 1928 onwards. The Kokerei Hansa has also meanwhile long been out of service, having closed once and for all in 1992. Today it is home to the Stiftung Industriedenkmalpflege und Geschichtskultur founded in 1995 (Industrial Monument Protection and Historical Culture; Pfeiffer, Strunk 2010). The windows of the coal bunker tower afford a view of Dortmund's city centre, but also of the village of Huckarde – a good observation point for flâneurs in the Ruhr Metropolis (fig. 7).

Walter Benjamin began his work on the *Arcades Project* in 1927, the same year the construction of the Hansa cokery, and with it the coal bunker, got underway. Two years

Fig. 7: Kokerei Hansa (coking plant), © Stiftung Industriedenkmalpflege und Geschichtskultur; photo: Klaus-Peter Schneider

later, in 1929, the "flâneurs' primer" came out: *Spazieren in Berlin: Ein Lehrbuch der Kunst in Berlin spazieren zu gehn ganz nah an dem Zauber der Stadt von dem sie selbst kaum weiß: Ein Bilderbuch in Worten* by Franz Hessel (Hessel 2012; 2017). Already back in 1922, Nikolai Antsiferov had published his work *Dusha Peterburga* (The Soul of St Petersburg) for another one of the early twentieth century's great European metropolises. It was not until 2003 that it was translated into German and, with an extensive foreword by Karl Schlögel, thus introduced to western discourse (Anziferow 2003; Schlögel 2003b; Oexle 2009). The three works tested, developed, and elaborated exploration methods for the growing metropolises Berlin, Paris, and St Petersburg, which were no longer describable within the parameters of premodern cities. That is a dilemma that also applies to the Ruhr Metropolis – for the years around 1927 as well as for the present-day reformation following the end of the industrial age. How does Huckarde belong to Dortmund? To this day, the village's inhabitants have a strong sense of its history as a place in its own right: when they go to Dortmund, they think of themselves as going not from a suburb to the city, but from Huckarde to Dortmund. When the premodern history of Dortmund is described, on the other hand, then it is usually not the polycentric history of the present-day town that is told, but the history of the free imperial and Hanseatic city (for example Ohm, Schilp, Welzel 2006). Measuring barely two square kilometres, it is the area within the four-lane ring road following the course of the demolished town wall that must bear the full weight of the city's premodern history. The remaining districts, of which many – like Huckarde – go back centuries, only entered the light of Dortmund town history when they were incorporated. The same applies to other cities of the Ruhr Metropolis. The remembrance sites of the industrial age, on the other hand, as recently surveyed by *Zeit-Räume Ruhr*, remain entirely on the city peripheries, topographically speaking (see Sonne 2020). Flâneurs are capable of breaking through this virtually schizophrenic perception of the region when they drift attentively through the present-day cities, listening, looking, and drawing on knowledge from the archives and libraries (Mühlhofer, Sonne, Welzel 2019). Walter Benjamin, however, leaves no doubt about the effort involved in escaping frameworks and paradigms so firmly fixed as to feel like a prison. He even resorts to drugs to overcome the gridded gaze (Benjamin 2006; see Welzel 2021). Franz Hessel puts it in more inviting terms in his "Afterword": "You can still sense that many parts of Berlin haven't been viewed enough to truly be visible. We Berliners must dwell in our city to a much greater degree." (Hessel 2017, 269–270)

It was also in 1927 that Walter Ruttmann's *Berlin: Symphony of a Metropolis* was released, a look at the industrialization of the city-turned-metropolis in the film medium. The striking images begin with a trip by train from the surrounding countryside into town and the Anhalter railway station. To this day, the train – for example the U42 in Dortmund, which travels partially above and partially below ground – can be a method of exploring a city that activates the stops as points of presence (Zeising 2022). The line passing through Huckarde is the U47 from Aplerbeck in the east via the main station, the port authority, and Huckarde to Westerfilde in the west. And in fact one can avail oneself of the entire network of connecting routes – railways, roads, and waterways – through the Ruhr Metropolis to activate the numerous points of presence. Such is one proposal for a method, means of access, and for initial building blocks for a working programme.

Translation: Judith Rosenthal

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II Metropolitan Functions and Infrastructures

Methods of Central Place Research

Thomas Terfrüchte

1. Positioning of the Research Field

Cities and urban systems are classic fields of research in spatial sciences. There is a vast international discourse on megacities, global cities and metropolises or rather metropolitan regions (Münter/Volgmann 2014). In Germany, urban systems research is also concerned with medium-sized cities, especially with a view to securing or restoring the equivalence of living conditions. The discourse is mainly based on the central place theory, founded by Christaller in 1933 (Christaller 1968) and was adapted by the German "Raumordnung" (spatial planning) in the 1960s. A recent discourse links aspects from metropolitan research and policy with central place policies: regiopolises are described as little sisters of metropolises and as 'deluxe' versions of higher-order central places ("Oberzentren") (Terfrüchte at al. 2021).

Based on these theoretical and political-normative considerations, modern central place research has been established as part of urban system research since the 1960s. Sometimes there are parallels to metropolitan research in terms of content and methodology (cf. Volgmann 2013). The descriptive-analytical approaches can be roughly divided into three research areas:

- *Benchmarking the performance of central places*, i.e. a hierarchical classification of cities;
- The *analysis of spatial-functional linkages* between cities;
- The *description of the urban system as a network* with central places as nodes and spatial-functional linkages as edges for a spatial-functional division (the so-called *central place system*) – as distinct from the political-administrative division (Terfrüchte/Flex 2018; Terfrüchte et al. 2017).

Depending on the research question, different research methods are suitable, ranging from procedures for determining centrality without reference to the surrounding area, to interdependence analyses with or without a priori defined centres, to integrated procedures and finally also heuristic approaches (Terfrüchte 2015, 126).

Preliminary Methodological Remarks

In the context of this paper, methodological approaches are presented and discussed that are applicable for addressing the three aforementioned areas of research, i.e. that are suitable for empirically mapping central place systems. Therefore, I suggest a few preliminary remarks (cf. Terfrüchte et al. 2017):

1. Central place systems basically comprise central places and their interactional areas. In order to describe the central place system, it is therefore necessary to determine the centrality (hierarchical level and gravity) of cities on the one hand and their interactional areas on the other.
2. Centrality is multidimensional. The hierarchy levels in the central place system are therefore not class divisions of the same dimension. In German spatial planning, a distinction is usually made between lower-, middle- and high-order centrality.
3. Depending on the epistemological interest, political-normative considerations can also justify or limit the suitability of the methodology.
4. There can thus be no single and correct research methodology. Each methodology, whether for centrality measurement or for area delineation, has its specific strengths and weaknesses.
5. However, none of the methods for the description of central place systems that are designed either solely for the benchmarking (assessment) of central places or for the delimitation of interlinked areas are applicable. Only those methods are appropriate that consider both elements of the central place system in an integrated way.

In consequence, the catalogue method frequently used in the past (i.e. the classification of cities into the central place hierarchy levels based on the presence of certain facilities, cf. Terfrüchte 2015) is not suitable on its own for measuring centrality in the sense of a classification into the hierarchical central place system. In the determination of the interactional areas, the so-called *Huff model* (gravity model by Huff 1964) is used in connection with assessment of the permissibility of large-scale retail trade centres (German "Kongruenzgebot"). However, the model is unsuitable for the delimitation of interactional areas of central places, as it infers actual interactions from potential interactions (based on accessibility). In this respect, only those delineation methods can be used that work with actual interactions (e.g. commuter linkages).

Against this background, the following procedural steps are appropriate for describing central places and their interactional areas (= central place system):

- Hierarchisation of central place supply goods and needs (Section 0),
- Determination of the gravity of all potential central places (generally all cities in the study area) – separated according to hierarchical levels – on the basis of the supply function (Section 0),
- Determination of the central place development function (Section 2),
- Determination of the supply linkages between all potential central places among each other and their respective surrounding area (Section 0),

- Area delimitation: Allocation of “co-supplied” cities to “co-supplying” cities separately according to hierarchy levels (Section 0).

1. Supply Function

The supply function of central places is the classic function in the sense that they supply their own population and the surrounding population with goods and services (cf. Terfrüchte & Flex 2018, 2972). Moreover, the supply function of central places is consistently addressed in all spatial development plans in Germany (Greiving et al. 2014). Central place supply facilities are thus geared to the end consumer; they are not ubiquitously available and clustered at central places (co-localisation). In this respect, neither technical infrastructures, such as power supply or waste disposal, nor services that are not oriented towards the end consumer, such as business consultants, belong to the central supply facilities. The supply function is equally well researched and discussed in spatial planning practice and science (Terfrüchte 2015, 98–105). Thus, while the supply function in general and also the facilities (in methodological terms, the manifest characteristics of central places) in particular can be considered indisputable (tab. 1), there are various methodological approaches to inferring the centrality of a place (in methodological terms, the latent characteristic of central places) from the facilities (Niedzwetzki 1977; Deiters 1978; Flex 2015, 235–271.; Terfrüchte 2015, 138–159).

The path presented here takes up the premises listed in Section 1 and suggests *one* possible path. Terfrüchte 2015 and Flex 2015 also show a variety of other paths, depending on the underlying premises.

The first methodological step in determining the supply function is the hierarchisation of the facilities (goods and needs) relevant to the central place (Section 0). The question is whether a hierarchy can be identified in the urban system with regard to the distribution of supply, and which facilities can then be assigned to these hierarchy levels. The dichotomously scaled data set is therefore included in the analysis, i.e. it is only asked whether at least one corresponding facility is located in the city or not. The supply strength is later constructed as a central-local gravity (Section 0).

2.1 Hierarchisation

The hierarchisation of the central facilities is carried out in two steps by the scalogram analysis (or guttman scaling, see below) and the principal component analysis. The combination seems appropriate for the following reasons: Using the scalogram analysis, hierarchy levels can be derived empirically on the basis of the dichotomously scaled frequencies of supply of central facilities; recourse to statistical class divisions (percentile values) or arbitrary threshold setting is no longer necessary. As soon as the individual facilities are divided into hierarchy levels – any number of levels can be determined – the co-localisation (covariance) is checked using principal component analysis. For this purpose, the dichotomously scaled supply frequencies of each hierarchy level are used. Facilities (variables) that have no or only a low common variance with the other facilities of a hierarchy level can thus be identified and eliminated. They are not relevant to

Tab. 1: Central facilities (supply function). Source: based on Terfrüchte 2015, 98–105

Functional sector	Central facility (examples)
Education	Primary school, Highschool
Retail	Shopping Centre, Discounter
Culture	Museum, Theatre
Healthcare	Hospital, General practitioner
Sports	Sports hall, Indoor swimming pool
Transportation	Train station, Motorway connection
Public Administration	Municipality, Employment agency
Finance and Insurance	Bank, Insurance office
Social Services	Nursing service, Counselling Centre
Other Services	Post office
Judicature	Local court, Administrative court
Science and Research	University, Research institute
Hazard Prevention	Police, fire brigade
Organisations/Associations	Chamber of Commerce and Industry
Tourism	Hotel

central places, as they do not fulfil the co-location requirement. Usually, the scalogram analysis already shows which facilities have a low common variance. The data set adjusted for the non-centrally relevant facilities defines the basis for the construction of the supply indices in Section 0.

Scalogram Analysis

Figure 1 illustrates for each facility whether it is located in a city/community at least once (1=present, 0=not present); for simplified orientation, the cells with the value 1 are coloured grey. The row sum now indicates the number of different facilities per city and the column sum the number of cities in which the respective facility is present at least once. If rows and columns are sorted in descending order, a saturation curve appears at the transition from grey cells (facility is present) and white cells (facility is not present). Wherever white cells lie in the predominantly grey area, the respective cities lack a facility that is usual for the hierarchical level. Conversely, grey cells in the predominantly white area indicate that a city has a facility that is not customary for the hierarchical level (this is often the case with airports, for example, as they are not infrequently located outside the municipal territory of the central places).

The actual classification is now done by counting the errors (grey fields in the white area and white fields in the grey area). Starting from the left, it is determined for each facility in how many cities they are not located, and starting from the right, it is determined for each facility in how many cities the facilities are located. Then the errors per facility are added up (cumulative errors). The cumulative errors are determined in the same way, starting with the rarest facility.

The principal aim now is to identify those two facilities between which the optimal class boundary lies. It is optimal when the sum of the errors on the left and right of the "dividing line" is the smallest. On the left side of the line, all white cells are counted, on the right side all grey cells. As soon as the first dividing line (class division) is found, further class divisions can be made according to the same principle; the error sums are then re-determined within one of the previously formed classes. Depending on the goal of the analysis and on the (interim) findings, individual classes can also be reassembled at the end. Such a step, however, already follows normative considerations.

Fig. 1: Scalogram analysis for hierarchisation of central facilities – Source: based on Terfrüchte 2015, 183

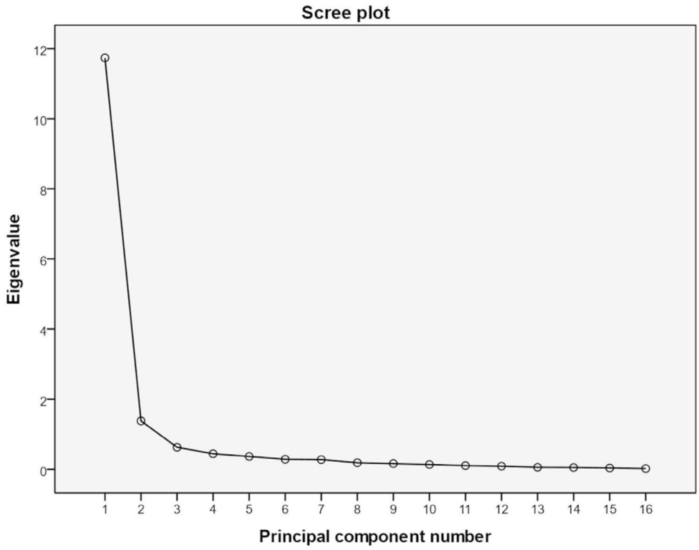
	a	b	c	d	e	f	g	...	x	y	z	∑
A	1	1	1	1	1	1	1		1	1	1	25
B	1	1	1	1	1	1	1		1	0	1	23
...												
X	1	1	0	0	0	0	0		1	0	0	3
Y	1	0	0	0	0	0	0		0	0	0	1
Z	1	0	0	0	0	0	0		0	0	0	1
∑ 1	26	24	17	16	15	11	11		5	3	2	
∑ 0	0	2	9	10	11	15	15		21	23	24	
∑ Error(left)	0	2	11	21	32	47	62		372	395	419	
∑ Error(right)	257	231	207	190	174	159	148		10	5	2	
∑ Errors	**257**	**233**	**218**	**211**	**206**	**206**	**210**		**382**	**400**	**421**	

Principal Component Analysis

With the result of the scalogram analysis, we identify those facilities that belong to a hierarchy level, at least due to the frequency of their services. The next step is to check whether the facilities fulfil the requirement of co-location. For this purpose, the spatial intercorrelation of all variables (facilities) is determined. This is done by principal component analysis.

The scree plot (fig. 2) shows whether a predominant principal component emerges. This is to be expected only for facilities whose high covariance is already apparent from the scalogram analysis. If the initial correlation of one or more variables (component/factor loading) has a value of less than 0.4, a low common variance is to be assumed and the respective facility is eliminated as not relevant to central places. This

Fig.2: Scree plot of higher-level needs. Source: based on Terfrüchte 2015, 224



procedure is repeated iteratively until the remaining facilities have a sufficient common variance with regard to spatial localisation; following the literature, this is initially assumed to be sufficient with a component/factor loading – i.e. a correlation coefficient of the original characteristic with the principal component – of at least 0.4 (Bühl 2012, 610). This threshold can also be justifiably defined differently. The remaining facilities of a hierarchy level are then used to determine the sub-indices for the supply function; one index for each level.

2.2 Gravity of Central Places

Centrality is multidimensional. The first step in dimensioning (or operationalising) centrality has already been taken with the selection of the central facilities for the scalogram analysis. The second step was the allocation of the facilities to the hierarchy levels. The next step is a dimensional reduction, i.e. the facilities of a hierarchy level are linked as manifest characteristics to a hierarchy level-specific index (interpreted as gravity of central places) as a latent characteristic. What is methodologically obvious has also become established in German-language central place and metropolitan research: the construction of centrality indices using multivariate statistics (here: principal component analysis) (Schmidt 1995, Volgmann 2013, Terfrüchte 2015, Flex 2015). This also offers the advantage that the statistical procedure already used to falsify the co-localisation hypothesis is used again, depending on the research objective with the dichotomously scaled variables (modelling the functional diversity) or the metric-scaled variables (modelling the co-supply potential).

Functional Diversity Indices

When it comes to describing the functional profile of cities, the only question is what different facilities are located in a city. In the example of universities, it is not a question of how many universities there are in a city, how many courses of study are offered there or how many students are enrolled there. It is only about the fact that the city is a higher education location.

Methodically, exactly one principal component per hierarchy level is extracted as an index. In practice, an additive weighted linkage takes place here, whereby the component/factor loadings (tab. 2) are interpreted as weights and the so-called factor values (as a result of the principal component analysis) are assigned to the cities as characteristic values. The idea behind this is that the more typical a central facility is for the respective hierarchy level, the higher its weighting.

(Co-)Supply Potential Indices – Gravity of Central Places

In contrast to the variety of facilities, the (co-)supply potential is about *how many* facilities of one type are located in a city or *how many* hospital beds are available (usage of metric-scaled variables instead of dichotomously scaled variables). One example is general education schools. Here, the number of school classes may be more relevant than the number of school locations. Sometimes no complete (service) offer is provided at certain locations (e.g. branch offices). In this case, (normative) weighting can also be applied. Ultimately, the aim is to generate a metric-scaled data set as the basis for the principal component analysis.

Based on a study of the *Mittelrhein-Westerwald* region, table 2 shows the difference between two index-varieties: functional diversity and supply frequency/potential based on the specific indicator-weights. In terms of supply frequency, facilities that have only one location in the city of Koblenz (orchestra and district court) correlate highly with other facilities that have several locations (e.g. doctors, schools, etc.). While orchestras and regional courts are rather atypical in terms of the variety of services (with a factor loading of 0.37 even just below the threshold value of 0.40), they are far more typical in terms of the frequency of services (0.73). Such differences are essential to consider for the subsequent demarcation of central places' interactional areas, as the index value (i.e. the central-location gravity) decides whether and to what extent cities can be area-forming in terms of the importance of the surrounding area (cf. Section 0).

2. Development Function

In addition to the supply function, the development function is a second essential characteristic of central places (cf. e.g. Ganser 1977). As Blotevogel (2005, 1314) puts it, the development function should be "emphasised more strongly", especially for the higher-order hierarchical levels. This is logical insofar as central places are also understood as development centres for the middle- and higher-order interactional areas (Terfrüchte 2015, 91). The more development-promoting and the fewer development-inhibiting features a city has, the more likely it is – according to the underlying thought process – to be able to set corresponding development or stabilisation stimuli for the interac-

Tab. 2: Weighting of central functions by index type. Source: based on Greiving et al. 2020, 34

Central function/facility	Diversity Index	Supply Potential Index
Job centre	0,82	0,66
Adult education centres	0,81	0,63
Primary care hospitals	0,79	0,79
Employment agency	0,79	0,72
Vocational schools	0,78	0,94
High Schools	0,77	0,94
Specialised doctors	0,76	0,94
Municipality	0,75	0,52
Local court	0,74	0,64
Orthodontists	0,67	0,92
Tax office	0,65	0,64
Theatres	0,58	0,84
Dentists	0,57	0,96
General practitioners	0,53	0,96
Specialised hospitals	0,53	0,46
Public libraries	0,46	0,60
County court	0,37	0,73
Orchestra	0,37	0,73

tional area. However, which characteristics can be regarded as conducive and which as inhibiting for (regional) development has not been sufficiently researched – in contrast to the supply function. While demographic, economic or fiscal characteristics are unanimously considered relevant, there is no agreement on the desired characteristics. The example of municipal debt, which is commonly classified as an obstacle to development, impressively shows this. Boettcher and Junkernheinrich (2010, 112) point out that "extensive investment credits tend to signal a high financial capacity", which is why primarily cash credits are "the signal of a particularly precarious financial situation" (Boettcher/Junkernheinrich 2010, 19). A differentiation of the type of credit is therefore necessary.

The same applies to demographic development: Terfrüchte (2015, 225) has found, using North Rhine-Westphalia as an example, that a low youth dependency ratio can be considered an inhibiting characteristic, but vice versa, neither a high youth dependency ratio nor a low old-age dependency ratio can be classified as development-promoting. Since the development function – in contrast to the supply function – can be said to have a considerable overall theoretical deficit (Terfrüchte 2015: 248f.), it is not surprising that there are also various methodological approaches in this area to infer the latent development capacity of cities. However, the development function is usually researched beyond the 'classical' central place research (cf. Wiechmann/Terfrüchte 2017), which can be problematic for political planning statements: when cities, on an empirical basis, are defined as central places, they should be able to remain like that in the future, and those that are not sufficiently equipped so far, should be able to 'make it' in the planning period. For this reason, a linkage of the central place concept with regional structural policy and/or municipal fiscal equalisation is sometimes made – although it is rather modest – in some German States (Greiving et al. 2014, 70–73).

Regional Development Indices

The determination of the development capacity of each city is also carried out by principal component analysis. For the development function, a preliminary hierarchisation is neither possible nor necessary. One problem with modelling the development function is the lack of information on the desired values of variables ("the more the better or the less the better?"). For individual indicators such as job density or tax revenue power, it can be assumed that particularly high values favour the ability to set development stimuli, whereas cash credits or a high unemployment rate are more likely to inhibit the development. Since, in contrast to the supply function, there are no theory-immanent prior assumptions, the index is formed in two steps:

1. First, all indicators considered to be relevant are examined in an exploratory principal component analysis (initially without rotation, see below). The component matrix (tab. 3) shows which indicators correlate with which extracted components, and how strongly. Ideally, components that can be described in terms of content as dimensions of the development function emerge at the outset. If this is not the case, the principal component analysis does not need to be considered a failure. Rather, such a finding indicates that relevant individual characteristics can be considered neither development-inhibiting nor development-promoting, at least not for the specific study area. The aim is to exclude all these indicators from the index construction (tab. 4).
2. The index construction itself is analogous to the indices of the supply function, with one difference: since two or more extracted principal components are assumed, either a so-called rotation (Bühl 2012, 589) is carried out in order to minimise the correlation between the principal components and to increase the characteristics of a principal component, or separate analyses are carried out per dimension.

Fig. 3: Scree plot for development indicators. Source: based on Terfrüchte 2015, 225

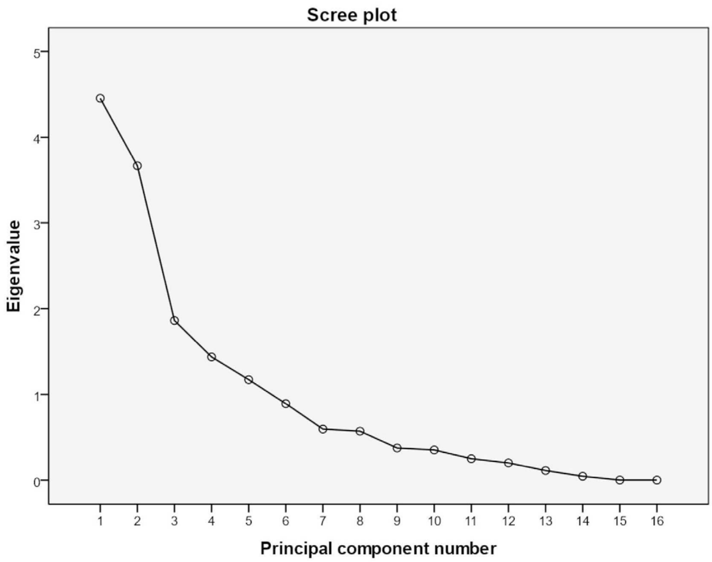


Fig. 4 summarises the functional profiles (supply function, development function and supplementary metropolitan function) for the *Mittelrhein-Westerwald* region.

4. Area-forming Function

According to the central place theory, the area-forming function serves to supply other surrounding towns (supply area) through the central places. In conjunction with the development function, the supply area can also be seen as the spatially-functional interactional area for which the central place can provide development or stabilisation stimuli. What is thus theoretically required is also regularly demanded by German jurisdiction, especially with regard to the congruence requirement ("Kongruenzgebot") and the impairment prohibition ("Beeinträchtigungsverbot") in connection with the approval of large-scale retail trade centres: central places are defined by their supra-local significance, which can only be attested if it is clearly stated how and where the supra-locality is spatially represented. Every central place therefore also needs a specific – or at least definable – supply area. Otherwise, the steering effect of the central place concepts come to nothing, because carrying capacity or accessibility criteria remain functionless as long as no "area setting is defined within which accessibility and carrying capacity are to be guaranteed" (Terfrüchte 2015, 245). The equation of central places with political municipalities, which is practised in many federal states, can nevertheless also enable so-called "self-supply areas", provided that a functional cluster also supplies

Tab. 3: Component matrix for development indicators (initially). Source: based on Terfrüchte 2015, 226

Development indicators	1	2	3	4	5
Commuter-adjusted population	0,85				
Labour market centrality	0,84				
Population density	0,69				
Employment Self-sufficiency	0,69		-0,50		
Employees in the service sector	0,57				
"Schlüsselzuweisungen"/inhabitant		-0,85			
Tax revenue/inhabitant	0,58	0,74			
Tax force/inhabitant	0,54	0,73			
Trade tax revenue/inhabitant	0,56	0,72			
Unemployment rate	0,63	-0,63			
"Kassenkredite"/inhabitant		-0,59			
Purchasing power/inhabitant			0,69		-0,44
Old-age-dependency ratio			0,65		
Youth-dependency ratio			-0,51		
Population growth				0,85	
Employees in the retail sector				0,57	

the other districts on the municipal territory. In this respect, supra-locality and supra-municipality should be separated from each other in terms of content.

As in the case of the supply function, there is widespread agreement in the literature on what needs to be researched in the delineation of linkage areas: the spatial-functional linkages between central places and non-central places, or between central places of higher hierarchical levels and central places of lower hierarchical levels (cf. e.g. Klöpper 1970; Heinritz 1977). From a methodological point of view, all interactions relating to the supply function of the central places must therefore be considered. These include, for example, visits to retail establishments, cultural facilities and events or the use of supply services. However, due to the considerable effort required for data collection, proxy indicators are usually used. In the area of medical care, for example, it was found that co-supply relationships correlate significantly with commuting relationships (Czihal et al. 2012, 9–10). In addition to commuter linkages, municipal statistics generally also show linkages in school transport, which, firstly, are directly related to the supply function (in the education sector) and secondly can also be regarded as a proxy

Tab. 4: Component matrix for development indicators (after excluding). Source: based on Terfrüchte 2015, 227.

Development indicators	Component 1 (development-promoting)	Component 2 (development-inhibiting)
Labour market centrality	0,96	
Commuter-adjusted population	0,96	
Employment Self-sufficiency	0,81	
Tax force/inhabitant	0,55	
"Schlüsselzuweisungen"/inhabitant		0,89
Unemployment rate		0,85
"Kassenkredite"/inhabitant		0,77
Youth-dependency ratio		-0,49

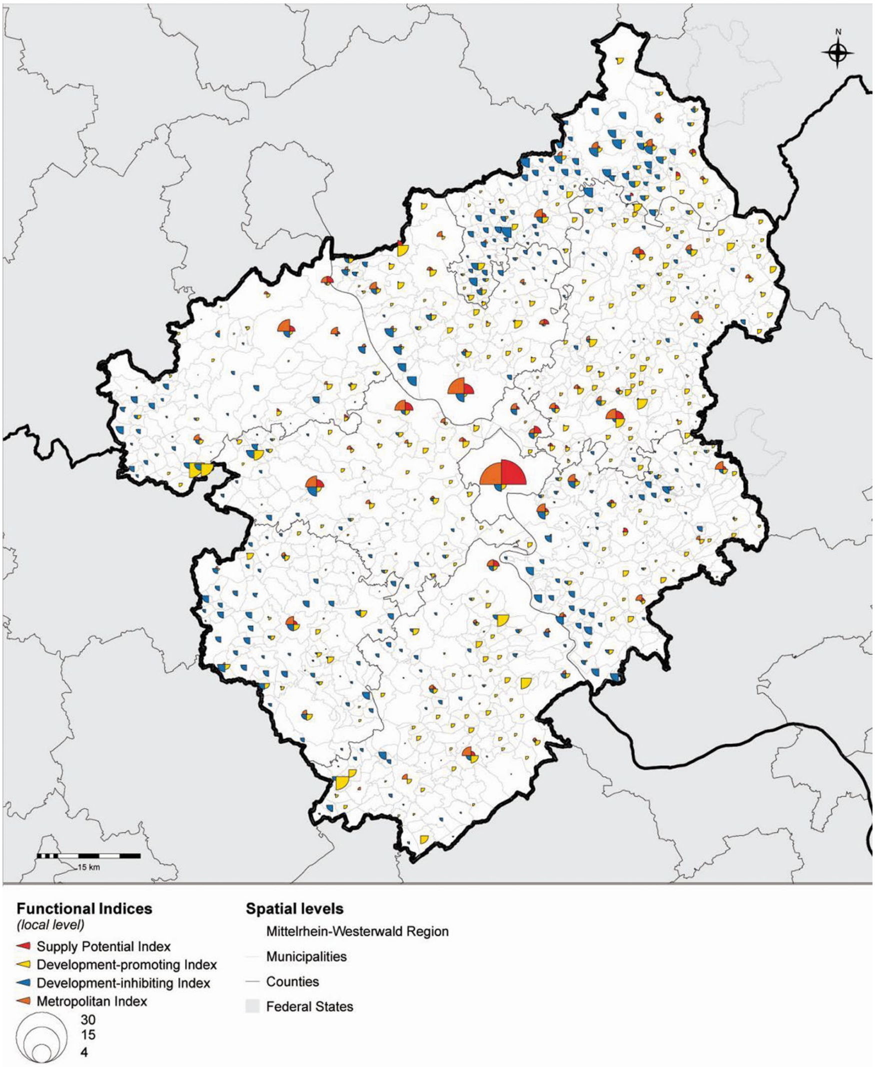
indicator for other linkages. Terfrüchte et al. 2021 were also able to show that source-destination linkages of patients to doctors can be modelled (cf. also Terfrüchte/Frank in this volume).

In contrast to the 'what?' of research, there is fundamental disagreement about the 'how'? There is no doubt about the object of research, but there *is* doubt about the way to achieve that objective. This already starts with the idea that central places can be empirically determined a priori on the basis of their supply function, without methodically considering the respective 'surrounding significance'. In terms of theory and jurisprudence, the formation of interactional areas cannot be based on threshold values (e.g., population or jobs), however normatively or empirically defined. Rather, 'area-forming' means two things: the ability to serve the population of other cities (gravity effect of central places, measured by the supply potential indices) and to actually 'unite' them on itself (measured by substantial linkages between the surrounding area and the central place).

4.1 Interconnectedness Modelling

The demarcation of the interactional areas is based on a graph-theoretical approach, whereby the gravity of each city corresponds to the supply potential index. In principle, the gravity in this model can also be determined using other methods, as Nystuen and Dacey (1961) did in their basic approach using incoming telephone calls or as is done in the labour market delineation using incoming commuter flows (Kropp/Schwengler 2011, 49). Through the underlying topological understanding of centrality, the areas/regions – understood as networks – are practically delimited on the way to identifying a network node. The assessment sounds plausible; after all, labour markets are not char-

Fig.4: Functional profiles in the Mittelrhein-Westerwald-Region. Source: based on Greiving et al. 2020, 40



acterised by one-sided and unambiguous commuter linkages from the surrounding areas to the centre, but by sub-labour markets (networks), which in turn are both embedded in a larger labour market and form sub-labour markets themselves. This indirect mapping is also referred to as the transitivity requirement. "The concept of dominant flows" (Kropp/Schwengler 2011, 49) or "strongest association" (Nystuen/Dacey 1961, 29) as a "subset of topology" (Güßefeldt 1978, 84) essentially aims at exploring redundancy within a city network, to which both direct and indirect connections contribute. It is now important that the weighting is directional: Edge AB has a value of one, whereas

Edge BA has a value of five (tab. 5). Intra-municipal linkages are indicated here with a value of zero, but they could also be quantified.

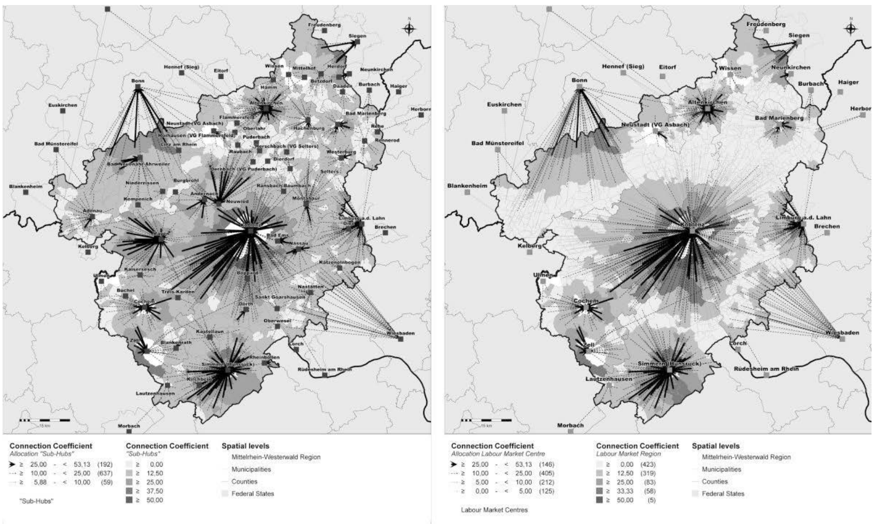
Tab. 5: Intertwining matrix for the graph theoretical approach. Source: based on Nystuen/Dacey 1961, 33

Source/ Target	A	B	C	D	Total (source)
A	0	1	2	0	**3**
B	5	0	9	2	**16**
C	7	6	0	1	**14**
D	9	1	8	0	**18**
Total (target)	**21**	**8**	**19**	**3**	**51**

For the delimitation of the interactional areas, the linkages between each city pair are modelled as a connection coefficient, i.e. it is determined how significant a certain source-target linkage is for the respective source (city). For each city, an n:n linkage matrix of all cities is then used to check where the strongest linkage exists. Nonetheless, an assignment is only made if the gravity of the target is greater than the gravity of the source. If a clear allocation is not possible because the connection coefficient to several targets (here: potential central places) is the same and the gravity of both destinations exceeds that of the source, the allocation is made to the destination that has the greater gravity. If the gravity is also identical, a normative allocation decision is necessary, possibly also as a multiple allocation. However, the latter will only rarely occur in practice, since due to the metric-scaled gravity, at least small differences in the characteristic values (i.e. the hierarchy-level-specific gravity) are usually to be expected. If the gravity were scaled ordinally (e.g. as a result of the above-mentioned catalogue method, which provides for classification into the hierarchy levels on the basis of the localised facilities), such provisional multiple assignments or normative assignment decisions would be necessary more frequently.

The assignment algorithm can be implemented as long as all cities are directly or indirectly assigned to the 'most central' place ('terminal point'). If the entire system (all cities in the study area) is considered, each city is part of exactly one interactional area. At the same time, (existing) linkages to cities outside the study area are ignored for the delineation, which can sometimes be problematic in the case of cross-border linkages (compare Osnabrück in Lower Saxony for parts of North Rhine-Westphalia in Blotevogel et al. (2009) or Bonn in North Rhine-Westphalia for the district of Ahrweiler in Rhineland-Palatinate [fig. 5]).

Fig. 5: Direct and indirect connections in the Mittelrhein-Westerwald-Region. Source: Greiving et al. 2020, 22–23



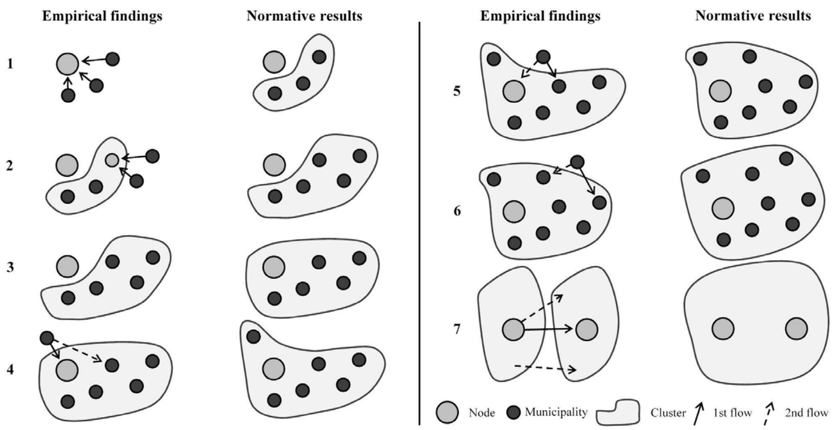
4.2 Area Delineation

Laan and Schalke (2001, 207) have modelled different topological constellations for the delineation of labour market regions in the allocation of cities to centres on the basis of interaction flows (fig. 6). This illustrates firstly the diversity of possible allocation rules and secondly the need to justify such rules against the background of the research objective and/or the use in spatial planning practice, starting with the renunciation of enclaves and exclaves up to the possibility of centre alliances with a common interlinking area.

As a result, area-forming cities are identified which are characterised by the fact that, firstly, they have a co-supply potential in the sense of a stronger supply index and, secondly, they actually realise this potential, resulting in interconnections between population in the surrounding area and the facilities located in the central place. In this way, the graph-theoretical approach also differs from pure gravity approaches such as the *Huff model*, in which potential interactional areas would be formed on the basis of the gravity in conjunction with the accessibility potentials. Stiens (1989, 33) therefore also criticises the appropriation of the gravity approach by planning, because the "fatal analogy formation" through recourse to scientific concepts is "no longer scientifically 'controllable'".

At this point, it is exciting to merge the actual interactions with reasonableness thresholds in terms of accessibility (e.g., a maximum of 60 minutes travel-time by car) and thus examine in which cases there are significant interactions despite existing accessibility deficits, or in which cases small-scale interactional areas with short distances emerge due to the density (redundancy) in the urban network (cf.fig. 5).

Fig. 6: Topological constellations in the urban system. Source: based on Laan/Schalke 2001, 207



5. Conclusion

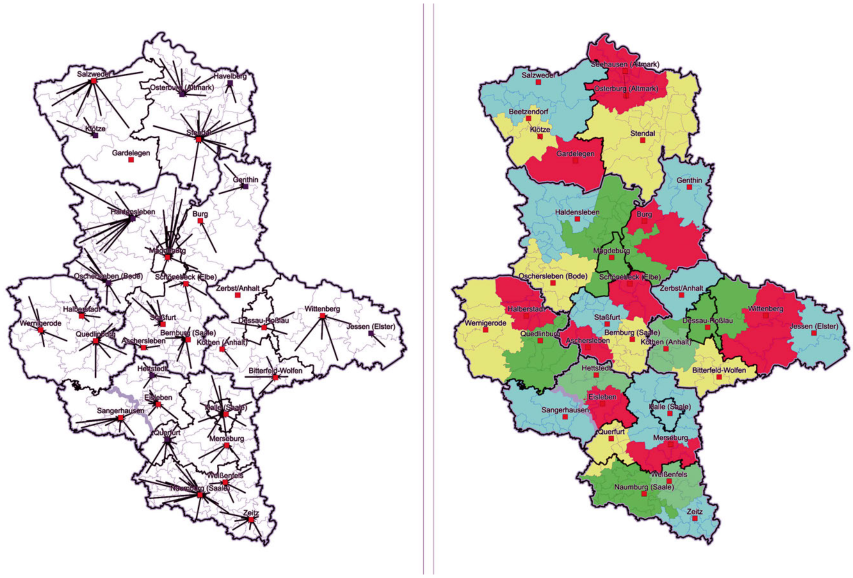
The aim of the chosen research methodology is to map the central place system empirically by analysing and describing the currently existing spatial-functional linkages and central-location functions of the cities. It is important to note that the empirical findings can and should be used to prepare political planning decisions in the sense of evidence-based planning, but should not replace them.

From Analysis to Planning Definition

The result of the analysis using the methodology presented here is a system of interactional areas and their assigned central places (separated by hierarchical levels, for the central level see fig. 7). Depending on the purpose of application, successive plausibility checks can be carried out on further – normative – premises. This is particularly necessary if the analysis is actually to prepare evidence-based political planning decisions. Such premises then also flow into the planning as rules and rule-exception relationships. The following adjustments are conceivable:

- Approximating the area boundaries to district boundaries (territorial principle),
- Allocation of enclaves and exclaves to the surrounding area (spatial contingency),
- Division of interactional/supply areas from which the assigned central place cannot be reached from all cities within the accessibility thresholds (accessibility standards),
- Combining areas that do not have sufficient carrying capacity according to normatively set population thresholds (carrying capacity standards),
- Consideration of cooperative central places as a common central place, for example to ensure a sufficient range of facilities.

Fig. 7: Central places and interactional areas at the middle-order. Source: Greiving/Terfrüchte 2020, 32–33



Taking Saxony-Anhalt as an example, figure 7 shows the existing linkages to potential middle-order centres as an empirical finding (left) and, after taking other premises into account, provides a justified proposal for middle-order centres and their supply areas.

Prospects for Further Research

This article presents methodological approaches to central place research and at the same time defines cities as spatial units for the study. Depending on the availability of data, the approaches are also suitable for identifying small-scale patterns of supply and interaction. A transfer to the neighbourhood level is discussed in the contribution by Terfrüchte and Frank in this volume. On the basis of georeferenced data, a linkage with core density approaches (cf. Flex 2015) is also possible in order to identify 'real' location clusters of central facilities. On the one hand, this makes it possible to check which facilities are actually located in the centre of the respective cities and thus characterise the actual central place. On the other hand, polycentric patterns within administrative boundaries can also be identified. For comparative metropolitan research, this offers the possibility of defining more comparable spatial units, for instance, if Berlin is not always to set the standard in a Germany-wide study.

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Methods for the Identification and Analysis of Clusters in Metropolitan Economies: Overview and Comparative Assessment

Matthias Kiese

1. Clusters in Metropolitan Economies

Economic activity is not randomly spread across space. It shows an increasing tendency to concentrate in cities and metropolitan regions, as evident from the global megatrend of urbanisation (UN 2019). Economists use the concept of agglomeration economies to summarise the benefits, but also drawbacks of spatial concentration. They distinguish between general effects of urban size (*urbanisation economies*) and spatially bound externalities emanating from the concentration of firms in the same, similar, or related industries, so-called *localisation economies* (Fujita/Thisse 2013; McCann 2008). Although the benefits of specialised knowledge, suppliers, and infrastructure in close geographical proximity have been studied since the 19th century (Marshall 1890; 1919), their resurgence in academic and policy circles is tied to the seminal publication by Porter (1990) showcasing the benefits of what he branded as *clusters* (for a critical review see Martin/Sunley 2003).

According to the most widely used definition, clusters are

> geographic *concentrations* of interconnected companies, specialized suppliers, service providers, firms in related industries, and associated institutions (for example, universities, standards agencies, and trade associations) in particular fields that compete but also *cooperate*. (Porter 2008, 213f.; emphasis added)

Within clusters, spatial proximity facilitates cooperation, the sharing of resources and the exchange of knowledge in localised learning processes (Malmberg/Maskell 2006). There is ample evidence that clusters can increase innovation, productivity and profitability in firms, as well as new firm formation and survival (Kiese 2012, 58–65). However, this link is not universal, but depends on specific circumstances, such as a cluster's position in its life cycle (Menzel/Fornahl 2010). History has shown that mature and declining clusters can turn former economic powerhouses into old industrial regions (Hassink 1997; 2010).

Furthermore, clusters differ widely in their state of development (Enright 2003, 104). While *working clusters* contain a critical mass of local knowledge, expertise, personnel, and resources that support the competitiveness of firms, *latent clusters* have a critical mass of firms in related industries but no sufficient level of interaction and information flows for firms to exploit the benefits. *Potential clusters* display some elements of working clusters but are too narrow and/or shallow to reap full benefits. Finally, there are many policy-driven clusters chosen by governments for support but lacking a critical mass of firms or favourable conditions and 'wishful thinking' clusters without any critical mass or any particular source of advantage for organic development.

Clusters are predominantly, but not exclusively, an urban or metropolitan phenomenon. Although their spatial extent may vary, an early literature overview by van der Linde (2002; 2003) showed that out of 705 clusters, the majority was confined to either individual cities (41.8 percent) or metropolitan regions (18.9 percent). While most other clusters extend beyond their urban or metropolitan cores, there are also clusters outside larger urban agglomerations, primarily feeding on localisation economies. Metropolitan economies often contain portfolios of clusters that may be diversified, thus reducing the exposure to asymmetric shocks, but may also overlap, converge, and reinforce each other (Evans/Karecha 2014). The spatial concentration of diverse yet often related pools of knowledge make them nodes in the expanding knowledge economy (Simmie 2003).

Over the last three decades, clusters have become a popular tool for the promotion of local and regional, i.e. sub-national economic development all around the world (cf. Lindqvist et al. 2013) and on all spatial scales as shown by Kiese (2012) for the case of Germany. First and foremost, cluster policies require the proper identification and analysis of (potential) clusters, which can also serve as methods for their evaluation at the end of the policy cycle (Kiese 2019). While *cluster identification* refers to the discovery of hitherto unknown or only assumed cluster potential and structures, *cluster analysis* denotes the quantitative and qualitative measurement and assessment of known cluster potential and structures.[1] In general, these methods can serve three different yet complementary purposes (Sautter 2004, 68):

- the sectoral and geographical delineation of clusters: what industries does a cluster contain, and what is its spatial extent?;
- assessing the presence (quantity) and quality of elements of a regional value system;
- identifying and assessing transactions in a cluster, including input-output (supplier-buyer) linkages as well as communication (knowledge flows).

A generally recognised methodology for identifying (potential) clusters does not exist, nor does a universal cluster theory (Martin/Sunley 2003, 18–23). In the meantime, however, a broad spectrum of methods is available, which differ in their approach (top-down versus bottom-up) as well as in the time and cost required and consequently

1 Note that this contribution does not deal with cluster analysis as a statistical procedure, which aims at grouping objects into clusters based on measures of similarity (Kaufman/Rousseeuw 2005).

also in their practical dissemination.[2] The aim of this chapter is to provide a structured overview and comparative assessment of the most common/relevant methods of cluster identification and analysis, which can be broadly classified into quantitative top-down (macro) and qualitative bottom-up (meso and micro) approaches (see table 1). While the former draw on aggregate statistical data, the latter focus on individual stakeholders or organisations and their linkages, often requiring the gathering of primary data through surveys.

Tab. 1: Methods of cluster identification and analysis: overview

Level	***Methods***
Macro (top-down)	measures of spatial and sectoral concentration growth analyses, e.g. shift-share input-output analysis
Meso	expert opinion, stakeholder participation cluster mapping for case studies competitive methods
Micro	value chain analysis network analysis

Source: Adapted from Sautter (2004, 68).

2. Top-Down Approaches

2.1 Measures of Localisation and Specialisation

The absolute number of firms and employment[3] in a regional industry or their share of the national total[4] offers a first indication of the specialisation of a place or region or of the concentration of industries across space. In addition, empirical regional research offers various *relative concentration measures* to identify spatial-sectoral agglomerations (cf. Westerholt in this volume).[5] These include above all the location quotient (LQ), but

2 See Bergman/Feser 2020, ch. 3; Krätke/Scheuplein 2001, ch. 3; Sautter 2004; and Koschatzky/Lo 2007.

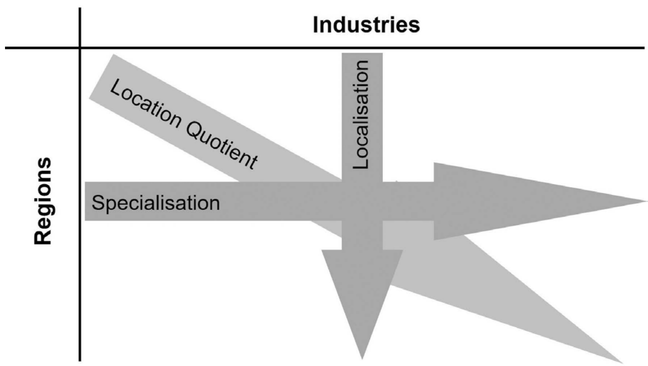
3 In the following, we will use *employment* (the number of employees) as the key measure for economic activity as it is most widely available in spatial and sectoral disaggregation. However, alternative indicators like value added (a net concept) or turnover (a gross concept including expenditures on inputs) might as well be used.

4 For simplicity's sake, we use the term *region* in this contribution to denote any sub-unit of a superordinate larger area, which we label as *nation*. In practice, this larger entity can also be subnational, e.g. a province or federal state, or a supranational entity like the European Union.

5 Spatial data analysis holds many generic measures of concentrations which are outside the scope of this review (Fischer/Wang 2011; Oyana 2021). Farhauer/Kröll (2014, ch. 14) provide an extensive introduction to various measures of spatial concentration and regional specialisation. Fornahl/Brenner (2009) apply the Ellison-Glaeser index, the Gini coefficient, the Herfindahl index, and Moran's *I* as a measure of spatial autocorrelation, to the spatial pattern of patenting activity across German regions. For spatial data analysis, cf. also Westerholt in this volume.

also coefficients of localisation (CL) and specialisation (CS; Schätzl 2000, 60–67). Fig. 1 illustrates their complementary relations: while the CL shows the degree of an industry's spatial concentration, the CS measures the degree of a region's sectoral specialisation. The LQ combines both the sectoral and the spatial perspective by indicating how strongly an industry is concentrated in a particular region, which may indicate the presence of a cluster.

Fig. 1: Measures of localisation and specialisation (Source: Author's illustration)



Measures of spatial and sectoral classification also comprise the coefficient of geographical association (CGA) that shows to what extent pairs of industries co-locate across regions (Schätzl 2000, 66). However, co-location does not necessarily imply a functional (e.g., input-output) linkage between industries. It may also be caused by drawing on the same locational endowments, or simply coincidental.

Location Quotient

The location quotient relates the employment share of an industry in a region to the share of this industry across all regions, i.e. in the nation:

$$LQ = \frac{\frac{Y_{ij}}{\sum_{j=1}^{m} Y_{ij}}}{\frac{\sum_{i=1}^{n} Y_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{m} Y_{ij}}} = \frac{\frac{\textit{industry j in region i}}{\textit{all industries in region i}}}{\frac{\textit{industry j overall}}{\textit{all industries overall}}}$$

The LQ can take values between zero and infinite. While LQ 1 indicates a less than proportional, LQ > 1 indicates a more than proportional presence of industry j in region i. LQ = 1 means that the industry's share in region i is exactly the same as overall. Comparing a region's LQ across all industries shows the region's industry profile, whereas comparing an industry's LQ across all regions shows the industry's geographic distribution (Krätke/Scheuplein 2001, 40). Changes of LQ values over time indicate increases or decreases in the level of concentration and specialisation.

Table 2 illustrates the calculation of the LQ, using employment in the furniture industry of North Rhine-Westphalia (NRW) as an example. While NRW's employment share in this traditional industry is already three times the national average (LQ = 3.26), further spatial disaggregation into counties shows the industry's strong concentration outside the metropolitan cores in the eastern part of NRW, Ostwestfalen-Lippe – Germany's largest furniture cluster with deep historic roots (Rafiqui et al. 2009; VDM 2019). This case shows that the highest LQ values can often be found in non-metropolitan regions due to their smaller and less diversified economic base. As another example, Lichtblau et al. (2018) employ the LQ extensively in a detailed analysis of spatial concentrations of the metal-processing and electrical industries across Germany.

Tab. 2: Location quotients for employment in the furniture industry in North Rhine-Westphalia, 2019

County	***Furniture Industry***	***Total Employment1***	***Regional Share***	***LQ2***
Herford	7,830	53,060	14.8 %	58.93
Gütersloh	6,632	111,577	5.9 %	23.74
Borken	2,252	88,326	2.5 %	10.18
Lippe	2,241	62,868	3.6 %	14.24
Minden-Lübbecke	1,940	70,512	2.8 %	10.99
Paderborn	1,600	68,589	2.3 %	9.32
Hochsauerlandkreis	1,260	60,633	2.1 %	8.30
Soest	941	62,292	1.5 %	6.03
Coesfeld	854	37,900	2.3 %	9.00
Steinfurt	685	91,642	0.7 %	2.99
Höxter	608	23,999	2.5 %	10.12
Oberbergischer Kreis	406	62,107	0.7 %	2.61
Bielefeld	303	84,369	0.4 %	1.43
North Rhine-Westphalia	31,568	3,865,016	0.8 %	3.26
Germany	101,779	40,645,000	0.3 %	1.00

1) Covered by social insurance
2) Location quotient (Germany = 1.00)
Data: IT.NRW (2021); Statista (2021); StBA (2021); own calculations

However, there is disagreement about the value of the LQ above which a significant regional industry agglomeration can be assumed (Martin/Sunley 2003, 20). In practice, very different thresholds are usually set arbitrarily: while, for example, the DTI (2001) identified clustered industries with an LQ of 1.25 or more for the UK, Isaksen (1996) set the bar much higher and still found 143 regional industry agglomerations for Norway, which together represented one fifth of the country's manufacturing workforce. In principle, however, the lower the threshold, the more potential clusters can be found, which makes the procedure very flexible but also somewhat arbitrary. O'Donoghue/Gleave (2004) contributed to the solution of the threshold problem by developing a standardisation procedure for the LQ and testing it for business services in the UK. For the standardised and logarithmised LQs, the significance level of five percent commonly used in the social sciences can be used as a threshold.

Further problems of the LQ, which also apply to other relative and absolute concentration measures, are:

- Employment data for industries at the regional level is often limited in order not to reveal information about individual establishments – a common obstacle to top-down cluster analysis especially in Germany.
- A cluster usually does not consist of a single industry alone, but a set of related industries that needs to be defined and assembled first with the help of complementary methods. These include input-output analysis, as well as alternative clustering algorithms like the one developed by Delgado et al. (2016) that systematically generates and assesses sets of cluster definitions, i.e., groups of closely related industries.
- The results depend on the level of aggregation chosen, as values increase with spatial and sectoral disaggregation.
- A high LQ says nothing about the absolute size of a sector agglomeration and must therefore be supplemented by absolute concentration measures.
- As a rule, clusters exceed the limits of statistical industry classifications; in particular, young fields such as biotechnology or nanotechnology and cross-sectional industries such as optical technologies or production technology are difficult to capture with concentration measures (Koschatzky/Lo 2007, 8f.).

Cluster Index

A high LQ could indicate an agglomeration of firms in an industry, but could also be caused by a single large firm. This is where the cluster index of Sternberg/Litzenberger (2004, 779) comes in, which expands the LQ by relating the number of employees in a sector in a region to the area, the number of inhabitants and the number of companies in that region.

$$CI_{ij} = ID_{ij} \times IS_{ij} \times \frac{1}{SB_{ij}} = \frac{\frac{e_{ij}}{\sum_{i=1}^{n} e_{ij}}}{\frac{i_i}{\sum_{i=1}^{n} i_i}} \times \frac{\frac{b_{ij}}{\sum_{i=1}^{n} b_{ij}}}{\frac{a_i}{\sum_{i=1}^{n} a_i}}$$

with

i = region
j = industry
ID_{ij} = relative industrial density of industry j in region i

IS_{ij} = relative industrial stock of industry j in region i
SB_{ij} = relative firm size of industry j in region i
e_{ij} = employment of industry j in region i
b_{ij} = number of firms (businesses) of industry j in region i
a_i = area of region i
i_i = population (inhabitants) of region i

As the formula shows, the cluster index consists of three components (Litzenberger/Sternberg 2006, 211–214):

1. The spatial concentration of industries in a region – in relation to the region as a whole – can be measured with the *relative industrial density* (ID_{ij}). To calculate ID, the value of the absolute industrial density of a region is divided by the absolute industrial density at the national level. The absolute industrial density in turn relates the employment of an industry or a group of industries to the area of the corresponding spatial unit.
2. This is combined with the *relative industrial stock* (IS_{ij}), which is calculated from the absolute industrial ratio of the region divided by the absolute industrial ratio at the national level. The absolute industrial stock relates the economic activity indicator – in this case employment – to the number of inhabitants or the total number of employees.
3. The relative firm size (SB_{ij}) is the ratio of the average establishment size of the industry in the region to the average establishment size of the industry at the national level.

Like the LQ, the cluster index assumes values from zero to infinite, while the average across all regions is always 1. It refines the LQ approach, but also requires more data that may not always be available. Apart from the inclusion of additional regional characteristics (number of firms, area, and population of the region), the drawbacks listed above for the LQ also apply to the cluster index.

Absolute and relative concentration measures are relatively easy to calculate when spatially and sectorally disaggregated data are available, but they can basically only provide indications of spatial-sectoral concentrations. The *cluster mappings* carried out top-down for Germany by Brenner (2004; 2006) and Sternberg/Litzenberger (2004) can only identify industry agglomerations and thus establish cluster assumptions. In order to draw conclusions about interdependencies or even institutional or socio-cultural cluster characteristics, a combination with bottom-up methods is necessary.

2.2 Growth Analyses

In economic development practice, expectations about the future growth of an industry on a national or supranational scale are often transferred to regional concentrations of that industry, without considering the existence of specific regional contexts. Instead, however, the development dynamics of an industry in a specific region can be determined by the absolute and/or relative change in the number of companies, turnover, or employees or with the help of *shift-share analysis (SSA)* introduced by Dunn (1960; for a more extensive introduction see Farhauer/Kröll 2014, ch. 15).

The latter decomposes a region's growth differential vis-à-vis the national total into a structural effect and a regional effect, which is the residual left after accounting for the impact of industry structure on regional growth (Krätke/Scheuplein 2001, 45–47). In essence, for a given period t_0 to t_1, regional employment or value-added growth is compared to national employment or value-added growth in the same period. This may basically be achieved through subtraction or division (table 3). In any case, a hypothetical value for the region in t_1 is computed under the assumption that all industries in the region grew with the respective industry growth rates at the national level, yielding the *structural effect* on regional growth. The residual between this hypothetical and the actual t_1 value is the *location effect* that can be attributed to anything but the region's industry structure.

Tab. 3: Shift-share analysis based on subtraction vs. division

Operation	***Method***	***Procedure***
subtraction	difference method	total net shift = net proportionality shift + net differential shift
division	index method	regional factor = structural factor + location factor

Source: Author's illustration based on Schätzl 2000, 77–84

The results of an SSA point at possible reasons for growth differentials across regions. Positive structural effects indicate agglomerations of dynamic industries, which could be high-tech clusters. Positive location effects, on the other hand, show that industries are more successful in a particular region than elsewhere. In contrast to global trend studies, SSA accounts for specific regional assets and may thus be used as a complement. The significance of SSA results, however, depends on the period examined as well as on the level of sectoral and spatial disaggregation of the initial data. It is often criticised as a descriptive tool and therefore complemented with shift-share regressions (Farhauer/Kröll 2009). Consequently, the suitability of SSA as a forecasting instrument is also doubted (Schätzl 2000, 84).

2.3 Input-Output Analysis

As a supplement to national accounts, input-output (IO) tables provide detailed insights into the flows of goods and production interdependencies in the national economy and with the rest of the world (Bleses 2007). It is a mandatory element in the European System of National Accounts, hence IO tables are available for all European countries. At the regional level, they would be an ideal instrument for identifying value-chain linkages as key elements of clusters, but domestic flows of goods are not captured in national accounts. National tables can therefore only be regionalised by means of very complex data collection or with the help of derivative methods in which the regional specifics that are particularly important for clusters can only be estimated (Krätke/Scheuplein 2001, 49). For instance, a textbook example provided by Farhauer/Kröll (2014, 402ff.) assumes no difference in technology and the age of the capital stock between the region and the nation in which it is embedded.

Feser/Bergman (2000) identified 28 cluster templates from national input-output tables for the U.S., which they applied to data for the state of North Carolina to map regional transactions. Their results deviated substantially from conventional industry-level analysis and provided an approximation of intra-firm linkages within the state. Here too, however, national patterns were broken down without considering regional specifics. The main problem with estimates of regional IO tables is the simultaneous export and import of goods from the same group of goods, so-called cross-hauling (Kronenberg 2009). Többen/Kronenberg (2015) developed a method to include this effect in estimates of multi-regional input-output tables. Vogt (2011) shows how this method was tested and further developed to estimate exports and imports according to the IO concept for Baden-Württemberg.

According to Farhauer/Kröll (2014, 424), IO analysis is mostly used to estimate the impact of one industry's demand on regional output, income, and employment. Its occasional application to the identification of clusters is limited to those based on value-chain linkages (vertical clusters). Its proper application would require data on three- or even four-digit industry classification levels, which is rarely available in IO tables. They conclude that IO analysis may complement other methods, but one should not rely on it as the sole method when looking for clusters.

3. Bottom-Up Approaches

3.1 Expert Opinion and Stakeholder Participation

Individual interviews or moderated workshops with representatives of business, science, the public sector, chambers and associations, etc. not only provide information on strengths and weaknesses as well as development trends of the regional economic structure, but can also mobilise regional actors for the subsequent implementation of a cluster strategy. According to Bergman/Feser (2020), this is the most common method of cluster identification. Taking into account existing sector analyses, expert, and media reports, it is possible to draw conclusions about existing input-output relations or other cluster potential in the region. The disadvantages of this method are generally to be seen in the limited reproducibility and comparability of the results, as well as in possible distortions due to the self-interest of the experts involved and other vested interests (Kiese/Wrobel 2011).

Brun/Jolley (2011) review a case study of a collaborative approach involving *stakeholders* in cluster identification in North Carolina and assess the costs and benefits of this method. They find that increased stakeholder participation in cluster identification improves the quality of the analysis, as well as community and political acceptance of the results. Stakeholders also challenged the authors to define a renewable energy cluster and analyse their county's competitive position in this sector. The main costs were the time and money required to organise stakeholder participation.

This basic approach can be extended to possible future trajectories in the *regional foresight* method (Koschatzky 2005; Stratigea/Papadopoulou 2013; Bassani et al. 2016). This is a participative and moderated procedure to forecast regional technological development. Regional actors with different technological and social backgrounds are brought together to exchange views on possible future development paths. This process condenses their assessments and expectations into a common vision of regional development, which enables regional specifics (traditions, established strengths) to be linked with global trends (Hospers 2004). This is very much in the spirit of the entrepreneurial discovery process that the European Union demands as part of smart specialisation strategies underlying their cohesion policy since 2014 (Foray 2018).

3.2 Value Chain Analysis

The ultimate goal of the analysis of regional clusters is to map inter-firm linkages in value chains and their degree of localisation. As a starting point, a value chain at the lowest possible aggregation level (bottom-up) can be chosen, whose links can be assigned to individual companies. It is advisable to first identify one or more cluster cores (e.g. end manufacturers as focal companies or important suppliers or distributors) and from there a cluster environment with subordinate chain links (Krätke/Scheuplein 2001, 52).

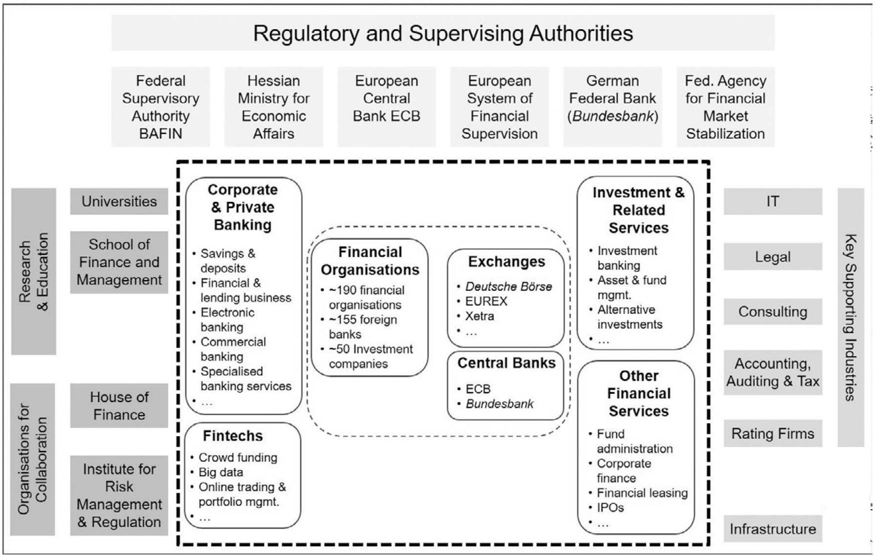
If the value chain is sufficiently mapped as a vertical cluster dimension, it should be expanded into a value creation system with horizontal and diagonal links to other companies and supporting organisations (Kiese 2012, 39). The functional analysis provides important information on the development status of the cluster and, if necessary, elements and links that are still missing for a functioning cluster. Due to the amount of research needed, however, the method can only be carried out on the basis of the value chain(s) relevant for regional specialisation.

3.3 Cluster Mapping for Case Studies

A cluster map is not a geographical map, but a visual schematic describing the different elements of a cluster and their relations. In a generalised overview, it illustrates the structure of industries and supporting organisations within a cluster. A cluster map can guide economic development strategies that account for the synergies between the cluster's components. It is not a primary method of cluster identification and analysis, as it merely structures information obtained from other methods, such as expert opinion and reports.

The example in fig. 2 shows that cluster maps are usually developed from the inside out. Some organisations may perform different functions, as can be seen from the double appearance of central banks as market players with some supervisory functions. Austrian (2000) points out that once accepted, a cluster map shapes the way in which a cluster is perceived both inside and outside the cluster. After reviewing different types of cluster maps, the author recommends an improved version that combines elements from several of the maps. Note that the term cluster mapping is also used for

Fig. 2: Schematic cluster diagram: Frankfurt's Financial Services Cluster (Source: Behrens et al. 2016, 17; slightly modified)



top-down quantitative approaches like the U.S. Cluster Mapping Project[6], the Italian cluster mapping project[7], and more heterogeneous data collections like the European Cluster Observatory[8].

3.4 Competitive Methods

Competitive procedures for identifying networks as important components of regional clusters have become popular since the mid-1990s. This is evidenced by the BioRegio, InnoRegio and leading-edge cluster competition of the German Federal Government, the cluster competitions of the NRW state government (Kiese 2012) or the initiative "Regional Competence and Innovation Centres" of the Stuttgart regional economic development corporation (Sautter 2004, 71f.). Although the efficient use of scarce funding and the mobilisation of regional potential can be singled out as the primary goals of these competitions, the origin of the applicants and award winners provides important indications of the existence and development status of (potential) regional clusters as a secondary effect. However, while the institutionalisation of networks is in the foreground, other characteristics of potential or functioning clusters are not considered in this method. As a consequence, significant cluster potential failing to mobilise collective action to apply for the contest may be overlooked.

6 www.clustermapping.us.

7 https://italiacompete.it.

8 http://www.clusterobservatory.eu.

3.5 Network Analysis

Developed for the analysis of social networks (Jansen 2014), network analysis is one of the more recent methods of cluster identification (Bergman/Feser 2020). In contrast to input-output analysis, the focus here is not on the supplier linkages of industries, but on the networking structure of actors which includes not only material supplier and buyer relationships, but also their communication networks for the exchange of knowledge. In addition to the exchange of goods, companies are surveyed about their respective contacts with other companies and other organisations in and outside the region. If the companies themselves are asked to name their most important business and communication partners, indications of other companies relevant to the clusters and supporting organisations will emerge. The information gained from a company represents the "ego network" of the firm. In summary, the information of all actors is aggregated into matrix representations of the cluster, whereby the actors are represented as nodes and their interactions as lines (Jansen 2014).

Since traditional approaches like the snowball method fail to identify isolated actors in networks, they have given way to the so-called roster-recall method (ter Wal/Boschma 2009). This method provides each respondent with a list of actors – the roster – that should ideally include the complete population to prevent a bias against those other actors not listed. In practice, however, this is often not feasible as the list would become too extensive. For each of the actors in the roster, the respondent is asked to indicate if she/he has a relationship of one or several predefined types.

Network analysis is more suitable than any other method for determining the quality of the interconnectedness, which is emphasised in theory as an essential determinant of cluster dynamics. It can be used to determine the density, cohesion, and centrality of the network as measures of the quality of the interconnections. As further indicators for a qualitative comparison of regional clusters, Krätke/Scheuplein (2001, 71) add the extent of functional differentiation, the supraregional transaction relations, the spatial concentration of cluster companies within the region, and the quality of the institutional infrastructure.

However, this approach comes at a high cost, since mapping a region's network structures in a reliable manner requires a high response rate, namely, a near-complete coverage of the relevant actors.[9] Even if this is achieved, however, a respondent's knowledge about the transaction and communication linkages of her/his organisation still introduces a considerable source of error that should always be remembered when interpreting fractional differences in network parameters (ter Wal/Boschma 2009, 748). Likewise, researchers depend on respondents' judgements when it comes to the intensity and quality of linkages of cooperation.

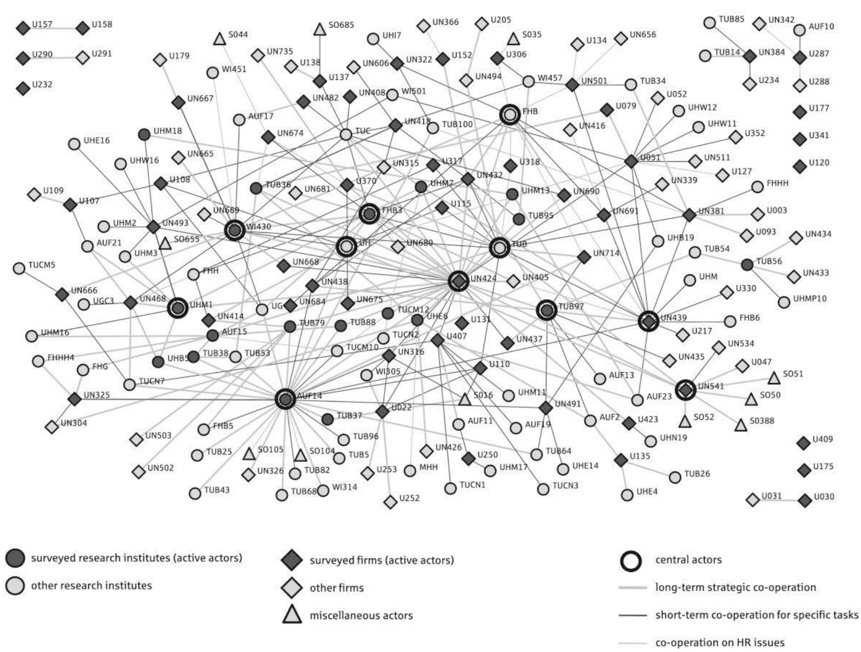
Due to the high costs of surveying entire cluster populations, the application of network analysis is usually constrained to smaller clusters with a limited number of firms and other organisations, such as the film industry in Potsdam/Babelsberg (Krätke

9 Some non-response is commonly considered tolerable since each link should ideally be mentioned by both of the partners involved (reciprocation; ter Wal/Boschma 2009, 747).

2002), logistics in Bremen and Hamburg (Wrobel 2004), the emerging IT security cluster in the Ruhr (Scheideler 2009), or nanobiotechnology in Münster (Ammermann 2011). A notable exception of an extensive regional network analysis covering the entire metropolitan region of Hannover-Braunschweig-Göttingen-Wolfsburg was conducted by Brandt/Hahn/Krätke/Kiese (2009) and updated to trace changes over time by Brandt et al. (2021). The population for the initial survey comprised 496 economically relevant university and non-university research organisations and 670 innovation-oriented firms, from which a sufficient response rate of 81 percent was obtained.

The results show clear differences between seven fields of competence across all network parameters, which are also expressed in network diagrams. The example for the competence field of mobility (i.e., automotive industry and research) represents a high degree of density and centralisation (fig. 3), in contrast to the much looser networks of the heterogeneous ICT field. The visualisation allows to identify focal organisations, but also peripheral actors with no or only weak ties into the network. Note that as for the cluster map, a network diagram is not a geographical map. Organisations, which are anonymised with codes in this example, are arranged according to their centrality in the network by the software.

Fig. 3: Network diagram for the mobility field of competence in the metropolitan region of Hannover-Braunschweig-Göttingen-Wolfsburg (Source: Brandt et al. 2009, 244)



As a consequence of survey costs, the application of network analysis to the identification and analysis of clusters has shifted to secondary data, such as co-patenting as ‘paper trails’ indicating knowledge flows. Ter Wal/Boschma (2009) provide a review of such studies. A more recent example is the analysis of cluster policy effects on local patent co-application and co-invention networks in 17 German regions that participated in the BioRegio contest by Graf/Broekel (2020). However, this data only captures one particular form of interaction, whilst surveying can basically cover any kind of linkage, which in turn increases the danger of mixing apples with oranges.

4. Comparative Assessment and Conclusion

All methods portrayed in this chapter have characteristic strengths and weaknesses, which is why a mix of complementary methods (see Terfrüchte/Frank in this volume) – such as top-down and bottom-up approaches – is generally recommended (Komorowski 2020). Industry agglomerations identified through top-down approaches can lead to the formulation of assumptions about potential clusters, thus serving as a starting point for the targeted use of bottom-up approaches. However, clusters are moving targets that require continuous monitoring. A one-off analysis can only provide a snapshot that may soon become obsolete as technologies and demand shift.

Tab. 4: Comparative assessment of methods (Source: Author's compilation)

Level	***Method***	***Strengths***	***Weaknesses***
macro	measures of localisation and specialisation	draws on secondary data, no surveying needed	captures agglomeration, but no linkages results depend on level of aggregation
	growth analysis (shift-share analysis)	dynamic approach (decomposing growth differentials) no surveying needed	descriptive and coarse (location effect as residual) results depend on level of aggregation
	input-output analysis	approximates interaction in clusters no surveying needed	only data on national patterns regional IO linkages can only be estimated
meso	expert opinion and stakeholder participation	relatively easy to organise	self-interest, vested interests
	cluster mapping		secondary method drawing on other approaches
	competitive methods		only captures organised clusters
micro	value chain analysis	provides detailed insights	costly
	network analysis	concrete measurement of interaction in clusters	

Due to the resources required by many methods, the spectrum summarised in table 4 is usually not fully exploited to inform the design and implementation of *cluster policies*. A survey of economic development agencies in 94 large cities across Germany by Hollbach-Grömig/Floeting (2008, 11) found that internal knowledge was most widely used to identify clusters: 71.3 percent of respondents already knew which clusters they had. Expert opinion was second, with 58.5 percent stating commissioned reports and 45.7 percent moderated processes. The latter share also came out for growth analyses, although this was not specified as SSA in this standardised survey. This methodology may also help to explain the responses for network analysis (29.8 percent), concentration measures (28.7 percent), and value chain analysis (25.5 percent), as respondents' understanding of these terms could not be verified. Interview research for multiple prominent regional cluster policy case studies suggests that only expert opinion and concentration measures are widespread in practice, while the political selection of clusters for promotion often precedes the analysis (Kiese 2012, 311).

In practice, the above-mentioned methods for identifying (potential) clusters are often supplemented by indicators for the measured or potential growth of sectors and technologies in order to identify growth clusters and to filter out stagnating or even shrinking clusters at the end of their life cycle (Menzel/Fornahl 2010). In addition to the analysis of the past employment trends, global trend studies are often very popular. However, this not only entails the risk of incorrect forecasts, but also infuses herd behaviour into cluster policy, as reflected in the high degree of congruence of regional cluster portfolios (cf. Kiese 2012). Region-specific development paths too often fade into the background. Sloppy cluster identification and analysis may save money short-term but increases the risk of misallocating public funds in the longer run. It thus appears advisable to exploit the available methods more fully – not just in reports commissioned by policy-makers, as more independent research is also needed.

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Agent-Based Modelling of Infrastructure Systems

Johannes Weyer/Marlon Philipp/Fabian Adelt

1. Introduction

Metropolitan areas are complex socio-technical systems whose governance is demanding, even if politicians' only aim is to maintain the current status. However, sustainable transformation of cities and urban infrastructure systems requires more dedication, i.e., to actively promote and manage an open-ended process of change, which involves the change of citizens' minds, habits and daily routines.

Agent-based modelling (ABM) has proved itself as a new method of investigating structures and dynamics of complex systems such as the economy or the climate (Resnick 1995). Social scientists have also adopted this method to study the dynamics of social systems, e.g., in the case of the spread of rumours, infections or innovations (Epstein/Axtell 1996; Ahrweiler 2013; Van Dam et al. 2013; Weyer/Roos 2017). ABM allows researchers to take into consideration the variety and heterogeneity of social actors. Additionally, conducting simulation experiments with artificial social systems enables social scientists to take a look into possible futures of metropolitan regions and to investigate various strategies of policy interventions.

The following article will first present some basic principles and methodologies of ABM by using the example of traffic simulation. Second, we provide an outlook on various simulation frameworks modelling transportation systems, parts of which apply ABM successfully in order to investigate, e.g., policy options to support sustainable transformation.

2. Modelling Complex Systems

Models are abstract representations of real systems (for a discussion of models, cf. also Gönsch/Gurr in this volume). They bridge the gap between theoretical propositions and reality. Models help to translate theoretical concepts, such as the idea of norm-following, into mechanisms that can be formalised as 'comply to norms in most cases'.

A sociological model of a socio-technical system, e.g., a megacity and its transportation infrastructure serving as an example in the following, needs three ingredients:

- *agents*, representing typical real actors, and their rules of decision-making,
- the *context* of action, e.g., the social, technical, political, and institutional structures that serve as boundary conditions for agents' actions,
- and, finally, *rules* of interaction between agents, but also between agents and context. Imagine for example the interaction of bike-riding agents and a traffic light: to what extent do they feel obliged to stop when a traffic light is red?

2.1 Agents

Agents have properties, preferences and strategies, which resemble real actors. Data needed for modelling agents is mostly gathered by means of surveys. This method allows researchers to construct typical agent types, such as eco-friendly or comfort-oriented agents. With modern simulation software one can parametrise each agent differently (referring to age, sex, income, agent type, preferences, routines, car ownership, daily tasks, etc.) so that large populations of heterogeneous agents can be generated for experimentation at the computer screen.

The decision rule in most models of artificial societies is very simple: confronted with various alternatives (e.g., taking the bus, the car or the bike), agents choose the option that benefits them most according to their individual preferences (Konidari/Mavrakis 2007). This concept of subjective expected utility (SEU) is a moderate version of the utility-maximising "homo economicus", including not only situational parameters, but also subjective expectations and preferences, making the model more realistic (Esser 1993; Velasquez/Hester 2013). Hence, given the same situation, the eco-friendly agent may take the bike, while the comfort-oriented one selects the car.

$$\mathrm{SEU}\,(A_i) = \sum\nolimits_{j=1}^{n} p_{ij} * U(O)_j$$

SEU calculation; U(O): utility of an expected result; p: probability of achieving a goal O. (see Konidari/Mavrakis 2007, 6247; quoted from Adelt/Weyer/Hoffmann/Ihrig 2018, 4.17).

Consequently, programmers do not need to implement different rules of decision-making, because one rule applies to all agents but – due to various input parameters – nevertheless produces different outcomes. Even in the case of conflicts of objectives (drive fast, but eco-friendly), this rule produces results which resemble the decision-making of real actors.

2.2 Context

The second ingredient of a simulation model is the landscape in which the agents are moving around. It typically consists of *nodes*, such as residential buildings, working places, shopping malls, crossroads, train stations or bus stops, and *edges* connecting them, e.g., roads, bike tracks or railways for public transport. The shape of this network largely depends on the topic of investigation. Together with available technologies (car, bike, public transport, car sharing, etc.), it constitutes the context and shapes the room for manoeuvre of all agents, providing them with opportunities (bike rental in the vicinity), but also with constraints (bikes forbidden on highways).

Similar to agents, every contextual component has properties, partly 'natural' such as the maximum number of cars on a residential road, partly politically definable such as the limit of CO_2 emissions or the amount of city toll at that road. These properties are one of the major 'levers' policy makers can utilise for intervention, e.g., by increasing the city toll for cars with combustion engines or, finally, banning their use.

The same applies to technologies, which have properties, e.g., low pollution of bikes, compared to cars, but even lower speed. These properties can also be changed by means of political intervention, e.g., by applying speed limits for cars, or by the invention of new technologies such as the e-bike, increasing speed and range of the bike.

2.3 Interaction

The final ingredients for an ABM are rules for interactions between agents, but also between agents and context. Agents in transportation systems will typically stay on their lane and maintain distance when approaching another agent. Maybe they also exchange information – referring to scenarios of Car-2-Car communication (Fuchs et al. 2015). Roads may influence agents, e.g., by speed limits or tolls, while agents change the state of a road not only by occupying it for a short period of travel time, but also by wearing it out and by polluting its environment.

Every agent using the transportation system contributes to system dynamics by changing parameters (e.g., the number of cars at a certain road section) and thus indirectly influences other agents, who may decide to switch to public transport if roads are overcrowded. If the current traffic situation is regarded as a relevant parameter, even the comfort-oriented agent, who normally prefers the car, might eventually take this action.

2.4 System Dynamics

A large number of autonomous actions, influenced by the current system state at time t, result in a self-organised process of system dynamics. The emergent effects of this process are hard to predict but constitute system state at time t+1. Agent-based modelling is capable of depicting this dynamic interplay of the micro level (agents' actions) and the macro level (system state) – with sometimes surprising results (e.g., traffic congestions), which are not part of the agents' strategies but emerge as a result of their autonomous, uncoordinated actions.

Complex systems often entail non-linear interactions, which can only be investigated by running experiments on the computer and trying to understand the results. For example, lowering prices of public transport does not change agents' behaviour in a linear way. Results reveal some tipping points, which are difficult to interpret, because not all agents change their mind simultaneously. In fact, only certain groups of agents switch at a certain price level.

2.5 Governance

As mentioned before, agent-based models of complex socio-technical systems are a well-suited means for investigating governance issues, e.g., in the case of sustainable transition of the transportation system. According to the respective scenario, various strategies can be tested by means of simulation experiments, e.g., speed limits for cars, rise of fuel prices, road charges, parking management, improvement of bike lanes, bicycle parking garages, reduction of prices for public transport and many more (Philipp/Adelt 2018). Strategies can be distinguished between soft control, using monetary or non-monetary incentives (e.g., tolls), and strong control, relying on bans (e.g., for older combustion engines), but typically are a mixture of various measures.

In terms of programming, intervening in a complex system mostly means to change parameters of technologies or contextual components. Since these parameters are part of agents' utility calculation, an increase or decrease may influence agents' decisions, but not in a deterministic way as former models of direct control may have assumed.

Another option of mobility transition is the introduction of new technologies, such as electric vehicles, and the invention of new mobility practices, such as car sharing or mobility-on-demand. Again, in terms of programming, these new options are included in a way that enables agents to consider them when making their choices, e.g., buying a new car with combustion engine or an electric vehicle.

2.6 A Sociological Perspective

This approach of modelling complex infrastructure systems in many parts resembles the way engineers would do it, e.g., when investigating the causes of congestions (Schreckenberg/Selten 2004). However, from a sociological perspective it is important not to treat human actors as mechanical components, who all behave the same – perfectly rational – way, but as conscious individuals, who act according to subjective preferences. Sometimes, their decisions seem to be irrational (e.g., taking the car for a trip of only one kilometre), but these are everyday practices that have to be considered if one wants to grasp the dynamics of socio-technical systems by analysing the interplay of the micro and the macro level.

Sociological theory of action as well as sociological macro-micro-macro models thus are essential ingredients to make artificial societies a realistic image of real societies, e.g., in metropolitan areas (Hedström/Swedberg 1996; Ostrom 2010; Esser 1993).

3. Traffic Simulation

During the last decades, various traffic simulation tools have been developed. Not all of them are ABM-based, and only a few refer to sociological concepts of action. Only in recent years have some of those frameworks started to include decision-making of social actors.

3.1 Nagel-Schreckenberg Model (NaSch)

In the 1990s, Kai Nagel, Michael Schreckenberg, and others developed a traffic simulation model, grounded in cellular automata concepts (Nagel/Schreckenberg 1992). This model can be regarded as the forerunner of all subsequent models. In their approach, a single-lane highway consists of cells, each occupied by a maximum of one car, which increases or reduces its speed according to the state of the cell ahead. The resulting traffic flow, created by all cars-on-cells, reveals various fluctuations (such as congestions) which can also be observed in real traffic systems.[1] Although Nagel and Schreckenberg frequently refer to the "individual (though statistical) behaviour of the driver" (1992, 2229), they mainly emphasise the technical performance of the car (conducted by a human driver) in terms of acceleration or deceleration.

OLSIM

Later, the NaSch model has been extended to two-lane highways in order to investigate the issue of lane change (Knospe et al. 2002).[2] Moreover, it was used to model the network of highways in North Rhine-Westphalia, a densely populated state of Germany with frequently congested roads (Selten et al. 2004; Schreckenberg et al. 2005).

In 2002 the government of North Rhine-Westphalia decided to establish the online traffic information service *autobahn.NRW*, based on the online simulation OLSIM, which used real-time data from 4,000 detection devices to calculate and to forecast traffic – again in real time (Schreckenberg et al. 2005; Weber et al. 2006). Plans to extend this service to secondary roads and to establish a comprehensive traffic information system called "Ruhrpilot", however, were facing the growing competition by commercial, but freely available services such as Google Maps, which entered the German market in 2011. The service *www.verkehr.nrw* still exists but meanwhile uses data from TomTom (Konrad/Weyer/Cepera/Adelt 2020).

3.2 Multi-Agent Transport Simulation (MATSim)

In contrast to Michael Schreckenberg's OLSIM, which is grounded in the cellular automata concept, Kai Nagel switched to agent-based modelling (ABM) and, together with other colleagues, in the late 1990s invented the general idea of MATSim, which was completed in 2004 (Nagel 2004; Nagel/Axhausen 2016). The Swiss city of Zurich was the first example that demonstrated the value of traffic demand modelling based on individual plans instead of origin-destination matrices, as in the case of other traffic planning tools. MATSim (www.matsim.org) is open source and today is used worldwide as a simulation and planning tool (Horni et al. 2016).

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1 A simple traffic simulation which resembles the NaSch model can be found in NetLogo (Wilensky 1997).

2 The research team of Reinhard Selten also investigated route choice behaviour and the impact of information on route choice but did not use the NaSch model, but instead performed laboratory experiments with students (Selten et al. 2007).

MATSim is a microscopic traffic simulation based on modelling the behaviour of large numbers of individuals and their daily plans, which are fixed in advance but can be improved if other plans are available (Horni et al. 2016, 3; 7; 37ff.). The traffic flow model is queue-based: links (e.g., roads) between nodes (e.g., crossroads) serve as waiting queues, where cars wait until they can step forward (Horni et al. 2016, 6–7). MATSim abstains from modelling physical movement of road users, as car-following models do.

MATSim has been designed to investigate (daily) traffic demand – as the aggregate result of various agents' daily plans, which are fixed and can only be changed the next day. Typically, MATSim scenarios depict real cities or regions and take available data, such as census data, traffic counting, OpenStreetMaps (OSM) data and others, to calibrate the model.

MATSim is rooted in computational physics and in complex adaptive systems (CAS), but it lacks a sociological foundation of action and interaction. Agents' preferences are modelled, but only considering time or budget restrictions, which is much less than a sociological concept of agency would do. Additionally, agents stubbornly follow their prefabricated plans and do not change behaviour during the day, e.g., due to situational restrictions such as congestions or road closure.

NEMO

The project "Neue EmscherMobilität" (NEMO, 2017–2020; http://www.nemo-ruhr.de; no longer exists) has used MATSim as a tool for modelling mobility in the Ruhr region. NEMO was the impetus for including sociological concepts of agency and governance into MATSim.[3] Similar to SimCo (see 3.4 below), the authors aim to include individual preferences in its behavioural models and to implement various scenarios and visions that entail intervention strategies, e.g., promoting bicycle traffic (Ziemke et al. 2019; Kaddoura et al. 2020). Furthermore, MATSim is now able to integrate multiple transport modes, but still not multimodal transport chains.

In the course of project NEMO, MATSim was used to investigate the impact of several measures, such as the closure of residential roads, the conversion of roads into bicycle tracks, but also new options like car-, bike- and ride-sharing, depending on the respective scenario to be analysed. These scenarios had been called "Healthy and Sustainable City", "Smart City" or "Deurbanisation". Experiments proved that most of the measures applied served to change users' behaviour, resulting in a measurable improvement of environmental indicators and/or quality of life (Ziemke et al. 2019; Kaddoura et al. 2020).

3.3 Various Frameworks

SUMO

Simulation of Urban Mobility (SUMO; sumo.dlr.de) is a traffic simulator, which has been developed by the German Aerospace Center (DLR) since 2000. SUMO is a "microscopic, space-continuous and time-discrete car-following model" (Krajzewicz 2010) consider-

3 Personal communication with J. Alexander Schmidt (5. November 2019).

ing mainly the physical movements of vehicles, e.g., in the case of lane changing (Krauß 1998; Krajzewicz et al. 2012).

Researchers from TU Dortmund University managed to integrate social behaviour and especially individual route choice into an extended SUMO-S (Adelt/Weyer/Fink 2014). Additionally, they considered "frame selection" (Kroneberg 2014) – a concept that takes into account routines and habits instead of assuming all actions being based on (subjective) rational calculation. However, Adelt, Weyer and Fink dropped SUMO-S, mostly because the efforts needed to create new scenarios for a microscopic traffic simulation were too high. In order to investigate more general questions of governance, they developed SimCo from scratch – a more abstract simulation framework rooted in sociological theory of action (see 3.4 below). Even the developers admit that "the usage of SUMO [is] a little bit uncomfortable in comparison to other simulation packages" (https://sumo.dlr.de/docs/SUMO_at_a_Glance.html#software_design_criteria).

IVV VENUS, VISUM and VISSIM

Compared to SUMO and MATSim, the purpose of which is mostly academic, other traffic simulation frameworks are more directed towards the practical use of traffic planning. For example, IVV VENUS (www.ivv-aachen.de/produkte/softwareprodukte/detailseiten/venus.html) is a macroscopic model using various structural data for modelling traffic demand and calculating the impact of, e.g., building new highways or new cycle tracks. IVV VENUS is trip-based, meaning that typical trips (from home to work, etc.) are primary constituents for modelling the macroscopic view.

This similarly applies to other commercial products such as VISUM (www.ptvgroup.com/de/loesungenprodukte/ptv-visum), which creates a macroscopic image and "predict[s] the effects of proposed changes in configuration of the transport network" (Jacyna et al. 2017), e.g., due to changing demand. The complementary traffic planning tool VISSIM (www.ptvgroup.com/de/loesungen/produkte/ptv-vissim) depicts the microscopic situation and provides realistic, virtual images of the traffic flow and the interaction of various transport modes, e.g., pedestrians and cars at a bus stop. VISSIM includes behavioural models of pedestrians and other transport users, but agents' behaviour and interactions are regarded from a technical point of view (Fellendorf/Vortisch 2010). This benefits traffic planners in their efforts of optimising transportation infrastructure, e.g., making bus stops safer or better suited for multimodal transport. However, decision-making of individual agents in terms of sociology is not considered here either.

Commercial Services

Finally, commercial services such as TomTom, Apple Maps, Google Maps, Here and others provide real-time services for the purpose of route guidance (Konrad et al. 2020). This differs from the long-term perspective of planning tools. However, these services also deliver valuable data, which can be used to improve the quality of other simulation frameworks.

3.4 Simulation of the Governance of Complex Systems (SimCo)

The simulation framework SimCo has been developed at TU Dortmund University, starting in 2012. Its main motivation has been to sustain and push forward governance research, which mostly had been case study-based and had been caught in a "governance trap" (Grande 2012; our translation). According to Edgar Grande, this was due to lacking knowledge of social mechanisms that make up social systems and allow external forces to intervene.

Focusing on governance issues, SimCo from the very beginning does not pay much attention to physical details, such as length and size of bus stops, but puts emphasis mainly on social mechanisms that shape and guide individual behaviour (Adelt et al. 2018). Therefore, the network, depicting a metropolitan transportation system, consists of nodes and edges, the dimensions of which are freely programmable. This allows for conceiving them as roads, cycle tracks or tracks for public transport (edges), as working places, residential areas or shopping malls (nodes). As a general-purpose framework, SimCo intends to explain system dynamics as a result of the interaction of heterogeneous agents making autonomous decisions – and vice versa: explain agents' behaviour as a result of individual preferences and situational constraints. SimCo thus is one of the first attempts to translate a sociological macro-micro-macro model systematically into an agent-based model (Esser 1993).

SimCo has been used for various experiments on risk management and system transformation, mostly in road transportation (Philipp/Adelt 2018; Weyer/Adelt/Hoffmann 2019; Weyer et al. 2020). Several what-if scenarios have been investigated analysing the effects of external interventions on individual behaviour of various agent types, above all on mode and route choice. One major result of these experiments is: political interventions, e.g., to minimise risks (congestions or emissions) or to change the system towards sustainability, work best if the governance mode of soft control is applied, working with incentives and not with strong measures such as bans (as in the case of strong control; Weyer/Adelt/Hoffmann/Konrad/Cepera 2020). Additionally, this sociological approach has also been used to model the energy system and its sustainable transformation (Hidalgo-Rodríguez et al. 2017; Hoffmann/Adelt/Weyer 2020).

4. Governing Transitions of Metropolitan Areas

All models presented here intend to contribute to a better understanding of the dynamics of metropolitan infrastructure systems, such as transportation or energy. In their self-perception, all approaches serve as analytical instruments and, finally, as planning tools, trying to better understand possible pathways towards a sustainable future, e.g., by implementing policy scenarios such as ride-sharing or multimodal transport.

However, the concepts differ with regard to their emphasis on physical infrastructure (e.g., VISUM and IVV VENUS), on physical movement of transportation units (e.g., NaSch, SUMO), on traffic demand (e.g., VISUM, MATSim) and on user behaviour (e.g., MATSim, SimCo).

Furthermore, traffic planning tools such as VISUM are not agent-based but use structural data for computation of (macroscopic) traffic demand, whereas SUMO, MATSim and SimCo are agent-based to better understand the non-linear dynamics of complex socio-technical systems by taking into account individual decisions of agents at the micro level.

However, as MATSim's interfaces for planning tools show, both worlds can be integrated and thus might profit from each other in order to better understand the sustainable transformation of metropolitan areas.

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Methodologies for Urban Transport Studies

Regine Gerike/Joachim Scheiner

1. Introduction: The Role of Transport in Urban Research

Transport has been an integral precondition and outcome of urban development from the ancient city to modern times. Efficient transport systems are an important success factor for societal development; at the same time, transport causes various negative side effects such as greenhouse gas emissions, air pollution, noise or space consumption. Being mobile is an inherent human need; people want to move; they want to be outside and to participate in social life. The current pandemic situation impressively illustrates this aspect. Even in lockdown periods, the share of persons leaving home at least once a day hardly dropped, whereas substantial changes in travel behaviour occurred in all other dimensions such as the number of trips, mode choice, etc. (Hubrich/Weber/Wittwer/Gerike 2020; Molloy et al. 2021).

The task of (urban) transport planning is to provide access for persons and goods to reach the relevant destinations while at the same time minimising negative side effects of transport demand. Transport research supports this task by investigating transport patterns and their determinants for persons and goods leading to various relevant research streams in urban transport studies:

- Travel behaviour: Profound knowledge on travel behaviour and its determinants is key for successfully modelling and shaping future transport systems. Travel behaviour is mainly analysed based on survey data, including quantitative and qualitative approaches as well as innovative emerging data sources.
- Freight traffic and logistics: These parts of the transport systems are mostly analysed based on quantitative measures of freight flows, firm interactions and logistics chains.
- Transport supply: This is largely analysed based on infrastructure data from Geographic Information Systems (GIS) as well as on data from operators of public transport and further mobility services such as departure frequencies or times. Further relevant data sources include provider data such as the current location of available shared vehicles and transport network mapping.

- Aggregate transport demand: Transport demand *generated* in an area would typically be estimated by travel behaviour surveys. This needs to be distinguished from transport demand *occurring* in an area or on a road link (which may be generated elsewhere), which can be estimated by traffic counts on roads or in public transport. Traffic counts can help validate the results of travel behaviour surveys or parameterise transport simulation models, but also have a strong value on their own.
- Transport simulation modelling: Transport studies have a strong practical value for policy, and one of their benefits is that they provide transport forecasts that are needed to adequately design future transport supply according to policy goals. The development of simulation models has a strong tradition in transport research, and it has reached an extremely sophisticated level in which the 'modelling community' can be characterised as a 'cluster' in its own right. Still, there are strong links to other communities since the results of travel behaviour surveys and traffic counts enter the modelling efforts in various places.
- Traffic safety: There is an equally distinct community of researchers who focus on traffic safety. Again, this research is largely based on quantitative data, often taken from official national, regional or local statistics on traffic accidents that are linked to road network data and sociodemographic information about those involved in accidents.

Transport thus connects people and urban activities and can largely be seen as a derived demand, though in certain ways it tends to have an intrinsic value, specifically in terms of psychological buffering (e.g. between home and work, Ory/Mokhtarian 2005), active physical movement (e.g. strolling, cycling) and symbolic representation (Steg 2005).

Transport demand has grown massively over the past century when mobility has become an inherent dimension of societies (Urry 2000) and economic development has transformed from 'spaces of place' to 'spaces of flows' (Castells 1996; 1998) including immaterial and material flows.

Transport studies have evolved from traffic engineering and economics. Even in 'side disciplines' engaged with transport such as geography, transport was closely linked to economic issues until the 1970s when the study of people's movement emerged in social geography as part of a broader agenda of looking at individual behaviour in time and space, inspired by time geography and other related schools (Carlstein/Parkes/Thrift 1978).

This rootedness of transport studies in engineering and economics has largely shaped their dominating methodologies. These are to a large extent based on the understanding that human behaviour is driven by utility maximisation and, thus, economic reasoning. Yet, these traditional models of individual travel behaviour have failed to date to fully account for the variation in observed behaviour, as can be seen in low rates of variance explanation. Combined with the need to better understand travel behaviour to develop targeted concepts to achieve more sustainability, this has led to the inclusion of the observed individuals' subjective perspectives including their perceptions, attitudes, preferences, subjective well-being and transport rationales (Scheiner/Holz-Rau 2007; Van Acker et al. 2014; Naess 2015). Not least, this development was accompanied by the intrusion of various (formerly 'neighbouring') disciplines into transport studies, including geography, psychology, sociology and others that introduced novel methods, theories and, broadly speaking, ways of understanding transport.

The majority of related studies are still based on the positivist understanding that objective knowledge ('truth') can be extracted from massive empirical observations. This is linked to strong methodological debates on data reliability, validity and representativeness, and advanced statistical methods of analysis. On the other hand, it can clearly be observed that the engagement of formerly 'neighbouring' disciplines in transport has led to radically different methodological understandings.

Firstly, the positivist paradigm has been criticised as being overly empiricist and focused on correlations ('correlationism'), and thus for failing to address the urgent questions of cause-impact relationships that need to be answered in order to target appropriate mechanisms to impact travel demand (Naess 2015). When addressing causality issues, this type of research typically looks at criteria such as statistical association, non-spuriousness and, in recent years, time precedence of the cause, but not the causal mechanisms that are at play (Naess 2015). In other words, some necessary, but not sufficient criteria are addressed. In response to this limitation, Naess (2015) proposes a critical realist position following Bhaskar (2008) to understand causality in terms of tendencies and generative mechanisms. According to this position, the world exists independently of researchers' knowledge and interpretations of it. Thus, there is need to sharply distinguish between the empirical (i.e. what we experience, what we can observe), the actual (i.e. whether events occur in reality or not, irrespective of whether or not we experience them) and the real (which includes what we experience, and the events that actually occur, and the cause-impact relationships that produce the events). This line of thought has generated rich mixed-methods research in which qualitative interviews are used to establish 'causal mechanisms' in terms of peoples' 'transport rationales' that help understand why they act the way they do (Wolday et al. 2019).

Secondly, a perhaps more radical departure from mainstream transport studies doubts that there is such a thing as cause and impact in human action. Rather it argues that cause-impact relationships can be observed in nature, while human action is based on people's reasons for acting (Scheiner 2005). While this point could be seen as being in line with critical realism as outlined above, a more radical reconstructive-interpretative approach claims that someone's mobility can be understood as a social entity that does not necessarily follow linear temporal and cause-impact structures, and that reflects social reality as well as subjective experiences (Rau/Sattlegger 2017). Hence, research should investigate people's memories as oral history that shapes present action (i.e. mobility), rather than questioning the validity of recall data. This approach aims to discover latent, less conscious structures of meaning in mobility (Rau/Sattlegger 2017).

The considerations briefly outlined above target travel behaviour, and this is what a large proportion of transport studies focuses on. It should not be forgotten, however, that there are a number of other key dimensions in transport studies (see above), which each have their own methods that cannot be covered in a single book chapter. Readers are referred to other resources in this respect.

This chapter focuses on quantitative travel behaviour analysis as one core data basis for urban transport studies. We refer readers to Røe (2000) and Goetz et al. (2009) for the discussion of qualitative methods. The following section outlines survey methods and data for investigating travel behaviour. Section 3 gives an overview of emerging new data sources on travel behaviour that increasingly complement the traditional survey data. This is followed by an example of a travel survey analysis taken from a project which was completed a few years ago but can still be seen as typical for recent related research (Section 4). The final section discusses methods, results and limitations and sets the study in context with metropolitan research.

2. Survey Methods and Data on Travel Behaviour

2.1 Diary-Based Travel Surveys as Main Quantitative Data Basis in Transport Studies

Early systematic and large-scale studies in data collection on travel behaviour date back to the 1970s. These were mainly motivated by the emerging mass motorisation and the increasing necessity to limit the negative side effects of motorised transport (Hubrich 2017). Diary-based approaches proved particularly suitable and are to this day the main workhorse for surveying the complex issue of travel for persons and households; they deliver the detailed information on the characteristics of trips, persons and households that is necessary for understanding, modelling and finally purposefully shaping travel behaviour and transport demand. The most serious drawback is that they are typically limited to only one randomly selected day because of the high response burden. This means that individual day-to-day variation in travel cannot be captured.

Fig. 1 shows a typical example of a traditional paper-based travel diary. Each single trip is listed in one column including at least the following information: start and end time, start and end location, main trip purpose, used transport modes, estimated distance. Further variables such as accompanying persons can be added if suitable. All transport modes used are to be ticked for each trip, but no information about the order, distance or duration of the separate trip stages (defined as trip segments that are covered by one specific transport mode) can be inferred. The main mode for each trip is determined based on a hierarchy of modes.

Travel surveys are today a standard tool in transport planning from national to municipal levels. These surveys are available in most metropolitan areas, the TEMS – EPOMM Modal Split Tool (see http://tems.epomm.eu) provides an overview of the modal split (defined as the share of trips per transport modes) in urban areas in Europe and beyond – and thus also on travel surveys as the typical database for generating the modal split.

Travel surveys are also a core data source for research on travel behaviour but are here often complemented by supplementary external data, additional questions or more specific surveys addressing the individual research questions of the study at hand.

Travel does not only mean to move from A to B, it is also an activity which takes time and it might mean physical activity if walking or cycling is involved. Time use surveys are therefore also used in transport studies. These are far more standardised than travel surveys, based on the guidelines for Harmonised European Time Use Surveys (HETUS;

Fig. 1: Excerpt of travel diary (source: Austrian national travel survey 2013/14, translated from German, BMK 2013)

	First trip
When did your trip start?	☐ : ☐ o'clock (Hour, Minute)
What was the purpose of this trip? *Please report only one!*	To work ☐ Business/official ☐ Study/education ☐ Bring/fetch/accompany a person ☐ Shopping ☐ Errands ☐ Private visit ☐ Other leisure ☐ Home ☐ Other, please specify: ☐
Which transport modes did you use? *Please specify if you used multiple transport modes. Please specify also if you walked only a leg or walked the complete trip.*	Walking ☐ Bicycle ☐ Car as driver ☐ Car as passenger ☐ Motorcycle ☐ Citybus/regional bus ☐ Metro/tram ☐ City train/train ☐ Other, please specify: ☐
What was the destination? *Please note the address as acurate as possible. If it is not known, please write down as short description.*	Postal code/city: Address/description:
When did your trip end?	☐ : ☐ o'clock (Hour, Minute)
What was the distance?	appr. ☐ km
Did you have further trips?	Yes ☐ → No ☐

Fig. 2: Excerpt of time-use diary (source: Eurostat 2019)

Time	*What were you doing?* *Record your main activity for each 10-minute period from 07.00 to 10.00!* Only one main activity on each line! Distinguish between travel and the activity that is the reason for travelling.	*What else were you doing?* *Record the most important parallel activity.*	*Did you use a computer, smart device, internet, online tool, or similar technology or device for doing this?* Yes	*Where were you?* *Record the location or the mode of transport.* e.g. at home, at friends' home, at school, at workplace, in restaurant, in shop, on foot, on bicycle, in car, on motorbike, on bus, …	*Were you alone or together with somebody you know?* *Mark "yes" by crossing* Alone (or with unknown persons)	With other household members: Partner	Parent	Children (up to 17 years)	Other household member	Other persons that you know
07:00-07:10	*Woke up the children*		☐	*At home*	☐	☐	☐	☒	☐	☐
07:10-07:20	*Had breakfast*	*Talked with my family*	☐	↓	☐	☒	☐	☒	☐	☐
07:20-07:30	–"–	–"–	☐	↓	☐	☒	☐	☒	☐	☐
07:30-07:40	*Cleared the table*	*Listened to the radio*	☒	↓	☐	☒	☐	☐	☐	☐
07:40-07:50	*Helped the children dress*	*Talked with my children*	☐	↓	☐	☐	☐	☒	☐	☐
07:50-08:00	*Went to the day care centre*	–"–	☐	*On foot*	☐	☐	☐	☒	☐	☐

https://ec.europa.eu/eurostat/web/microdata/time-use-survey). Fig. 2 gives an example of a time use diary based on HETUS standards. These questionnaires collect data on all activities carried out throughout one or more diary days and thus provide valuable background information on the activities carried out at the trip destination. At the same time, important information on trip characteristics is left out such as trip origin and destination. The focus of the questionnaire and also the field work on time use might lead to under-reporting of trips, for example when these are merged with related activities or not reported at all because of the pre-set time-intervals of usually 10 minutes.

Standards for data collection on physical activity are provided by the World Health Organisation (WHO) and increasingly used also in transport studies. The Global Physical Activity Questionnaire (GPAQ) is an established tool for physical activity surveillance, the questionnaires are provided at http://www.who.int/ncds/surveillance/steps/GPAQ/en (see Dons et al. (2015) for a research-based application and adaption of the GPAQ). Data from GPAQ-based surveys is a valuable resource for transport studies as it provides information not only on the duration of walking and cycling for transport in a typical week but also on other forms of physical activity, e.g., at work or for leisure purposes. Major limitations include the lack of spatial information as well as missing data on the detailed walking and cycling episodes and on trips with motorised modes.

Studies with more complex research questions and designs combine the different survey traditions in order to collect comprehensive data on human behaviour including travel, activities, physical activity and possibly also consumer expenditure (see, e.g., Aschauer et al. (2018a) for the Mobility-Activity-Expenditure-Diary (MAED) design). These studies are costly and associated with a high response burden but at the same time, they provide unique information and allow researchers to analyse various different aspects and determinants of travel behaviour jointly.

Travel surveys collect data on reported travel behaviour; these are also called revealed-preference studies. Studies on stated behaviour are another important source in transport research when people are asked about anticipated behaviour and travel choices in possible future scenarios and framework conditions.

2.2 An Alternative to Diaries: Frequent Activities

As outlined in the previous section, trip (or time use) diaries normally capture travel behaviour only for one single day. This means that they cannot be used to detect activity and travel patterns on the individual level, as these patterns may vary strongly from day to day and over time. E.g., a respondent who cycled to work on the diary day is not necessarily a frequent cyclist. Also, diary surveys need very large samples due to substantial variation between individuals, e.g. in distances travelled.

An alternative is to collect information on 'typical' transport modes, trip distances and frequencies for a set of pre-defined activities such as going to work, shopping, attending cultural or sports events, or strolling (Rieser-Schüssler/Axhausen 2014).

This method, sometimes called 'frequent activities' approach, results in typical patterns on the individual level and can easily include rare activities (e.g. going to the opera), but comes at the expense of accuracy, as variation in modes used, distances covered, destinations visited or departure time within an activity class will not be captured. Further, this method requires a carefully defined set of activities. Generally speaking, the broader the categories, the more likely bias will occur. For instance, asking for several types of shopping goods (groceries, clothes etc.) allows respondents to report their behaviour more accurately than just asking for shopping trips in general.

In a reduced form, frequency questions are sometimes included in socioeconomic surveys such as the Mikrozensus or the SOEP (Socio-Economic Panel) in Germany, where information on the trip to work is recorded.

2.3 Evolving Survey Methods

Most travel surveys offer different channels for survey participation. Self-administered mail-back questionnaires and telephone interviews have dominated over many years. These are complemented by online questionnaires which are increasingly used by participants. Personal interviews are carried out in some countries and research projects (Aschauer et al. 2018a).

All these different survey methods are characterised by specific strengths and weaknesses (Hubrich 2017) but suffer generally from trip-underreporting particularly for short and irregular trips and for trips with short durations of the subsequent activity (Aschauer et al. 2018b).

Further challenges to the traditional survey methods are decreasing response rates particularly in register-based samples leading to the increasing use of convenience samples and commercial panels even for national travel surveys such as the Dutch Mobility Panel (Aschauer et al. 2018a).

Technology-based surveys using smartphones or dedicated GPS-devices are increasingly applied in transport studies with mainly non-representative convenience samples and are a promising avenue for future research (see, e.g., Harding 2019; Hubrich et al. 2020; Molloy et al. 2021). Smartphone-based surveys track respondents' trips and activities automatically with the aim to minimise respondent burden while at the same time achieving highest levels of detail and data quality. They allow collecting more comprehensive information than traditional trip diaries, e.g., not only on trips (defined as movements from an origin to a destination where an activity will be finally carried out) but also for trip stages. Smartphone-based surveys also allow to collect data for longer time periods than the traditional one-day diary. This is useful for daily mobility which involves substantial variation over time and particularly also for long-distance travel and rare events. These are not covered reliably in standard travel surveys.

Methods for sampling and surveying in transport studies are interdependent. For example, the combination of convenience sampling or commercial panels with smartphone-based tracking surveys allows for setting up surveys far more quickly than this could be done with traditional survey methods. Molloy et al. (2021) is an example for such a study collecting up-to-date data on travel behaviour in a longitudinal setting.

2.4 Cross-Sectional Versus Longitudinal Data

Travel surveys are with few exceptions cross-sectional surveys with the household being the usual sampling unit (Hubrich 2017). This means that fresh samples report their mobility in each new survey. Continuous surveys are carried out in some countries and studies. These are a special case of cross-sectional surveys that run throughout the year for one or more years.

Respondents in longitudinal panel surveys participate more than once in the same survey or a set of surveys. Longitudinal panels are usually administered with long time intervals between waves (e.g., one year). They often work with rotating samples incorporating a pre-defined refreshment in each new wave. Pseudo-panels are repeated cross-sectional surveys with similar or matched individuals with before-after-studies as the typical application.

Both cross-sectional and longitudinal survey designs have individual strengths and weaknesses. These are listed in Table 1. Many questions in research and practice can be answered based on the far more economical cross-sectional surveys, whereas only longitudinal designs capture the dynamics and processes of inter-individual and, in the case of panels, intra-individual change.

Tab. 1: Strengths and weaknesses of longitudinal panel survey versus cross-sectional survey methods (adapted from Gerike/Gosselin 2015)

Longitudinal panel survey	***Cross-sectional survey***
Strengths	
Allows for analyses of the effects of change in levels of causal factors	Allows for analyses of the effects of differences in levels of causal factors
Provide greater statistical reliability for a given sample size because of multiple observations of the same respondent	Lower response burden, limiting fatigue Larger sample sizes and possibility of higher response rates Representative samples are easier to achieve Data suitable for answering most of the relevant questions in transport research and practice, especially for survey periods of one week or longer
Can provide the basis for a quasi-experimental design for before-and-after evaluation of interventions	Continuous cross-sectional surveys and pseudo-panels can support limited control group strategies for before-and-after analysis of interventions
Data directly usable for observing the effects of unexpected events	Data from continuous cross-sectional surveys and pseudo-panels are directly usable for observing the aggregate effects of unexpected events
Panel ageing can be avoided and attrition reduced by rotating panels	Not subject to ageing or conditioning
Funding for further waves appears easier to obtain because of survey continuity	Funding for a target sample size can be easier to obtain because the per-respondent costs are lower and because of survey continuity for repeated and continuous surveys
Decreasing marginal costs from wave to wave thanks to increased competency and efficiency in survey work	Decreasing marginal costs thanks to increased competency and efficiency in survey work for continuous cross-sectional surveys
Weaknesses	
High response burden, possibility of low response rates, greater selection bias	Limited intra-personal variation but one-week survey periods sufficient for many analyses of intra-personal variation
Recruitment and maintenance of the panel sample is challenging because of high response burden	Limited opportunities to distinguish between inter-personal and intra-personal variation
Small and decreasing sample sizes (in second and following waves) Attritions, fatigue, panel ageing Conditioning (can be also a source of valuable data on learning) Privacy issues (easier to uncover the identity of individuals in panels; patterns of locational data may reveal addresses, etc.)	Questionable assumption of reversibility of effects: e.g. persons who have just sold their car assumed to behave the same as persons who never had a car
Difficulty to change the survey method without creating artefacts	Continuous and repeated surveys: difficulty to change the survey method without creating artefacts

3. Innovative Data Sources for Investigating Travel Behaviour

Various new data sources have emerged in the last years. They open new perspectives and opportunities for investigating travel behaviour and are increasingly used in research and also in practice. Examples for such data sources are smart card transactions in public transport, data from providers of innovative mobility services such as sharing companies, various types of smartphone data, online social media and mobile phone data. Most of this data is "passive data" that is collected without explicitly asking the users any questions (Rieser-Schüssler/Axhausen 2014).

Data from smart card transaction can be distinguished into data that is directly provided by the passengers (e.g., automatic fare collection, Wi-Fi or Bluetooth data from passengers in the system, trip planning logs) and data provided by the transport system (e.g., General Transit Feed Specification (GTFS), automated vehicle location, automatic passenger counting) (Chandresis et al. 2018).

Mobile phone data means passively collected location data from smartphone users (Bonnel et al. 2018). It allows researchers to construct origin-destination matrices including increasingly reliable distinctions between road and rail-based transport. It is mainly applied for investigating long-distance travel, as short-distance trips are hardly detected.

Data from social media is used for recruiting respondents in convenience samples (Hubrich/Weber/Wittwer/Gerike 2020) but also for analysing travel behaviour, e.g., by mapping locations reported in social networks such as Twitter or TripAdvisor. Social networks also open new opportunities for interacting with respondents, e.g., for giving feedback in travel surveys or for asking questions in real-time prompted by triggers such as specific travel situations.

Most of these new data sources are passively collected with the main advantages of large data volumes and high timeliness; the commonly continuous data stream usually provides real-time data. This leads to the need for new techniques in data storage, processing, analysis and visualisation but at the same time opens plenty of opportunities for new research questions and designs. On the other hand, such data do not permit to study individual travel behaviour, and they do not provide any information on social context (e.g., personal and household sociodemographic information, car ownership etc.).

4. Analysis Methods: Residential Preferences, Residential Choice and Travel Behaviour

4.1 Background and Methods

In the past decades, several debates have developed in transport studies that seek to understand how household residential choices are linked to travel behaviour, and how both residential choices and travel behaviour are linked to subjective preferences, attitudes, perceptions, and lifestyles (Scheiner/Holz-Rau 2007; Van Acker et al. 2014). Additionally, the links of all these concepts to people's life situations – as reflected in sociodemographic variables – are discussed intensively, and the debate as a whole is embedded in a long-established discussion on the effects of the built environment on travel behaviour. These debates have contributed substantially to a better understanding of travel behaviour and its links to societal change and housing needs, especially in metropolitan areas where the majority of related studies have been conducted.

There is no space in this section to adequately outline these rich debates comprehensively. Instead, readers are referred to the recent literature (Van Acker et al. 2016). It is important to note, however, that much of the discussion revolves around an adequate understanding of cause-impact relationships between the concepts mentioned above. As these concepts involve multiple angles and dimensions, various sophisticated statistical methods tend to be used to adequately capture associations (Mokhtarian/Cao 2008).

One of these methods is Structural Equation Modelling (SEM). SEM can be described as a combination of factor analysis and a generalised form of regression analysis. Contrary to other multivariate techniques, SEM allows the investigation of multistage interrelations between variables. Unlike regression analysis, SEM is not limited to the analysis of explanatory (exogenous) variables on a single dependent (endogenous) variable. It can deal with several endogenous variables with interdependent relations with one other, as well as the inclusion of intervening variables that are endogenous to some but exogenous to other variables (see Scheiner/Holz-Rau, 2007, for more details). The factor analysis part of SEM consists of measurement models that measure latent (i.e. unmeasured) variables by manifest variables.

There is much debate about the conditions under which the classical Maximum Likelihood (ML) approach can be regarded as superior to non-parametric procedures even when the normality assumption is violated (e.g., Hoogland and Boomsma, 1998). The available sample of about n=2,000 seems well appropriate for a robust application of the ML procedure, even if the sample is split into two halves (see below). The asymptotically distribution-free (ADF) procedure then reaches the limit of reliability but seems to still be acceptable. In the study presented here, a rather rigorous approach was applied. First, the sample was split into two halves by a random procedure. Then each model was estimated in four versions: (1) ML estimation of a theoretical model with the main sample; (2) empirical fitting of the model to the data; (3) ADF estimation of the theoretical model; (4) ML estimation of the theoretical model with the second sample for validation.

Version 2 served to verify the coefficients in the theoretical model version when fitted to the data, while our substantial interest lay in the theoretical models. Each of the four model versions was compared to the others with respect to the strength and sign of the effects. The results for each of the four versions turned out fairly stable and may clearly be interpreted in terms of the sign and strength of the effects. Hence, the results of Version 1 are presented here for two models.

The interpretations are based on direct as well as total effects. Total effects of one variable on another are calculated as the sum of direct and indirect effects, the latter being mediated by intervening variables. Taking total effects into account allows for a more thorough interpretation of interrelations. An example for the calculation can be found in the text below fig. 3. The analyses were undertaken with the programme AMOS 5.0 to 7.0 (Analysis of Moment Structures).

The data used in this chapter were collected in a standardised household survey within the framework of the project StadtLeben[1]. The survey was undertaken in ten study areas in the region of Cologne in 2002 and 2003. 2,691 inhabitants aged 16 and older were recruited based on random route procedure (representing a response rate of 27 percent) and took part in extensive face-to-face interviews.

The analysis is based on the seven (out of ten) study areas surveyed in 2003. The resulting net samples have a value of about n=2,000. The working samples have a size of about n=1,000 due to the split of the sample (see above). The areas range from high-density inner-city quarters of the 19th century to suburban neighbourhoods with detached single family houses at a distance of about 30 km from Cologne.

The theoretical structure of the models, as represented by the arrows in the figures below, are based on a number of assumptions and ideas.

1. Preferences towards certain residential environments (here: proximity to public transport [PT]) depend on the individual life situation, i.e. sociodemographic variables, and car availability.
2. Life situations can be described by a limited number of dimensions ('factors' captured by measurement models). Gender is represented in the models by a single variable, as it does not correlate sufficiently to other sociodemographic variables.
3. Actual residential location choice, represented here by the objectively measured PT quality in the residential neighbourhood, depends on life situation, car availability, and residential preferences.
4. Travel behaviour is a multi-dimensional construct composed of interrelated decisions such as trips made for certain purposes, mode choice, distances travelled, departure times chosen, routes chosen and more. This is represented here by mode use and trip distances covered.
5. Trip distances travelled depend on life situation, car availability, and residential preferences and actual residential location.
6. Modes used depend on the same variables plus distances travelled.

It is important to understand that the analysis takes place on the person level, not the trip level. Thus, trip distances are mean distances travelled for various trips of different purposes. Mode use is the percentage of the mode under study among all trips reported by a respondent. The trips are recorded using the 'frequent activities' approach, i.e. by asking for a broad range of pre-defined activities with 'typical' modes, frequencies and distances, rather than using a trip diary. This means that the trip records are not limited

1 StadtLeben – Integrated approach to lifestyles, residential milieux, space and time for a sustainable concept of mobility and cities (2001–2005). Project partners: RWTH Aachen, Institute for Urban and Transport Planning (coordination); FU Berlin, Institute of Geographical Sciences, Department of Urban Research; Ruhr-University of Bochum, Department of Cognition and Environmental Psychology; Dortmund University of Technology, Department of Transport Planning (see http://www.isb.rwth-aachen.de/stadtleben).

to a single random day, with all the limitations this implies. The downside is that the frequency estimates may be biased, and more 'unusual' modes and distances tend to be hidden.

4.2 Results

There are a number of heuristic indicators to assess the goodness-of-fit of structural equation models. One of these indicators is RMSEA. A rule-of-thumb decision rule is that model fit is adequate if RMSEA<0.05, and RMSEA>0.10 is unsatisfactory. In our case, RMSEA for the car use model is 0,127, and 0,112 for the PT model. However, the model versions 2 (fitted to the data) achieve RMSEA values of 0,035 and 0,043, respectively. 'Fitting' means that model restrictions (e.g., unpermitted associations between variables) are liberated so that the model fits the data better. This is at the expense of theory. As the results we present are virtually equal to those in the fitted versions, we see no reason to dismiss our theoretically justified models.

Now, we turn our attention to the effects found in the models. High social status is associated with markedly longer trips and higher shares of car use *as well as* PT (public transport) use (fig. 3, fig. 4). At the same time, individuals with high social status have lower NMT (non-mororized transport) shares (Scheiner 2010). The effects of social status on travel mode choice are a result of direct effects as well as indirect effects mediated by trip distances and residential location choice. Individuals with high social status tend to locate in central areas with good PT systems. These residential location decisions encourage PT use and counterbalance car use to a certain extent, but without fully offsetting the positive relationship between status and car use.

Women's shorter job trips account for a large part of this difference (models for trip purposes not presented here). Gender does not have much of an impact on travel mode choice. Thus, gender differences seem to be more a matter of activity spaces.

The life situation dimension 'family' is associated with a high mode share of the private car.

This association is mediated by higher car availability, less importance assigned to PT supply, and more remote residential locations in families, while there is no direct effect of 'family' on car use.

The availability of a car strongly increases trip distances and, obviously, car use, but decreases the use of PT. To some extent this is a result of the tendency for car-owners to locate in more peripheral places with lower PT quality, and to have lower preferences for PT.

With respect to the built environment, PT supply corresponds with relatively short trips, which is likely to be an effect of the generally higher urbanity found in neighbourhoods with a good PT system than of the PT system per se. The effect PT has on travel mode choice is even stronger than its effect on trip distances: living at a place with a good PT system leads to more PT use and less car use.

A high subjective preference for PT affects PT use more strongly than the objective quality of the system. Residential self-selection according to travel mode preferences is particularly pronounced in this case.

Last but not least, there is a clear and strong relationship between trip distance and travel mode choice: the longer the trips, the greater both car use and PT use. Firstly, mode choice depends on realised trip distances. These may be affected at best indirectly by urban policy concepts, e.g., by impacting on the monetary or generalised costs of travelling. Secondly, the *necessary* distances to potential destinations – i.e. to opportunities – may be affected directly by land-use planning. It should be encouraging for policy makers and planners that land-use does indeed seem to have a strong independent impact on travel behaviour, irrespective of people's attitudes and social background.

Fig. 3: Model of trip distances and car share – all trip purposes. This and the following figures show the estimated standardised path coefficients and the proportion of explained variance of the endogenous variables, the latter being indicated next to the variable boxes. Significant coefficients (p=0.05) are marked with an asterisk. The rectangles are observed variables, the ovals are latent constructs. The total effect a variable has on another variable is calculated as the sum of direct and indirect effects. For instance, the total effect of 'importance of PT' on 'car trips' equals -0.07 + 0.25-0.20 + 0.25*-0.11*0,20+0,02*0,20 = -0.12.*

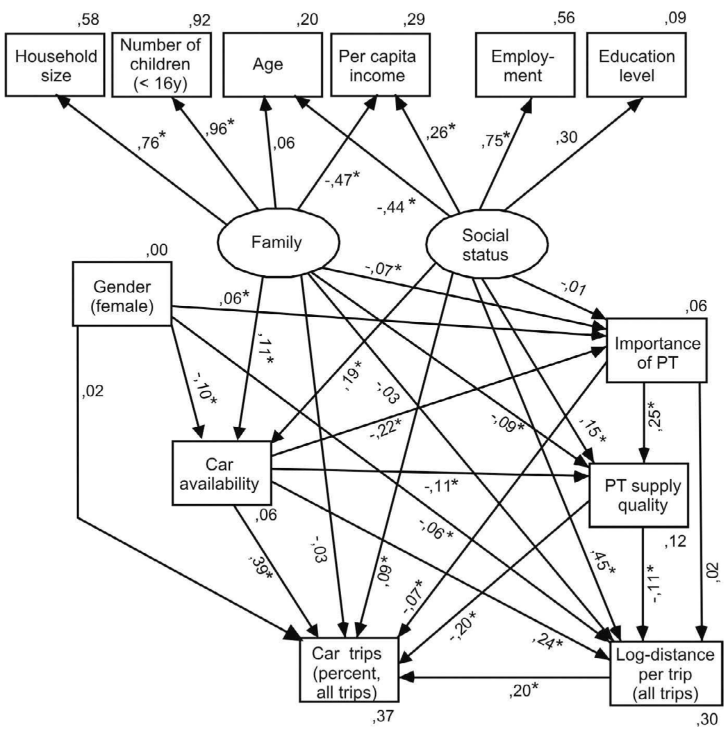
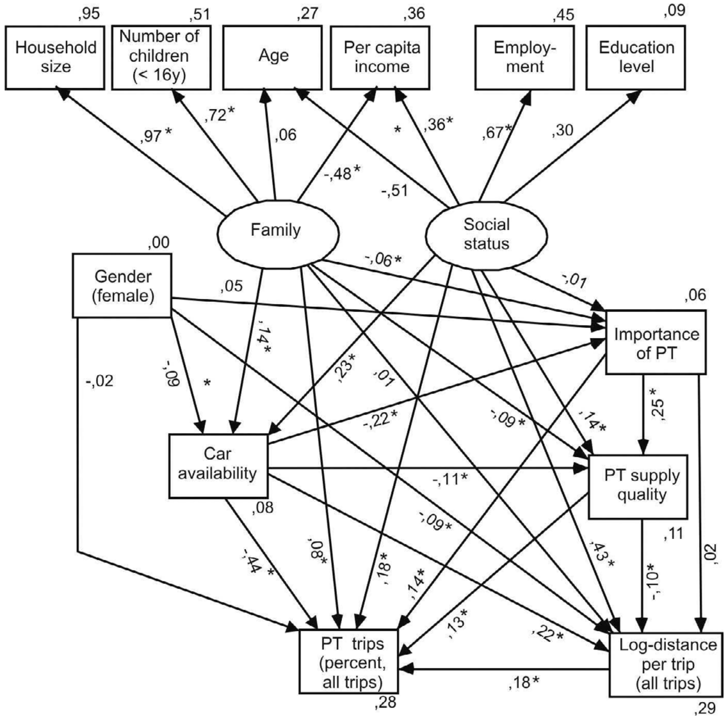


Fig. 4: Model of trip distances and PT share – all trip purposes



5. Conclusions for Metropolitan Research

Transport analysis is an integral part of urban and metropolitan research. Transport is not just physical movement, but reflects economic and social spatial exchange in metropolitan areas and beyond. This is mirrored in the fact that the various activities performed in daily life are an integral part of travel behaviour analysis. Travel behaviour analysis thus serves to better understand what people do, where they go, how they interact with other people, and in which ways and to which extent they are engaged in societal and economic metropolitan life.

The Covid-19 pandemic was accompanied by much substitution of physical transport by virtual communication and activities (e.g., work or shopping), and this amplified trends of substitution and complement that have been observed for decades, as expressed in terms such as the 'city of flows' (Castells 1996; 1998). Still, physical co-presence in time and space and the trips associated with this remain of key importance for economic, social, cultural and psychological well-being.

Our example study shows interdependencies between urban structure, individual life situations and preferences, and transport in terms of trip distances and mode choices. It represents a glimpse at the spatial interrelations in a metropolitan area shaped by social and economic as well as spatial circumstances people live in.

In terms of methods for data analysis, there is a need to clearly reflect the levels on which transport analysis is typically done. The analysis presented here is on the person level. This implies that the link between distance and travel mode is not studied on the trip level but on the level of a person's average trip distances and relative dominance of certain modes. Also, the individual household context of a person is only insufficiently considered by controlling for household income and household type. Actual travel interactions between household members were not included. In recent years there has been much research effort on inter-person interactions in travel, either within households or beyond (Ho/Mulley 2015; Scheiner 2020), and these interactions are clearly a fruitful field for metropolitan studies. Also, multiple dimensions of the urban environment remained unconsidered, such as density and land-use at sites other than the residence, e.g., at the workplace. Finally, although respondents' subjective preferences have been captured by standardised scales, this only poorly reflects their own perspectives and reasonings, but rather the researchers' theoretical assumptions about statistical associations.

In terms of data on travel behaviour, we have found a long tradition going back to the 1970s. Methods for data collection in travel surveys have evolved over time from mostly paper-and-pencil surveys to mixed-mode approaches including increasing shares of online interviews and smartphone-based tracking of respondents' behaviour. Early data is less rich and comprehensive than the more recent one but still, the harmonisation of historical datasets from different time periods up to today holds a great potential for research on travel behaviour.

Various emerging new data sources open completely new perspectives and opportunities for understanding travel behaviour mainly because of their scope and timeliness. They lead to the need to develop new methods for data processing, analysis and visualisation. Privacy issues are a major concern and also the transparency and reliability of the often commercial data.

What is more, recent qualitative research in transportation (Rau/Sattlegger 2017) provides promising avenues for future research that has hardly been touched upon in this chapter.

An important task is to combine the different data sources for each planning task or transport study anew in a way that the respective research questions can be answered comprehensively. New data sources and techniques of analysis also open new opportunities for advancing transport models.

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III Metropolitan Resilience, Sustainability, and Health

Disaster Risk and Climate Impact Research

Stefan Greiving

1. Introduction

Risk is defined in its broadest sense as "the combination of the probability of an event and its negative consequences" (UN ISDR 2009). Spatial planning comes into play, because it takes decisions for society on whether and how space is used (Greiving 2002).

Concepts for assessing risk from a spatial perspective were first developed by geographers in the 1970s (Hewitt 1971). This was first dominated by a focus on mapping hazards ('hazards of place') and risks. However, as Cutter (1996) noted, further methodological elaborations on this subject were only rarely attempted until the mid-1990s. It is due to authors like Burby (1998) or Godschalk et al. (1999) that the important role of land-use planning, and how it plays out in the whole disaster management cycle, was highlighted.

There is also an ongoing discussion on transformative resilience focusing on a system's capacity to adapt or transform in the face of emerging multi-risks to support sustainability (Pelling 2011; Biggs et al. 2015). For its application in the practice of disaster management and urban sustainability, building resilience for reducing vulnerability needs flexibility, learning and change (Adger et al. 2005) as well as a participatory and inclusive approach allowing vulnerable individuals and groups to play an active role in determining how best to avoid hazards and build capacity and, ultimately, just cities (Sarabia et al. 2020). These theoretical discussions on sustainability and resilience clearly underline the importance of community-based strategies which are tailor-made to specific legal and cultural contexts.

Spatial planning is asked to coordinate different demands on space with one another and conflicts arising at the respective planning levels are to be balanced out. This calls for a multi-risk perspective which considers all spatially relevant hazards, but also the specific vulnerability of various land-use classes, infrastructures and social groups (Greiving 2011).

Decision-making on tolerating or altering risks requires a sound evidence basis in terms of a multi-risk assessment which determines the total risk from several hazards either occurring at the same time or shortly following each other. They may be dependent from one another or caused by the same triggering event or hazard; or merely threatening the same elements at risk (vulnerable/exposed elements) without chronological coincidence (EC 2010). In contrast to the well-established assessment of single hazards and risks, this kind of assessment looks at the interdependencies of the occurring hazards and requires a consideration of cascading effects, even outside the exposed area. Coinciding hazards can result in cumulative and cascading effects, meaning that one hazard can follow up with subsequent hazards with bigger impacts and, in total, accumulate negative effects. However, multi-risk perspectives are not systematically addressed among disaster risk management approaches and single-hazard maps are still the decision support tool most often used (Poljanšek et al. 2017). Challenges of assessing multi-risks occur because of the interdependencies of sectors and related communication channels, and require multi-risk governance (Renn 2008; Scolobig et al. 2014).

However, the impacts of extreme events are not solely determined by a given place-based hazard and vulnerability profile, but considerably influenced by cascading effects caused by the service disruptions of critical infrastructures (CI), which may even take place outside the exposed areas (Pescaroli/Alexander 2016). For example, the current Covid-19 pandemic is costing between 8.1 and 15.8 trillion USD globally, primarily because of disrupted global supply chains (World Economic Forum 2020).

The European Union defines critical infrastructure as "assets or systems, essential for the maintenance of vital social functions, health, safety, security and economic or social wellbeing of people" (see Art. 2, Council Directive 2008/114/EC). This directive determined the following criteria for criticality (see Art. 3 § 2), but does not provide a methodology for assessing criticality holistically:

- Causalities criterion: assessed in terms of the potential number of fatalities or injuries;
- Economic effects criterion: assessed in terms of the significance of economic loss and/or degradation of products or services; including potential environmental effects;
- Public effects criterion: assessed in terms of the impact on public confidence, physical suffering and disruption of daily life; including the loss of essential services.

However, negative consequences caused by hazards of any kind are typically assessed through an examination of vulnerability. Established disaster risk concepts cannot address the systemic criticality of CI systems and subsystems (Hellström 2007). Moreover, risk and vulnerability are place-based concepts, but the CI systems are of functional character. Consequently, the systemic focus of criticality runs counter to the areal-oriented view of spatial planning, which is primarily asked to place key infrastructure elements outside exposed areas (Greiving et al. 2016). In addition to a multi-risk assessment and its output, a parallel string, the assessment of criticality, is needed.

Multi-risk assessment and management is an issue in the Sendai Framework for Disaster Risk Reduction, which propagates disaster risk reduction practices "to be multi-hazard and multi-sectoral, inclusive and accessible in order to be efficient and effective" (UNISDR 2015:10). The New Urban Agenda (UN 2017) vows to "commit ourselves to strengthening the resilience of cities and human settlements, including through the development of quality infrastructure and spatial planning […], especially in risk-prone areas of formal and informal settlements." Sustainable Development Goal 11 points at "a significant reducing of the number of deaths and the number of people affected and substantial decrease of the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations."

In principle, there are a couple of explicit relationships between several targets of the SDGs and the Sendai Framework, namely SDGs 1, 11 and 13: eradication of poverty, resilient and sustainable cities, and action to climate change, as shown by fig. 1.

Fig. 1: Sendai Framework and the 2030 Agenda (UN-ISDR 2019)

For these communalities, a joint monitoring scheme has been adopted by the UN (UNISDR 2019).

The climate has always been changing as a result of changes in various factors such as solar activity, the earth's orbit around the sun, the atmospheric composition and large volcanic activities (EEA 2017). The extent and impact of human influence on today's and the future's climate system has become evident as recent anthropogenic emissions of greenhouse gases have reached the highest level in human history. Consequently, recent climate changes have already had widespread impacts on human and natural systems and will have even more severe impacts in the future (IPCC 2014).

In contrast to climate protection, which requires global action, climate adaptation is primarily a local to regional task due to the specific, territorially diverse impacts of climate change on a small scale (EEA 2013). Cities are not only particularly affected by climate change, but urban development also plays a decisive role, as it is responsible for the control of many fields of action affected by climate change, such as settlement, open space and transport development, but also human health (Deutscher Städtetag 2012). Spatial planning is of central importance for the reduction of vulnerability as well as the targeted development of climate protection and adaptation capacities against the impacts of climate change (Stern 2006; IPCC 2014). The German Adaptation Strategy (DAS, Federal Government 2008: 42) also emphasizes: "Spatial, regional and urban land-use planning are at the beginning of the risk prevention chain, as they develop spatial precautionary concepts, the planning documents are of long duration and legally binding, and there are sometimes long lead times before the plan contents can be implemented in practice". In this context, climate adaptation is to be seen as an integrated component of urban development that also keeps an eye on interactions (synergies and conflicts) with other challenges such as climate protection or demographic change (Greiving/Fleischhauer 2012).

There is a need for better informed decision-making in addressing these impacts amidst a changing and uncertain environment (EC 2013. The extent and territorial patterns of these impacts cannot be precisely predicted due to uncertainty with regard to further greenhouse gas emissions, which depend on demographic, socio-economic and technological development. Moreover, there is always an enormous bandwidth of potential future local socio-economic conditions. Addressing the deep uncertainty of the future status of both climate and society calls for flexible, resilient adaptation strategies (Walker/Haasnoot/Kwakkel 2013). But also the implementation of global, national and local mitigation policies in the future is uncertain (EEA 2012). In general, "uncertainties about future climate change are smaller for changes in temperature than for precipitation and other climate variables, for changes at global and continental scales than at regional scale, and for changes in mean climate than for extreme events" (EEA 2017, 54).

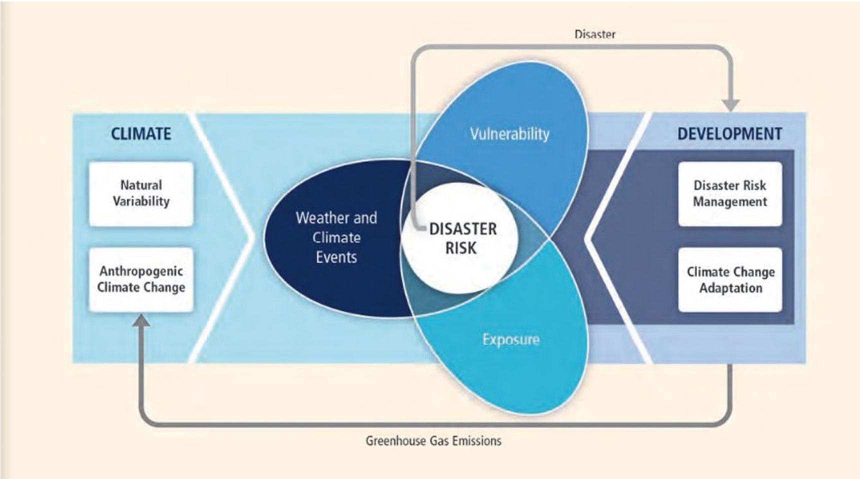
There are connections between climate change on the one hand and hydro-meteorological extreme events on the other hand. The combined impacts of projected climate change and socio-economic developments (e.g., in floodplains) that trigger vulnerability and exposure lead to higher damage costs (EEA 2017). Disaster risk management can therefore contribute to climate change adaptation. Thus, both fields of action need to be coordinated (Field et al. 2012; Costa/Kropp 2012; EC 2021), see also fig. 2:

Nonetheless, the scope of adaptation to climate change goes beyond dealing with extreme events and addresses also creeping changes in temperature and precipitation and related impacts on the society and the environment. Moreover, several hazards which are hardly or not at all influenced by climate change such as volcanic eruptions or earthquakes are to be considered by disaster risk management. Consequently, the related assessment frameworks fundamentally differ. (Probabilistic) disaster risk assessments are based on statistics from past events, whereas the assessment of potential future impacts of climate change requires a prospective, scenario-based approach (Greiving 2019). Consequently, this paper addresses disaster risk and climate impact assessment methodologies separately.

2. Assessment Methodologies

In planning and decision-making processes, evaluation and decision-making phases are often interwoven. Nevertheless, the level at which facts are determined for the subsequent decision must be separated from the process level at which these facts are eval-

Fig. 2: Climate change and disaster risk. Source: Field et al. (2012)



uated and decisions are made by politically legitimized representatives. Defined goals serve here as a normative basis for the evaluation of the determined facts.

Assessment and evaluation methods generally serve to structure the complex evaluation process in terms of both form and content (Scholles 2005). Accordingly, they consist of a factual model, a target system as well as allocation and aggregation rules. They can also reduce the complexity of the factual level and focus the political decision-making problem on those questions that are to be assigned to the (political) value level and clarified in the target system. There is no one-size-fits-all evaluation method, but only more or less appropriate procedures, whereby the appropriateness can only be judged in the individual case and the given framework conditions. It is undisputed that the chosen methodological approach must be consistent in itself (Faßbender 2012).

Risk can be presented in a number of different ways, depending on the objectives of the risk assessment. It can be expressed in absolute or relative terms. Absolute population risk can be shown as individual risk or as societal risk (the relation between the annual probability and the number of fatalities). Absolute economic risk can be presented in terms of average annual losses or maximum probable loss, each with a relation between frequency and expected monetary losses.

In any case, a differentiation is needed between direct risk (which is the risk directly resulting from the impact of the hazard) and indirect risk (which may occur later as a consequence of the direct impact due to cascading effects). Examples of indirect losses are loss of revenues and economic production, disruption of transportation networks leading to longer travel time etc. Significant components of losses are intangibles (difficult or impossible to quantify), for example the societal or psychological impacts of disasters.

Risk assessment as such is a process to determine the probability of losses by analysing potential hazards and evaluating existing conditions of vulnerability that could pose a threat or harm to property, people, livelihoods and the environment on which they depend. DIN ISO 31000 (2018) defines risk assessment as a process made up of three steps:

- Risk identification is the process that is used to find, recognize, and describe the risks that could affect the achievement of objectives.
- Risk analysis is the process that is used to understand the nature, sources, and causes of the risks that have been identified and to estimate the level of risk. It is also used to study impacts and consequences and to examine the controls that currently exist.
- Risk evaluation is the process that is used to compare risk analysis results with risk criteria in order to determine whether or not a specified level of risk is acceptable or tolerable.

The process can be carried out at a number of scales and for different purposes.

2.1 Probabilistic Approaches

Probabilistic approaches are based on a quantification of the risk caused by a certain hazard. In this quantification, the probability of occurrence of one or all conceivable damaging events is first determined. Furthermore, the effects and the extent of such events are quantified. The risk is the product of the probability of occurrence and the extent of the impact. If the risk is determined via the integral of all conceivable or observed frequency-magnitude relationships, damage functions can be derived in this way, which can also be expressed as annualized quantities or "annualized average losses".

These damage functions are then suitable for a cost-benefit analysis of protective measures, whereby the protection in the sense of a reduction of the damage expectation values is considered on the benefit side and the efforts to plan, construct and operate the protective structure matter on the cost side.

Another characteristic of the probabilistic approach is that the risk analysis is to be carried out repeatedly. This is the case, for example, if changes in the environment (for example, settlement density) lead to changes in vulnerability, even if the probability of occurrence has not changed.

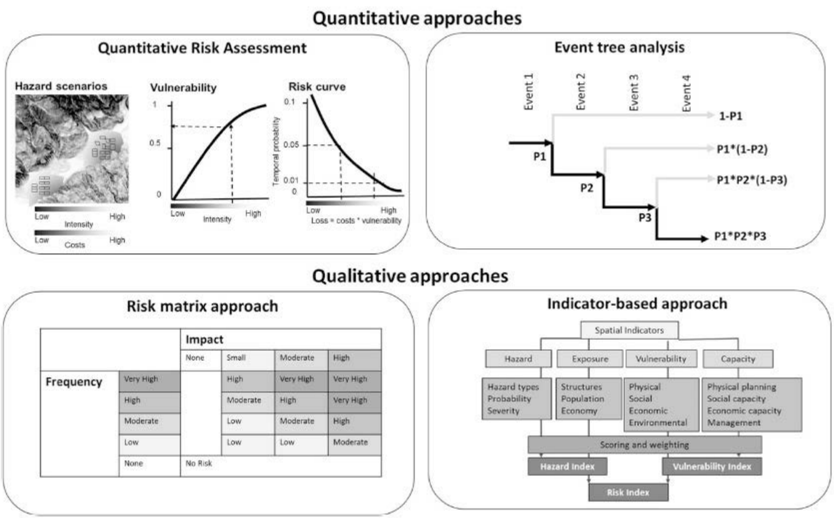
In a probabilistic risk analysis, the weight of the concern results from the combination of the probability of occurrence and the consequence of certain events. The scope for consideration then consists of whether a (probabilistically) determinable risk should be accepted because other concerns are given priority, or whether this is not to be accepted. In the latter case, the planning justification must transparently explain in detail which technical data and forecasts were used and for what reasons. Deterministic approaches (see section 2.2) do not know such a scope of consideration.

The planning authority must not be content with a schematic and abstract assessment. Rather, the assessments and forecasts must be plausible on the basis of the empirical material required in each case. For this purpose, a methodological approach of the relevant risk analysis must be explained and adopted by the planning authority. The determination of the factual basis and the consistency of the methodological approach is of great importance for the legality of the planning consideration, which is based on this methodology.

Within probabilistic approaches, a distinction can be made between quantitative and qualitative risk analyses (see fig. 3):

- Quantitative risk assessment (QRA), Event-tree analysis (ETA), Risk matrix approach (RMA) and Indicator-based approach (IBA).
- Quantitative approaches can be used for deriving CBA as basis for the judgement of mitigation measures, but disregard intangible elements of risk.
- Qualitative approaches are highly scale-dependent and express only relative ratios between different areas of investigation.

Fig. 3: Risk assessment approaches. Source: van Westen/Greiving (2017)



Quantitative approaches are established as a basis for the economic efficiency of protective measures and are used to calculate premiums in the insurance industry, but they cannot capture intangible factors. While quantitative risk assessments are established above all for natural hazards, for which corresponding time series from past events are available, (rare) technical incidents are usually investigated using so-called event-tree analyses, since there is a lack of comparable cases. In this case, all conceivable accident sequences are examined and the risk is determined by summing up all individual effect chains.

Qualitative approaches are scale-dependent and only express relative ratios between the units of a study area. However, min-max normalizations can be used to transfer indicators to a harmonized scale and thus also capture intangible factors.

The risk matrix approach is used, for example, by the BBK (German Federal Office of Civil Protection and Disaster Assistance) for risk analyses in population protection (BBK 2010) and sometimes adapted for spatial planning purposes (Greiving et al. 2016).

Indicator-based approaches are mainly applied at the global or European level (Schmidt-Thomé/Greiving 2013). Due to the size of the study areas, proxy indicators are used in an attempt to determine a given risk measure or to make study units such as nation-states or counties comparable with each other, whereby the selection of indicators and weighting factors for each indicator considerably determines the overall result.

2.2 Deterministic Approaches

In deterministic approaches, decisions are not based on an explicitly calculated risk, but on a set of design cases. Coastal flood defence structures in Germany are designed for a reference case which is derived from the highest observed sea level in history (for the North Sea, this is the storm surge that hit Germany in 1976, for the Baltic Sea the 1872 event), but not linked to a certain return period. In fluvial flood protection, this form of rule-based action is found in Art. 78 § 1 No. 1 Federal Water Act (WHG): "In designated floodplains, the designation of new building areas in urban land-use plans or in other statutes according to the Building Code is prohibited." This rule applies regardless of the level of the existing flood risk within the floodplain (new buildings are prohibited) or (in the case of extreme floods or dike breaches) outside of floodplains where all developments – even of specifically dangerous facilities or critical infrastructures are allowed. Defined safety standards for locations where dangerous substances are stored or processes are based on a deterministically chosen major accident design case which lacks a certain return period (see Art. 4 directive 2012/18/EU on the control of major-accident hazards involving dangerous substances in accordance with Art. 50 Federal Immission Protection Act [BImSchG]).

Deterministic approaches are common for conditional-programmed law-making via rule-bound decisions. Conditional programming can be defined as the rule-based assignment of facts to normative factual prerequisites from which a certain legal consequence inevitably results (for example, the entitlement to an operating permit if safety standards are met). A rule is a prohibition or requirement that comes into effect if a condition contained in the rule is met. If two rules conflict, exceptions must be made or a rule must be declared invalid. Rules are to be understood as the result of a compromise decision between conflicting principles that has already been made by the norm maker (e.g., federal legislator) and is binding for the norm user (e.g., a lower water authority). If rules exist for a certain issue, they must be followed. In weighting-up processes, these rules can be found as so-called planning principles or target binding clauses (e.g., the obligation to adapt to the objectives of regional planning according to Art 1 § 4 Federal Building Code (BauGB). In this context, these rules represent mandatory legal regulations that control public planning, i.e. also urban land-use planning, by ordering their strict observance.

2.3 Scenario-Based Approaches

Climate change itself, but in particular its regional and local impacts are characterised by deep uncertainties (van Asselt 2005; Walker et al. 2013; Reckien et al. 2014). Data from past events which inform probabilistic approaches are not representative anymore in view of the changing framework conditions.

The uncertainties about future climate change impacts require a scenario-based, so-called "parallel modelling approach".[1] This means that demographic and socio-economic changes are projected in parallel to the changes of the climatic system in order to assess the future impacts of climate change on a future society. This is not only relevant on the global level as a basis for emission scenarios, but also on the regional and local levels in order derive tailor-made adaptation strategies (van Ruijven et al. 2014; Greiving et al. 2018). In this context, the assessment should be based on a scenario combination of climatic scenarios derived from an ensemble of climatic models and socio-economic scenarios in order to reflect the bandwidth of potential future conditions (see fig. 4).

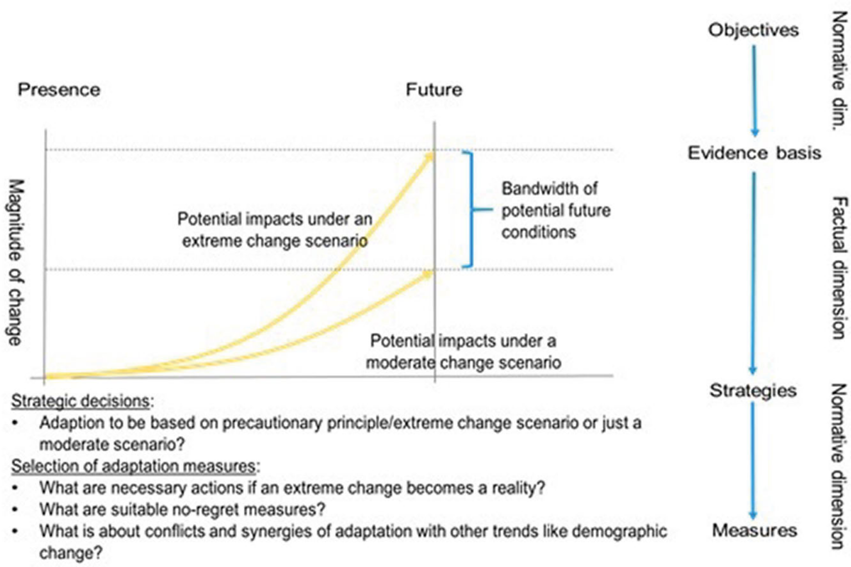
The recent amendment of the Environmental Impact Assessment Directive (2014/52/EU) underlines the need for a parallel modelling approach by stating: "Climate change will continue to cause damage to the environment and compromise economic development. In this regard, it is appropriate to assess the impact of projects on climate (for example greenhouse gas emissions) and their vulnerability to climate change" (EC 2014). Consequently, a so called "evolving baseline trend" (of both climate and society) has to be taken into account when assessing the effects of a plan or project on the environment (EEA 2013). A similar reference is still missing in the Strategic Environmental Directive (2001/42/EC), although the DG Environment argued for an inclusion of climate change (EC DG Environment 2013).

The change of the sensitivity (i.e. demographic change, economic change and change in land-use patterns) may determine – at least for rapidly growing or shrinking urban environments – the extent of climate- and weather-related impacts in the near future more significantly than the changing climate (temperature and precipitation mainly) itself (Greiving et al. 2018). Due to this fact, for each time slice (present and future), a potential impact needs to be determined using either only recent monitoring data or only projections (for both, changes in the climate and the socio-economic changes are taken into account). In doing so, the dynamics of climate change impacts can be determined.

Adaptive capacity is left out of the climate impact assessment framework. That is particularly relevant because adaptive capacity by definition only relates to the future,

1 The "parallel modelling approach" was introduced in IPCC AR5 (IPCC 2014) with the parallel approach of the "Representative Concentration Pathways". As succinctly described by van Vuuren et al. (2011) "Socio-economic and emission scenarios are used in parallel to provide plausible descriptions of how the future may evolve with respect to a range of variables including socio-economic change, technological change, energy and land use, and emissions of greenhouse gases and air pollutants. They are used as input for climate model runs" (van Vuuren et al. 2011, 6). This (global) parallel modelling approach was further elaborated with stress placed on local and regional levels (and land use at these levels) as a basis for assessment of possible local and regional climate impacts by van Ruijven et al. (2014) and Greiving et al. (2015).

Fig. 4: The parallel modelling approach. Source: Greiving et al. (2018)



i.e. to the possibility of implementing additional adaptation measures. The climate impact assessment approach presented here aims at creating a sound evidence basis for decisions on adaptation to climate change. Taking potential adaptation measures into account already during the assessment phase would definitely weaken the awareness and willingness of decision-makers to give priority to adaption against other conflicting social or economic interests.

A central question within the parallel modelling approach is how to address the uncertainty of future developments. In the approach presented here, the inherent uncertainty of climatic models is taken into account by using an ensemble which considers several global and regional models, as well as socio-economic emission scenarios. Two ensemble members are used in parallel for each climatic stimulus (e.g., the 15th and 85th percentiles of all ensemble members).

The uncertainty related to future socio-economic conditions should be taken into consideration by using different sensitivity scenarios (represented by the key variables changes in demography and land-use). This means, in case of population data, to pick different population scenarios and build an ensemble of these and subsequently build percentiles (e.g., the 15th and 85th). However, the specific availability of different sensitivity scenarios has to be checked case-by-case. This method seems to be appropriate in case of a high uncertainty. In contrast, there might be cases where the specific development of the future sensitivity can be quite certain. If so, it may be applicable to include only one (realistic) sensitivity scenario for representing the future (e.g., if the sensitivity remains stable or the development is well-known). However, a key component of this approach is to base decisions on scenario combinations of climate change and changes in the sensitivity instead of just a change of the climatic system. That is also why fig. 4 shows a bandwidth of potential future conditions that is fed by both trends.

Nevertheless, normative questions remain: On which scenario combination should an adaptation strategy and subsequently the adaptation measures be based? A combination of rapid land-use change under extreme climate change or a more moderate one? The role of science in this context is problematic because science cannot give a proof of future climate impacts in view of given uncertainty. Science in this context is inconclusive (van Asselt 2005). Hereby, justification of actions and consensus about thresholds for acceptable risks and response actions becomes more important (Fleischhauer et al. 2012; Walker/Tweed/Whittle 2014).

3. Applications in Spatial Planning

3.1 Probabilistic Flood Risk Assessment

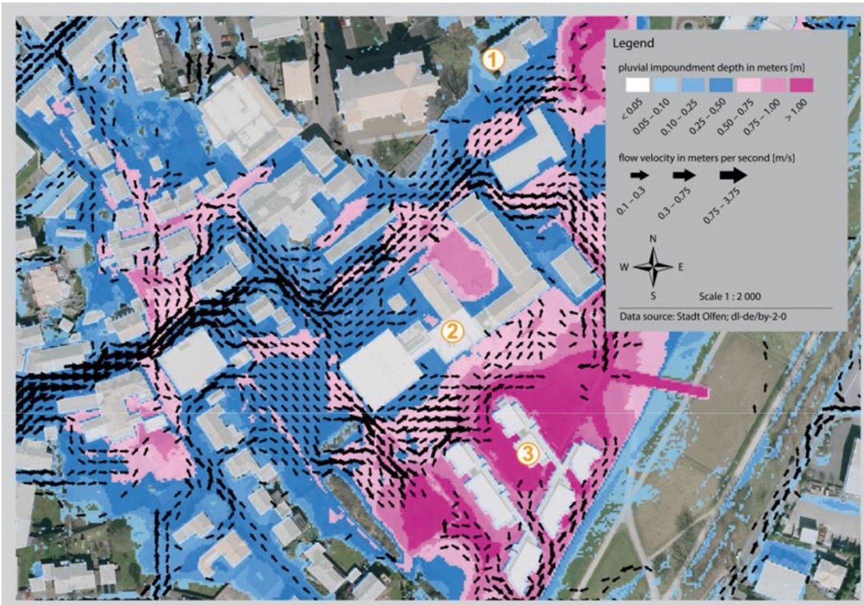
Pluvial flooding as local phenomenon is not classified as flooding by the Federal Water Act (WHG). This understanding is in line with Art. 2 § 1 Floods Directive 2007/60/EC ("may exclude floods from sewerage systems"). Instead, the WHG addresses pluvial flooding in section 2, which is on sewage water treatment (Art. 54 No. 2 WHG). Consequently, the responsibilities for pluvial flood risk assessment and management are up to the municipalities as responsible public bodies for sewage water treatment (see Art. 56 WHG).

Priority zone flood protectionState-of-the-art probabilistic pluvial flood hazard assessments are two-dimensional (2D) surface run-off calculations with hydrodynamic models (LAWA 2018, Othmer/Becker/Schulte/Greiving 2020). In most cases, such kind of assessments are provided by expert statements of consultancy companies on behalf of municipalities. The German Met Office (*Deutscher Wetterdienst, DWD*) offers statistical data on extreme rainfall events of different durations and return periods on a grid cell basis (8 x 8 km) for the entire country. This information is based on the reference period 1951 to 2010 and does not consider potential impacts of future climate change on precipitation patterns (DWD 2020). For this purpose, the German Association for Water, Wastewater and Waste (DWA) developed area-specific "Enhancement Factors" which serve as multiplier of the statistical data on past rainfall events (Schmitt et al. 2018).

The following fig. 5 shows an exemplary hazard map (scale 1/2000) for the City of Olfen, based on a rainfall event of 90 l/m² and a duration of 60 min (return period 100 years).

The hazard map is typically overlaid with information on land-use and infrastructures in order to determine a pluvial flood risk. Clearly visible are the water streams and inundation depth (partly more than 1 m in built-up areas). In some cases, the water streams follow former creeks which were covered by settlements or infrastructures. The numbers 1-3 indicate exposed infrastructures at risk (1= town hall, 2 = elementary school, 3= retirement home). Municipalities are asked to consider pluvial flood risks within land-use planning and sewage water treatment.

Fig. 5: Pluvial flood hazard map (Source: Othmer et al. 2020, 11)



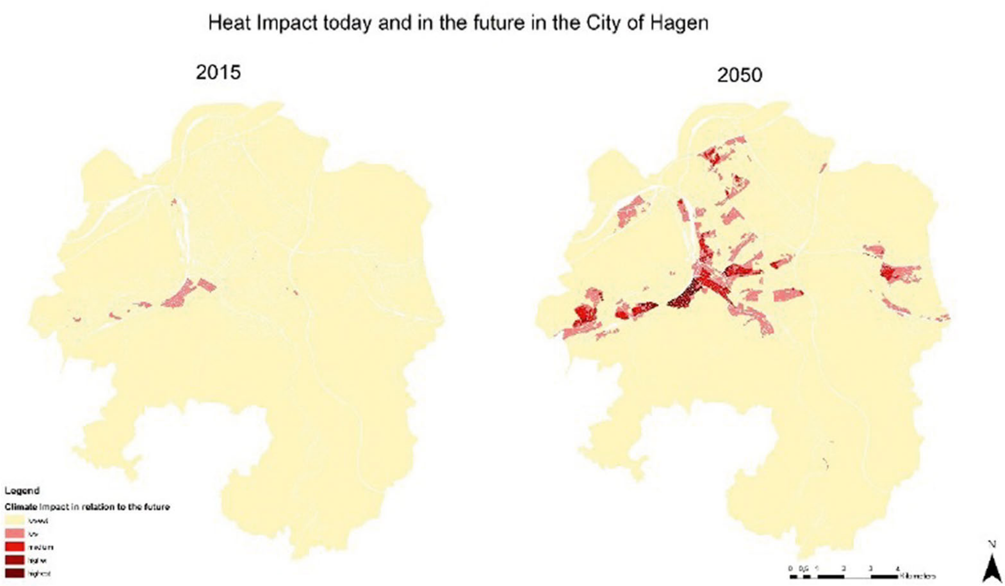
3.2 Scenario-Based Climate Impact Assessment

The project InKlaH (Integrated adaptation concept for the City of Hagen) aimed at an integrated adaptation strategy to climate change and demographic change for the City of Hagen. It is intended to mainstream adaptation by coordinating actions like mitigation of urban heat and flood risk management strategies with land-use and landscape planning of the City of Hagen. This strategy was informed by an impact assessment that followed the parallel modelling approach.

For the analysis of urban heat, a holistic approach was applied in order to estimate the impact on human health from both, climatic and demographic change. For projecting the influence of climate change on the urban climate, the change in the number of heat days (more than 30 °C) and tropical nights (more than 20 °C) was projected. In this context, known potential changes in the settlements structure (depicted from political debates) were taken into account for calculating the future urban climate by means of the urban climate model ENVIMET (Bruse and Fleer 1998). Basis of the sensitivity analysis was the number and the change in the number of people in the age groups younger than 6 and older than 65 years between 2015 and 2050. Additionally, the working population was considered since especially the day time heat island effect will most likely increase in the future and may lead, e.g., to a lower productivity (Greiving et al. 2016).

Fig. 6 shows the change of the impact of urban heat on human health. It is based on a composite index that merges heat days/tropical nights (equally weighted) with the number and density of the population per city quarter (age groups were differently weighted in accordance with their sensitivity to heat stress). The heat-related impact was calculated for the present and the future. The values were normalised (0–1) over both time slices in order to visualise the change of the impact over time. It becomes clear that tomorrow's impact on human health in suburban residential areas will be more serious than it is today in the densely populated city centre.

Fig. 6: Temporal change of the heat island effect in the City of Hagen (Source: Greiving et al. 2018)



4. Perspectives and Access Points

Art. 3 § 2 Directive 2014/52/EU on the assessment of the effects of certain public and private projects on the environment points at the importance of "expected effects deriving from the vulnerability of the project to risks of major accidents and/or disasters that are relevant to the project concerned." The directive was implemented into national German planning law by Art. 1 § 6 No. 7 j) Federal Building Code (BauGB) and annex I § 2 ee) BauGB. The same applies for "the impact of the proposed projects on the climate (for example, the nature and extent of greenhouse gas emissions) and the vulnerability of the proposed projects to the impacts of climate change." [Annex I § 2 gg] BauGB). These legal regulations underline the need for risk and climate impact assessments as part of environmental assessments. Consequently, all planning authorities are obliged to consider disaster risks and impacts of climate change when setting up spatial plans or programs.

However, Art 5 § 2 Strategic Environmental Assessment Directive (2001/42/EC) states:

> The environmental report […] shall include the information that may reasonably be required taking into account […] the contents and level of detail in the plan or programme, its stage in the decision-making process and the extent to which certain matters are more appropriately assessed at different levels in that process in order to avoid duplication of the assessment.

Different spatial scales require adjusted methods for both, disaster risk and climate impact assessment. On the national and regional levels, risk index or indicator-based approaches are suitable for the identification of hot-spots. For large-scaled climate impact assessments, grid-cell-based land-use models informed by demographic projections are the appropriate way to assess a changing sensitivity due to a lack of detailed knowledge on potential local land-use changes.

For local risk assessment, a probabilistic approach which is driven by damage models is recommendable in order to determine a given risk. By doing so, appropriate risk reduction measures can be economically judged and land-use plans adequately adjusted.

For local climate impact assessments, modelling is equally important, but must consider fine-grained demographic data including information on age groups, social milieus, data which allows a more precise assessment of the changing sensitivity. Moreover, reliable scenarios for local land-use change can be created based on reasonable alternatives of further settlement expansion or urban renewal. These scenarios enable an iterative process between urban climatic modellers and urban developers. In doing so, planning alternatives can be derived that are optimized to the potential future status of the climate. That is exactly what Directive 2001/42/EC requires when asking for these "reasonable alternatives" (see Art. 5 § 1) but what has rarely been done in planning practice.

Generally speaking, the quality of assessment depends – apart from the chosen methods – on the quality of the input data. An enormous challenge in this regard is the lack of available and reliable demographic data – and subsequently land-use data – for the remote future. There is definitely a need for future research in this respect. Another limiting factor is the deep uncertainty concerning the future potential change of the local patterns of extreme events such as urban flooding. Here, the available data from regional climatic models is not sufficient as it offers for instance just the 98th percentile data for daily rainfall, which does not represent real extreme events, but needs to be replaced by deterministically chosen enhancement factors (Schmitt et al. 2018).

It was shown that spatial planning is asked to consider both disaster risk and climate change for decisions on urban and regional development. The necessary evidence basis requires a set of methodological tools. Here, GIS-based modelling of today's and tomorrow's potential characteristics of hazard and vulnerability patterns is a key component. However, qualitative methods such as needs assessments, interviews and participatory approaches are of equal relevance. Normative decisions are needed for determining the framework conditions for scenarios and selecting reasonable alternatives, but also for decisions about tolerating or altering risks. Thus, risk management and adaptation to climate change need to be organised in a collaborative way which takes the knowledge, but also the concerns of the addressees into full account – from the early beginning of the problem framing and the assessment phase to the selection of risk reduction and adaptation measures.

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Volunteered Geographic Information for Sustainable Urban Development

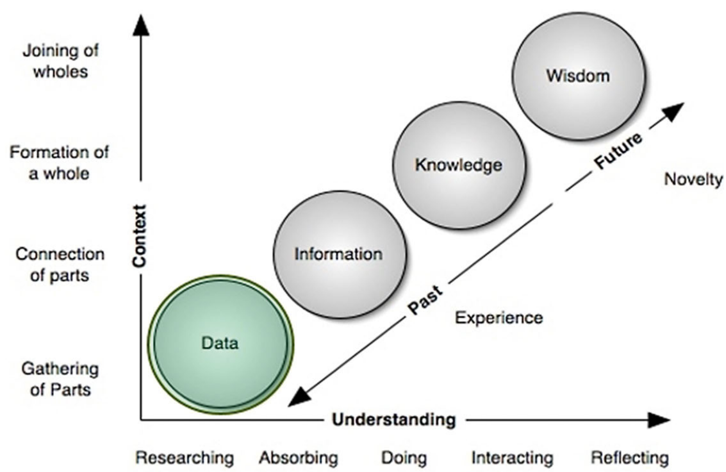
Andreas Rienow

1. Introduction

By 2050, two thirds of the global population will live in cities (UN, DESA 2018). With this continuously increasing urban population and their footprint, the need to assess, map, and quantify the urban environments and their sustainable urban development with high spatial detail grows significantly. Metropolitan regions are complex coupled human-environment systems comprising urban agglomerations and their peri-urban hinterlands. Thus, understanding transformations of metropolitan regions and navigating those transformations toward more sustainable pathways, is of utmost societal relevance. An increasing urbanization makes urban areas highly dynamic (El Mendili et al. 2020), causing research on the detection of land consumption and building activities in cities to become even more important. In 2015, the United Nations highlighted the importance of "[m]ak[ing] cities inclusive, safe, resilient and sustainable" in Goal 11 of the SDGs (Sustainable Development Goals; UN 2021b). Target 11.3 focuses on the enhancement "of inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management". Target 11.7 again aims at the provision "of universal access to safe, inclusive and accessible, green and public spaces" (UN 2021b; Ravanelli et al. 2018). The effects of urban growth affect the coupled human-environment system with several social, economic, ecological, and cultural implications on different spatial and temporal scales (EEA 2006). One difficult problem for countries to meet the UN SDGs is a lack of access to relevant geospatial data supporting the measurement of the 231 unique indicators. In strengthening the capacity of national statistical offices, the UN propagates to ensure access to high-quality, timely, reliable, and disaggregated data based on geospatial information (UN 2021a). In that regard, the application of geographical information systems (GIS), remote sensing (RS), and global positioning systems (GPS) is promoted (UN 2021a). Another important geospatial data source for deducing human-environmental information can be seen in volunteered geographic information (Ibrahim et al. 2015).

In 1507, Martin Waldseemüller (as professor of cosmology) drew the first world map with “land masses in the west” based on the “Soderini Letter”, the infamous 1497 letter from Amerigo Vespucci to Pier Soderini: America was mapped for the first time (Goodchild 2007). Waldseemüller’s mapping activities could be understood as an early form of a current phenomenon: engaged, but not specially trained citizens create geodata on a voluntary basis. Goodchild (2007, 212) first termed the phenomenon of “a special case of the more general Web phenomenon of user-generated content” “volunteered geographic information” (VGI). VGI is also referred to as crowd data, user-generated content, geo web 2.0, citizen cyberscience, or participatory sensing. Contrary to citizen science, it exhibits a looser formalization, the know-how of the people involved, the relation to the topic, and a certain tension between activity and passivity (Arias de Reyna/Simoes 2016). Moving along the axes of “content” and “understanding”, VGI generates data and information as the foundation for knowledge and informed decision-making (fig. 1).

Fig. 1: Information as resource (Cleveland 1982; modified)



Users, transactions, or sensors are involved in the formation of VGI. Accordingly, the main sources of VGI are application programming interfaces of social media platforms (e.g., Twitter, Flickr, Instagram, GooglePlaces, Facebook, Uber, Strava, etc.), data brokers (e.g., DataSift, Gnip, AirDNA), communities (e.g., OpenStreetMap, Geograph, Wikimapia), or web scraping techniques (e.g., Wget, Selenium). But how does the “G” get in VGI? The geographic part originates in manual or automated georeferencing activities with geotags or in meta information on locations and hashtags. A typical example for an XHTML web page tag would look like this:

<meta name="geo.region" content=“DE-NW”/>
<meta name="geo.placename" content=“Bochum”/>
<meta name="geo.position" content=“51.4441; 7.2609”/>
<meta name="ICBM" content=“51.4428; 7.2624”/>

VGI has changed the traditional way in which geospatial information is collected, produced, and distributed. Users have become producers. Hence, the potential for applying VGI for monitoring the SDGs, which are the "blueprint to achieve a better and more sustainable future for all" (UN 2020) is *eo ipso* given. Recent studies apply VGI for flood impact analysis (Barz et al. 2019), understanding patterns of social segregation (Taubenböck et al. 2018), and the creation of land use classifications (Olteanu-Raimond et al. 2020). The DFG SPP 1894 "Volunteered Geographic Information: Interpretation, Visualisierung und Social Computing", e.g., is focusing on a sustainable use of VGI software elements and their analytical possibilities.

The goal of this contribution is to present a short review of studies on VGI for sustainable urban development in the economic, social, and natural spheres. Subsequently, a study carried out at the Institute of Geography at the Ruhr University Bochum dealing with VGI in the context of land consumption and individual temperature stress in Western German cities is added. It bears the potential for an easy-to-use mapping activity in order to sensitize citizens for climate adaptation issues and participatory urban planning possibilities at once. A conclusion provides future perspectives of VGI in sustainable urban development.

2. Volunteered Geographic Information in Urban Studies

Spatially explicit information on land use and land cover is essential to understand the implications of driving forces, actors and factors, impacts and feedback loops as well as the configuration and composition of the pattern and dynamics of urban systems. Fonte et al. (2017) created an automated procedure to convert OpenStreetMap (OSM) data into land use and land cover maps using the nomenclatures of the Urban Atlas and Corine Land Cover. Both products are satellite-derived and among the most popular land use and land cover information sources on the European level. The VGI-based approach outperformed the satellite-based one in terms of minimal mapping units and spatial accuracy. The OSM initiative Humanitarian OpenStreetMap Team (H.O.T. OSM) is using open data for mapping infrastructures and their vulnerabilities in order to support disaster risk management in a fast, efficient, and exact manner. One example is the voluntary mapping of the hydrological system of Dar es Salaam (Dar Ramani Huria 2016) providing information on potential inundation areas. In that regard, Šterk/Praprotnik (2017) developed a smartphone app to speed up the acquisition and the reliability of emergency response calls. Automated data collection and calculation of road access times for emergency response units are used in day-to-day operations. Among disaster risk management applications, one can also find an approach by Vannoni et al. (2020) dealing with the mobility assessment based on VGI in the early phases of the COVID-19 pandemic.

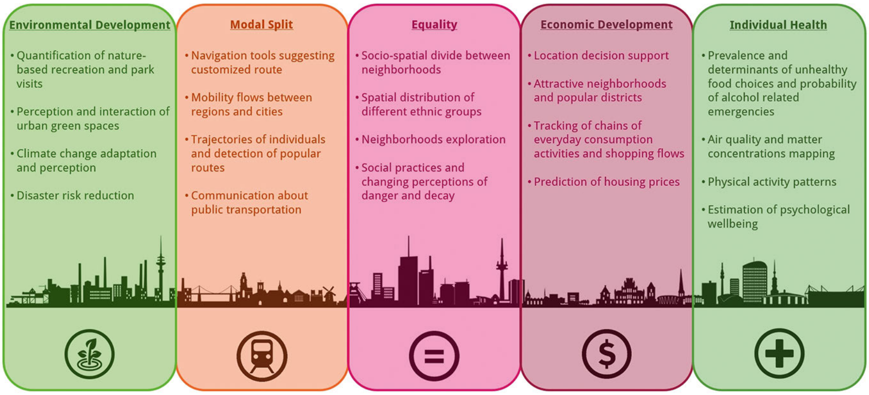
VGI exhibit the four big "v" of big data characteristics: volume, variety, velocity, and veracity (Bitkom 2014). There are several studies applying the big data potential of VGI to urban studies. Sun/Paule (2017) analyzed Yelp ratings in Phoenix, USA, indicating that high ratings are spatially structured, so that bars within or near the city center are more likely to get higher ratings than others further away. Ying et al. (2017) compared the interpersonal network and virtual network exchange in Chinese cities based on Sina Weibo microblog user relations to conclude that the degrees of cohesion and outreach in a city node were significantly positively correlated with the economic development level of the city. Sayegh et al. (2016) combined subjective and objective characteristics of built environments leveraging emotive perceptions of the urban actors. The findings can inform design decisions of urban planners. McArthur/Hong (2019) applied Strava source data in order to compare the most commonly used routes of daily bike commuters with their expected routes. The outcome helps to understand how street networks can be organized better in order to provide access to safe and unimpeded biking routes. In doing so, the path of a transformation toward a sustainable individual mobility behavior can be initiated. Ilieva/McPhearson (2018) reviewed over 100 studies dealing with the application of social media geographic information (SMGI) as a specific form of big data VGI (Campagna 2016). Investigation of social media (such as Twitter, Flickr, Instagram) enables sustainability researchers in conducting

- spatial analysis of user interests,
- temporal analysis of user interests,
- spatial statistics of user preferences,
- multimedia content analysis on texts, images, video, or audio,
- user behavioral analysis or
- spatial-temporal textual analysis.

I argue that as soon as it comes to the analysis of social media as a data source of VGI, one has to discuss the degree of voluntariness with which the users of social media contribute to a data base utilizable for scientific purposes. People participate within social media to communicate and exchange experiences or ideas. The purpose of geodata provision for scientists is rather involuntary, so that we actually deal with a special case of unvolunteered geographic information when it comes to SMGI. Nevertheless, the connection of semantic information and geoformation with the help of tags, geotags, images, or written text can be exploited as an important data source for analyzing, e.g., the experience of clean air as an important topic in-between social and natural spheres of urban systems. Most recently, Du et al. (2016) developed a sophisticated approach in order to mine alternative pollutant data to assess air quality in urban areas with a two-phase approach for opinion mining, targeting domain-specific knowledge and analyzing sentiments of crawled tweets. Yan et al. (2019) used geotagged check-in records on Sina Weibo, a Twitter-like platform, to systematically investigate the effect of air pollution on urban activity. Based on panel models, they found clear evidence that such an effect exists and varies between pollutants, visitors and residents, and different activity types.

Fig. 2 depicts how SMGI is currently utilized to analyze the various compartments of the urban system. Accordingly, studies dealing with the environmental development of inner urban areas and their perception (Guerrero et al. 2016; Keeler et al. 2015; Roberts 2017; Sessions et al. 2016; Sonter et al. 2016; Schwartz/Hochman 2014), urban mobility (Assem et al. 2017; Hawelka et al. 2014; Hasan/Ukkusuri 2014; Li et al. 2015; Lucchese et al. 2012; Luo et al. 2016; Schweitzer 2014; Paldino et al. 2015; Zhou et al. 2017), socio-cul-

Fig. 2: SMGI for analyzing the urban system and its compartments



tural equality (Adnan et al. 2013; Hoogendoorn/Gregory 2016; Shelton et al. 2015; Quercia/Saez 2014), economic development (Brandt et al. 2017; Lovelace et al. 2016; Martí et al. 2017; Zhai et al. 2015), as well as health and well-being (Ben-Harush et al. 2012; Chen/Yang 2014; Gore et al. 2015; Mitchell et al. 2013; Nguyen et al. 2016; Ranney et al. 2016; Widener/Li 2014; Yang/Mu 2015) have recently been carried out (Ilieva/McPhearson 2018).

In general, the question of accuracy and scientific rigor is not only important when one deals with data gathered by social media. Hence, quality assurance is an important aspect when it comes to VGI (Goodchild 2007). The credibility of data relies on its completeness, positional accuracy, attribute accuracy, logical consistency, and comparability. OSM, e.g., makes use of a variety of tools to ensure a certain level of reliability (OpenStreetMap 2021):

- reporting,
- error detection,
- visualization,
- monitoring,
- assistant tools as well as
- tag statistics.

Hollenstein/Purves (2010) detected typical error sources when it comes to the relation of name tagging and geotagging based on Flickr data. Besides objective errors like location or semantic errors, one also has to deal with the subjective representation of space. Keil et al. (2020) investigated the structural salience of landmark pictograms in VGI-based maps. The aim was to identify distance parameters that predict the structural salience of landmark pictograms in an object location memory. They conclude that landmark pictograms close to a memorized location or the cardinal axes of a memorized location are structurally salient. Results like these might improve the applicability of voluntary mapping activities such as OSM or WUDAPT.

The World Urban Database and Access Portal Tools (WUDAPT) project is a community-based project for gathering a census of cities around the world. One main aim is the classification of cities in local climate zones (LCZ) (Bechtel et al. 2019, Ching et al. 2018). The LCZ typology combines vertical and horizontal elements to ten building types and seven non-urban land cover types. Demuzere et al. (2020) anticipate that LCZ-based data sets deliver information on configuration, size, and shape of cities impacting important human and environmental relations such as human health and well-being, environmental hazards, energy demand, and climate mitigation. The application of the LCZ scheme by voluntary users generates urban data needed by climate models for simulating the impact of land use and land cover change on the overlying atmosphere.

3. "Too stuffy and too hot" – VGI for Climate-Adapted Urban Areas

Cities consisting of more than 50 percent of impervious land cover have a specific impact on ecological effects. Besides runoff and infiltration, the physical conditions of urban surface materials like concrete, bitumen, asphalt, tar, etc. are contributing to the infamous urban heat island (UHI) effect. Simply phrased, the UHI effect indicates the temperature differences between cities and their rural surroundings (Oke et al. 2017). Regularly, we observe higher temperature in urban areas than in rural surroundings. In that regard, Chen et al. (2020) concluded that in order to mitigate UHI effects, a reasonable urbanization mode needs to be promoted. This is directly addressed by SDG 11.b, demanding to "substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards […] mitigation and adaptation to climate change" (UN 2021b).

The citizen science project "Town and Country in the Flow – Network for the Creation of a Sustainable Climate Landscape (KlimNet)" pursued the goal to mobilize and bundle knowledge and commitment regarding climate change adaptation, especially among young adults, and thus stimulate concrete action. It aimed at the exchange between municipal administrations, civil society, and universities in North Rhine-Westphalia (NRW). KlimNet was funded by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety following a decision of the German Bundestag (funding code 67DAS098 ABC, 2017–2020) and implemented by the WILA Bonn Science Shop and the Universities of Bonn and Bochum. A three-step approach was pursued, consisting of providing information about climate change in the region, developing opportunities for action with the goal of a climate-resilient city, and institutionalizing the transfer of knowledge (fig. 3):

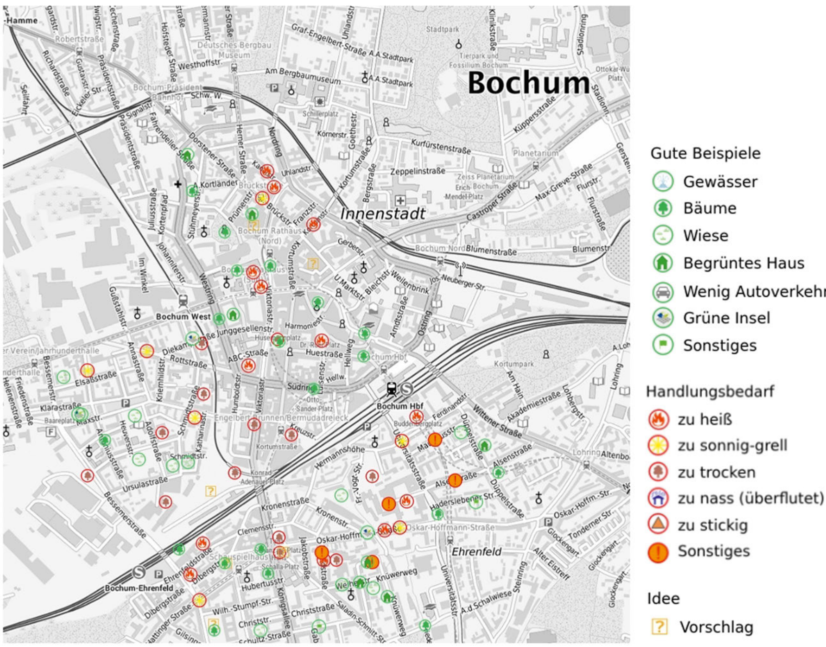
- provision of information on the possibilities for adapting to climate change in the region for local stakeholders and groups that are affected and active in the region,
- development of local options for action with the stakeholders themselves instead of implementing adaptation measures and

- anchor methods of knowledge transfer by the partnering communities in the long term.

Fig. 3: Guideline on participatory climate adaptation crowdmapping (WILA Bonn e.V. 2020)

One way to achieve these goals was the implementation of regular crowdmappings with interested citizens and young adults who have finished school but have not started their tertiary education path yet. The Geomatics Research Group of the Ruhr University Bochum was responsible for preparing a Web GIS required for the dissemination of past and future land consumption information on the one hand and for hosting the crowdmapping platform on the other hand. The structure of the developed Web GIS (klimnet.geographie.rub.de) is divided into four selectable main maps: the map of NRW serves as the start page and contains the land cover classifications. Each of the NRW pilot cities, i.e. Bonn, Gelsenkirchen, and Bochum, are represented in their own maps, in which crowdmapping is possible. For the crowdmapping, interested users need to choose their pilot study area, then a point in the map must be clicked and a category selected (fig. 4).

Fig. 4: Crowdmapping section in KlimNet (klimnet.geographie.rub.de)



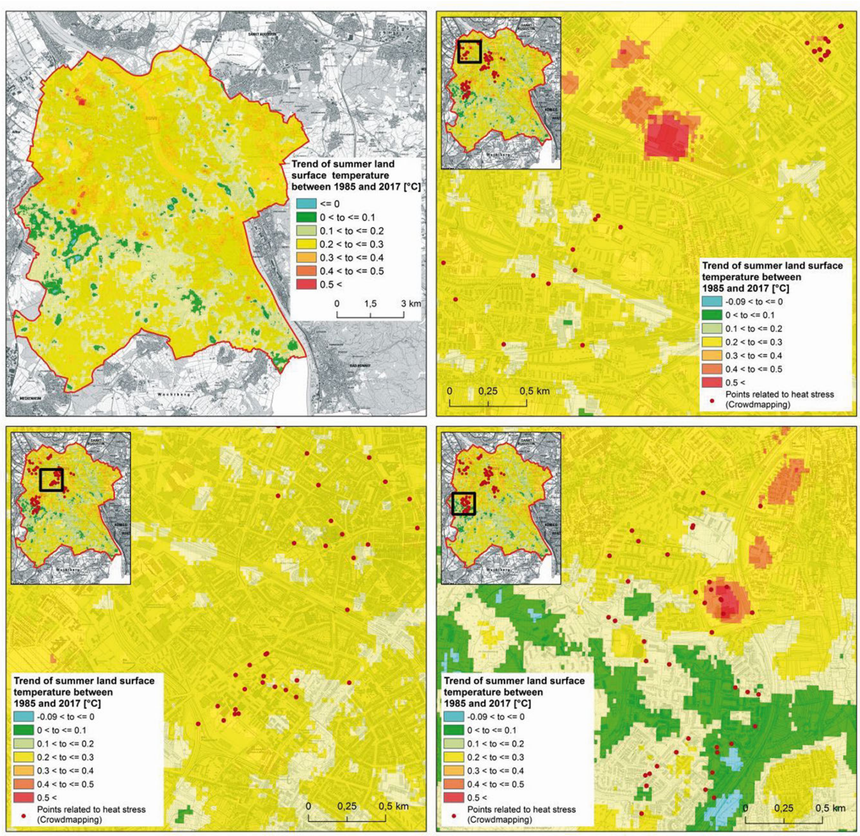
So far, one can choose between several categories. The 'good practice examples' category contains the classes 'water bodies', 'trees', 'meadow', 'vertical green', 'reduced traffic', 'green island' and 'other'; the category with needs for action contains the classes 'too hot', 'too sunny', 'too dry', 'too wet (flash flooded)', 'too stuffy' and 'other'. Finally, individual ideas can be added in the open category 'suggestion', like potentials for solar panels, green roofs, green islands, trees, or wildflower meadows. This should serve to identify special places in the cities where there is still a need for climate-adaptive measures versus where such measures have already been implemented. The monitoring is done by the users themselves. The administrator is able to change the class of registered locations or to remove them completely if some 'internet trolls' appear. The operation of the Web GIS is done using .json files and a QGIS project which contains the data for the Web GIS. An SQL database is used for the statistical data. Users are able to share their image detail from the map via Twitter and Facebook as well as a QR code.

Tab. 1: Overview of crowdmapping locations on climate adaptation in Bonn, Bochum, and Gelsenkirchen (NRW, Germany)

Type	*Count*
Good Practice Examples	
Water bodies	6
Trees	72
Meadows	40
Vertical green	32
Reduced traffic	3
Green island	19
Other	27
Need for Action	
Too hot	61
Too sunny	26
Too dry	33
Too wet (flash floods)	4
Too stuffy	6
Other	19
Ideas	
Suggestions	42

In addition to the crowdmapping section, maps depicting 32 years of urban expansion and resulting land consumption patterns are accessible via the portal (Ghazaryan/Rienow et al. 2021). The analysis of the maps shows that impervious surfaces comprised about 552,464 ha in 1985. Three decades later, impervious surfaces had increased by more than 167,000 ha in 2017. The dispersion and densification of urban areas come along with surface sealing processes affecting the thermal conditions of their direct surroundings. Accordingly, 390 locations have been mapped by citizens depicting good examples, action needed, and ideas related to climate adaptation (tab. 1). These locations have been mapped based on very subjective categories, experiences, and impressions. However, in total, 93 points were collected, reflecting locations inducing subjective thermal stress ('too hot': 61, 'too sunny': 26, 'too stuffy': 6). Fig. 5 shows points of that category mapped in the city of Bonn in the Southern part of the Rhine-Ruhr metropolitan region in comparison to Summer Land Surface Temperature (LST) trends from 1985–2017. The transformation of metropolitan configurations induced by land consumption dynamics can affect the thermal characteristics of a region. These changes are often studied using remote sensing-based LST. Particularly data from Landsat, the Moderate Resolution Imaging Spectroradiometer (MODIS) (Fu/Weng 2018), and NOAA's Advanced Very-High-Resolution Radiometer (AVHRR) (Khorchani et al. 2018) have been used for LST change assessment. Landsat 5, 7, and 8 data was accessed and analyzed using Google Earth Engine. The areas with significant trends can show the heating or cooling processes. Furthermore, LST was extracted for several locations of interest, such as areas where, according to crowdsourced information, changes of temperature and heat were observed (fig. 5).

Fig. 5: Summer LST trends 1985–2017 maps compared to locations related to heat stress gathered by citizens in Bonn, Germany

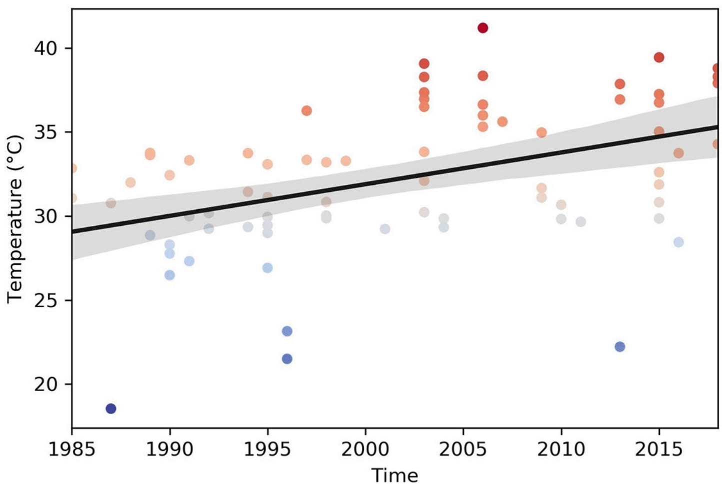


Most of the points are located in regions with an increase in the Summer LST. It indicates an UHI effect on a higher temperature level in 2017 than in 1985. Of course, one has to differentiate between canopy layer UHI (UHI_{UCL}) and surface UHI (UHI_{surf}). While UHI_{surf} is defined by "temperature differences at the interface of the outdoor atmosphere with the solid materials of the city and equivalent rural air to ground interface" (Oke et al. 2017, 198), UHI_{UCL} addresses

> the difference between the temperature of the air contained in the urban canopy layer, [i.e.] the layer between the urban surface and roof level (the exterior UCL), and the corresponding height in the near-surface layer of the countryside. (Oke et al. 2017, 199)

While the UHI_{surf} type can be measured remotely via satellites, UHI_{UCL} needs to be measured with temperature sensors at fixed points or acustical wind direction instruments like mini-sodars (sonic detection and ranging) (Oke et al. 2017). However, the small study demonstrates that even in places where no significant increase in Summer LST has been measured, citizens feel exposed to thermal stress and action is needed.

Fig. 6: Average mean of the Summer LST trends of all crowd-mapped locations related to climate adaptation in Bonn 1985–2017. Each dot represents a day of a year in the Landsat archive



Furthermore, fig. 6 plots all points mapped by the citizens against the LST development from 1985–2017. In reference to table 1, most of the crowd-mapped points are dealing with good practice examples reflecting where climate-adaptive measures have already been implemented. Hence, despite already existing good practices in configuring and compositing the urban neighborhood and thus mitigating climate change impacts, a steady increase of the LST over the last decades can be observed. Taking action is still necessary.

4. Future Perspectives

It has been shown that VGI is a promising source for information and data on urban sustainability topics. In that regard, table 2 presents the opportunities and challenges remaining when it comes to the application of VGI in urban studies. Besides a high volume, variety, velocity, and veracity of data and topicalities, VGI comes with low-cost investment and is publicly available. Still, quality assurance and subjectivity are important challenges for the future. The issue of data privacy becomes more and more urgent in regard to the rise of SMGI and probable unvolunteered geographic information. Additionally, having citizens involved in participatory projects raises awareness for scientific topics but also expectations which need to be satisfied quickly.

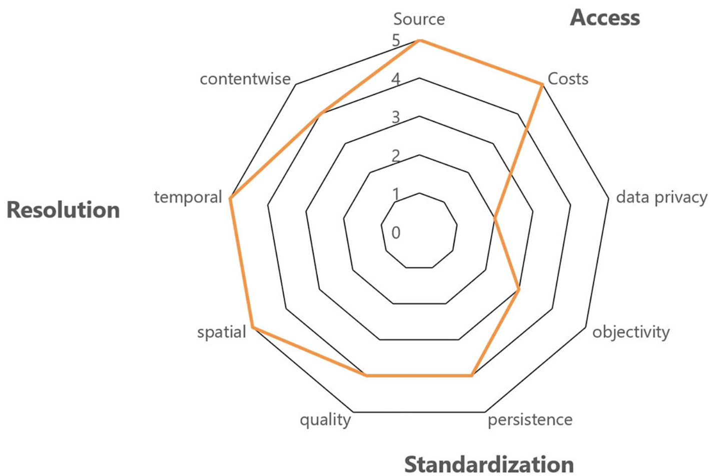
Tab. 2: Opportunities and challenges of VGI in urban sustainability studies

Opportunities	***Challenges***
High data topicality	*Quality assurance*
Big data characteristics (volume, variety, velocity, and veracity)	Community maintenance
Open data	Subjectivity
Low cost	Trolling
Participation of the public	High expectations
Issue-specific	Data privacy

Urban areas are open and dynamic systems in which macro-level patterns are a result of behavioral-driven processes of micro-level actors (Batty 2005; Geist et al. 2006). Accordingly, urban sprawl is a direct effect of the interaction and decision-making processes of individuals as well as public and private stakeholders. Those interactions are performed continuously and simultaneously by decision-makers showing an irrational and adaptive behavior. They change the state of the whole system and additionally react to these changes. Thus, urban systems reach a level of self-organization in which actors determine factors and conversely (Haase et al. 2012; Inostroza/Zepp 2021). It is a horizontal and vertical interplay within and between organizational levels, making the urban system elastic (Geist et al. 2006). The social subsystems undergo a path-dependent transition, implicating their own structural transformation and that of their environment (Geist et al. 2006). Perceiving and detecting these alterations, actors are able to modify their behavioral attitudes. This results in attenuating mechanisms ("negative feedback loop") reducing the speed and intensity of change. In contrast, amplifying mechanisms can also be initialized, leading to an acceleration of degrading effects ("positive feedback loop"). In doing so, a clear distinction of what is significant cause and what is random correlation is very difficult (Kroll/Haase 2010). The resilience of urban systems is not constant. At certain thresholds, critical nodes are reached where internal or external influences previously thought of as unproblematic can have unpredictably higher impacts and determine the future trajectory of urban systems (Batty et al. 2006). These bifurcations illustrate that the cause-effect relationship within urban systems is neither linear nor unilateral. Urban systems cannot simply be explained by the equilibrium result of a certain set of driving forces. They exhibit characteristics of hysteresis so that future developments and changes of urban systems are not only influenced by the current environment, but also by the past one (Alcamo et al. 2006).

Most recently, concepts from biology have found their way into urban studies in order to address the complexity of urban systems and treat them like socio-ecological systems. Accordingly, Andersson et al. (2021) introduced the concepts of traits to frame the support of urban sustainability. A functional trait is a feature of an organism determining the organism's response to pressures and its effects on ecosystem processes or services. Socio-ecological traits mediate reactions to selective socio-ecological filtering or determine effects on ecosystem processes or services. The three dimensions of a socio-ecological traits framework consist of (1) observable traits of the urban envi-

Fig. 7: Characteristics of VGI for analyzing observable traits in socio-ecological systems



ronment, (2) feedback loops with individual and collective perceptions and decision-making, as well as (3) urban ecosystem planning and management. For the first dimension, easily accessible (low-cost, open-source, privacy-secure) data and information with high resolution (spatial, temporal, content-wise) is needed (fig. 7). Assuring the quality, persistence, and objectivity of VGI, this exciting and vivid source of geodata may find entrance into urban planners' work in order to shape policy decision-making.

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Assessing Metropolitan Biodiversity Using Aquatic Environmental DNA Metabarcoding

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1. Abstract

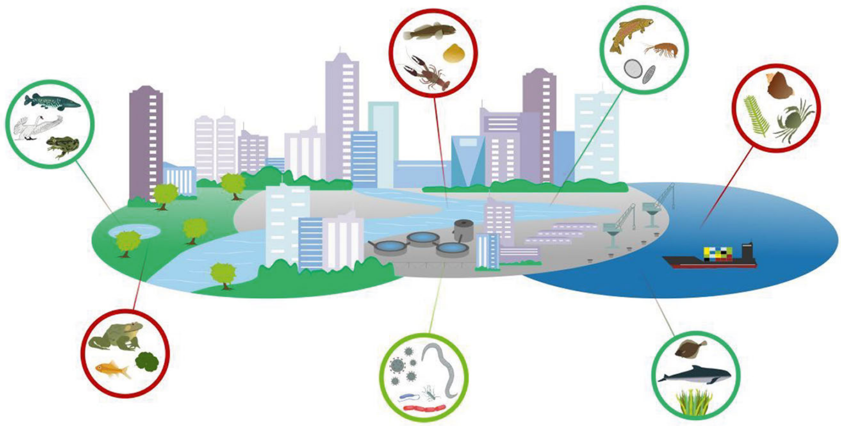
In recent years, metropolitan areas are expanding faster than ever, largely affecting neighboring biodiversity and even forming an ecosystem of its own inhabited by often peculiar fauna and flora. Ongoing urbanization is known to affect the metropolitan biodiversity by altering the available habitats, causing biotic homogenization and introducing alien, often invasive species. Urban freshwater ecosystems are particularly vulnerable, and since all cities heavily rely on healthy aquatic ecosystems, further understanding and recognition of metropolitan freshwater biodiversity is key for sustainable planning and management of freshwater ecosystem services. Thus, we here showcase the potential of using DNA-based methods, in particular environmental DNA (eDNA) metabarcoding, i.e. a technique for biodiversity assessment from DNA traces in the environment, for assessing the metropolitan diversity and evaluating potential threats to healthy aquatic ecosystems. We present the advantages as well as the shortcomings of eDNA metabarcoding and by evaluating several studies, we discuss pathways for its future application in routine biomonitoring of metropolitan freshwaters (fig. 1) while at the same time also engaging city inhabitants. With that, we show that environmental DNA is a very capable tracer of environmental change in aquatic ecosystems and can be a promising solution for future sustainable development of metropolitan ecosystems.

2. Introduction

2.1 Impact of Urbanization on Metropolitan Biodiversity

Cities are arguably the fastest developing ecosystems in the world. Over half of humanity is currently living in metropolitan areas, and it is predicted that by 2050 the number of city inhabitants will exceed two thirds of the global population (United Nations 2019). This trend is particularly striking in Europe, where already about 70% of the population

Fig. 1: City of the future – utilizing eDNA-based biomonitoring tools to assess metropolitan aquatic ecosystems, including monitoring species of interest (examples presented in green circles), invasive species (red circles) and pathogens (light green circle)



lives in cities, which cover approximately 4% of the continent (Koceva et al. 2016). Given that the physical extent of metropolitan areas grows even faster than the metropolitan population, it has major implications for metropolitan biodiversity resulting in habitat loss, biotic homogenization and the introduction of alien species (McKinney 2006; Elmqvist et al. 2013). On the other hand, metropolitan areas host a unique and often exceptionally high biodiversity and with that, they are often considered as hotspots of peculiar, urban biodiversity (McKinney 2008; Dearborn/Kark 2010). Nonetheless, since it is predicted that urbanization will in particular affect natural or near-natural areas recognized as key biodiversity hotspots (Seto et al. 2012), the trend poses a serious conservation challenge (McKinney 2002). Thus, a better understanding of the composition and dynamics of metropolitan biodiversity seems essential for the sustainable planning and management of metropolitan ecosystems and their services.

Recently, public interest in biodiversity in cities and metropolitan areas is growing with an increasing number of studies focusing on the impact of urbanization on the diversity and distribution of metropolitan biodiversity. This also translates into an increased awareness of metropolitan society (e.g., via citizen science projects) and policies of local decision-makers to protect metropolitan ecosystems, e.g., through various restoration efforts (McKinney 2002). However, to plan and implement conservation efforts reasonably and sustainably in metropolitan ecosystems, vast and global knowledge on the impact of urbanization on city-dwelling species is needed from all ecosystems encompassed within metropolitan areas (Rebele 1994). Yet, up to now the majority of the global surveys regarding metropolitan biodiversity focus mostly on terrestrial organisms (e.g., Aronson et al. 2014), leaving metropolitan aquatic ecosystems relatively poorly studied.

2.2 Metropolitan Freshwater Environments – Biodiversity as a Proxy for Healthy Ecosystems

Fig. 2: Example of a metropolitan stream: the river Emscher located in the Ruhr region (Germany)

Every city depends on various freshwater environments to provide inhabitants with clean water for direct use and recreational purposes, but also for transport, industry and agriculture (Elmqvist et al. 2013; Higgins et al. 2019). Thus, having healthy aquatic ecosystems is of paramount importance and is recognized as one of the top priorities in municipal management (Palmer et al. 2004; Walsh et al. 2005). On the other hand, urbanization heavily alters the land cover, which then impacts metropolitan water resources in terms of both quality and quantity (McDonald et al. 2011a; Elmqvist et al. 2013). Facing constantly increasing anthropogenic pressure results in increased loads of pollutants, altered geomorphology and finally, loss of native biodiversity with the establishment of alien, often invasive species in the resulting heavily modified water bodies (Paul/Meyer 2001; Walsh et al. 2005). On top of this, global climate change leads to drastic changes in the availability of suitable water as a resource and habitat (Tonkin et al. 2019). In effect, these factors pose a great challenge for sustainable management and distribution of freshwaters in metropolitan environments worldwide (McDonald et al. 2011a; 2011b).

Recognizing cities as ecosystems marked a gradual paradigm shift in conservation policy for metropolitan environments (Rebele 1994; McKinney 2002; Hobbs et al. 2006). Putting stronger emphasis on metropolitan ecology and ecosystem functioning corresponds with the increased interest in the composition and structure of metropolitan biodiversity (Rebele 1994; Grimm et al. 2000; Savard et al. 2000). Similar trends have been observed in particular in metropolitan freshwater biomes (Hering et al. 2013; Oertli/Parris 2019). Treating freshwater biodiversity as a proxy for a healthy aquatic ecosystem has been a focal point of most biomonitoring and ecological restoration initiatives worldwide (Geist/Hawkins 2016) and is a building block of the concept underlying the EU Water Framework Directive (WFD; 2000/60/EC). For metropolitan freshwaters (fig. 2), the reference conditions set by the WFD refer to near-natural waters. Obviously, such conditions can never be met in urban environments. Therefore, these urban water bodies have to be assessed independently. However, to date there is still no urban-specific framework for assessing and monitoring freshwater biodiversity present in metropolitan streams. Implementing systematic scanning of freshwater biodiversity in metropolitan management policies could be beneficial for planning reasonable and effective strategies for protecting and developing healthy metropolitan aquatic ecosystems.

2.3 DNA-Based Research on Metropolitan Biodiversity

Box 1: From Single Specimens to Whole Communities: A Brief History of DNA-Based Research
In the early 2000s a new method to identify species based on DNA sequences was introduced: DNA barcoding (Hebert et al. 2003). Here, the DNA from a single specimen of a given species is extracted and sequenced to generate a genetic barcode. These genetic barcodes are in most cases unique in their DNA sequence composition for most species and thus were proposed as a straightforward way of species identification. The individual barcodes are stored in publicly available databases, for example GenBank (NCBI), Barcode of Life Data Systems (BOLD) or the UNITE database, and whenever the barcode of a new specimen is sequenced, its identity can be revealed by cross-matching its barcode to a reference database. Even though at the moment not all described species have been genetically barcoded, the taxonomic coverage of many ecosystems is already high and still rising, with new initiatives in place working towards completion of DNA barcode reference databases in the foreseeable future (e.g., BIOSCAN, eBioAtlas).

Then, in the early 2010s the advancements in sequencing technology allowed researchers to take the next step: Suddenly many million sequences could be sequenced in a single experimental run. Now, instead of just sequencing a single barcode of a single specimen, whole collections of specimens from different species (bulk samples) could be analyzed at once. The rise of this so-called DNA metabarcoding has led to a drastic increase in DNA-based bioassessment studies during the last decade (Taberlet et al. 2012). Even though it rapidly increased the throughput and outcome of the DNA-based species assignment, it became apparent that for many organismal groups, in particular large vertebrates such as fish, it is not feasible to collect these in large quantities, i.e. as bulk samples. On the other hand, it was recognized that all species release genetic traces, such as cells, hair, feces, skin, and mucus, into their environment. So, the idea of simply collecting an environmental sample (e.g., water, soil, air) and sequencing the genetic traces in the sample, led to the development of the so-called environmental DNA (eDNA) metabarcoding (Deiner et al. 2017), which allowed for rapid and non-invasive studies of entire communities of organisms. Today, researchers work towards application and validation of eDNA metabarcoding in routine biomonitoring studies by conducting eDNA-based research all over the world and across various taxonomic groups, from freshwater macroinvertebrates, via tropical fish to arctic microbes.

DNA as a molecular fingerprint has been used for decades in multiple disciplines. The uniqueness of DNA allows comparing individuals, e.g., in order to investigate paternity or suspects of crimes. DNA-based analyses also became a frequently applied methodology in taxonomy. Books had to be rewritten after DNA investigations revealed unexpected evolutionary relationships. Depending on the questions asked (e.g., relationship among members of a population, phylogenetic relationship among taxonomic groups), the choice of the investigated DNA section differs. Highly conserved and slowly evolving sections can be used to address phylogenetic questions among species or higher taxa (genus, family, order, etc.). Variable, fast evolving gene sections can be used to differentiate individuals within a single species. In a biodiversity context, we differentiate between the analysis of DNA for single species or individuals (single-specimen DNA barcoding) and the analysis of entire communities with multiple species at once (DNA metabarcoding; see Box 1). Both approaches were successfully applied to study biodiversity in a variety of different habitats across the globe (Janzen et al. 2009; Bucklin et al. 2011; Valentini et al. 2016; Schütz/Tollrian/Schweinsberg 2020).

In recent years, it was recognized that all organisms constantly shed DNA to the environment they inhabit. This can be hair, fur, skin, feathers, scales, saliva or excretions. Traces of DNA are everywhere. Those DNA traces are collectively referred to as environmental DNA (eDNA), which allows the passive and non-invasive detection of species. Environmental DNA can be extracted and analyzed from a variety of different media such as soil, sediment, water and air. Since all life depends on water in some form, it can be seen as a sink for DNA that was released by life within and surrounding the catchment. Cities, metropolises in particular, have almost always been built near freshwater habitats, ranging from metropolitan rivers, to harbor coastlines, park lakes, canals or small ponds in citizens' backyards. Therefore, assessing biodiversity through eDNA collected from these waters is a rather straightforward task. Since the collection of the samples is simple, it can be performed by citizens and can increase the interest of communities in science, raising awareness of biodiversity and the value of metropolitan wildlife. Such eDNA-based approaches have already been applied to metropolitan environments (Francis/Chadwick 2015; Stoeckle et al. 2017; Bagley et al. 2019), in particular aquatic catchments, delivering invaluable data on communities, which would otherwise be very difficult to obtain. The results of eDNA metabarcoding, when used routinely, would offer important data on species distribution, the state and health of the environment and the success of restoration measures right around us. Scientists as well as officials can implement this data for a sustainable city development that meets the needs of the citizens, while also offering suitable habitats for metropolitan wildlife and with that increasing the quality of life.

2.4 Environmental DNA Metabarcoding – A Promising Tool for Estimating Metropolitan Aquatic Biodiversity

As mentioned in the beginning of the chapter, biodiversity assessment in metropolitan areas is still a highly undervalued, yet very important topic. The diversity of novel species and the complexity of their interactions in particular with native ones is drastically higher than in natural habitats, despite habitats often being artificial. This holds true in particular for metropolitan freshwater ecosystems that act as recreational ecosystems, as drinking water resources, as entry points of surface runoff water or as sinks for purified water from sewage plants. Biodiversity traces from land and water can be captured using environmental DNA comparable to the forensic DNA fingerprinting, offering unparalleled insights into the biodiversity associated with these freshwater ecosystems. Here we want to i) highlight the potential of environmental DNA metabarcoding methods to assess metropolitan biodiversity much more holistically than traditional assessment methods, ii) provide an overview of contemporary approaches to capturing biodiversity with eDNA metabarcoding and iii) outline perspectives to implement eDNA metabarcoding as a simple analytical tool for metropolitan biodiversity monitoring.

3. Environmental DNA Methodology – A Holistic Approach for Biomonitoring

The choice of eDNA methodology strongly depends on the type of ecosystem and taxonomic group that are to be investigated. Despite a generally similar workflow, the methodologies can drastically differ by sample type, habitat and target organism. We will here outline general principles for collecting, analyzing and interpreting eDNA data.

3.1 Environmental Sample Types

First, eDNA can be collected from different environmental sample types (sediment, water, ice, etc.), which can give insights into different communities and on varying time scales. With the collection of water samples, mostly the active and present fauna and flora of the water body and the surrounding area is detected, depending on the persistence and stability of DNA traces as well as the character of the water body (Harrison et al. 2019). On the other hand, the collection of sediment samples can give insights into the benthic (i.e. living at the bottom of a water body) and terrestrial fauna and can also date back years to millennia in time when collecting sediment from greater depths, permafrost or even ice cores. However, this chapter focuses on the application of the aquatic eDNA and therefore, the following parts will be oriented around the potentials of using DNA information gathered from water samples.

3.2 Freshwater Habitats

Freshwater habitats can generally be divided into flowing water bodies (lotic), such as streams and rivers, standing water bodies (lentic), such as ponds and lakes, and groundwater habitats. The sample collection differs between these habitats. Lotic ecosystems are sinks in their environment and act as conveyor belts, transporting eDNA downstream for many kilometers. Thus, water samples from lotic environments usually have a greater spatial inference, representing the community of even up to (or more than) 12 km upstream of the sampling site (Deiner/Altermatt 2014; Deiner et al. 2016). The eDNA detection range, however, can be strongly influenced by DNA degradation and retention as well as resuspension and dilution. Therefore, typically already within a few hundred meters or less the eDNA community can substantially differ (Harrison et al. 2019). For flowing water bodies, rather small volumes (1–2 l) are often collected in biomonitoring campaigns and already allow the detection of a great portion of the present community. However, to depict the whole community, usually larger volumes have to be collected (up to 100 l; Cantera et al. 2019).

In standing waters, on the other hand, the water column of lentic ecosystems is usually highly stratified with little transportation of water in vertical or horizontal directions, which makes eDNA signals very local. During the collection of water samples from ponds and lakes, this is accounted for by sub-sampling from different locations along the shore and from the middle of the water body and additionally from various depths. Usually, greater water sample volumes from different spots are required to depict the whole community. Several guidelines to optimize the sampling strategy of ponds and lakes have been proposed (Beentjes et al. 2019; Harper et al. 2019).

Groundwater bodies are a highly important source of drinking water in metropolitan areas and encompass an aquatic habitat particularly difficult to access and assess. Nevertheless, the cold temperature and absence of light offer optimal conditions for eDNA preservation. However, only a few studies have investigated groundwater using eDNA (Niemiller et al. 2018), collecting only limited water volumes. While being mostly unexplored to this day, groundwaters should be sampled similarly to surface standing waters to account for stratification effects.

3.3 eDNA Sampling Techniques

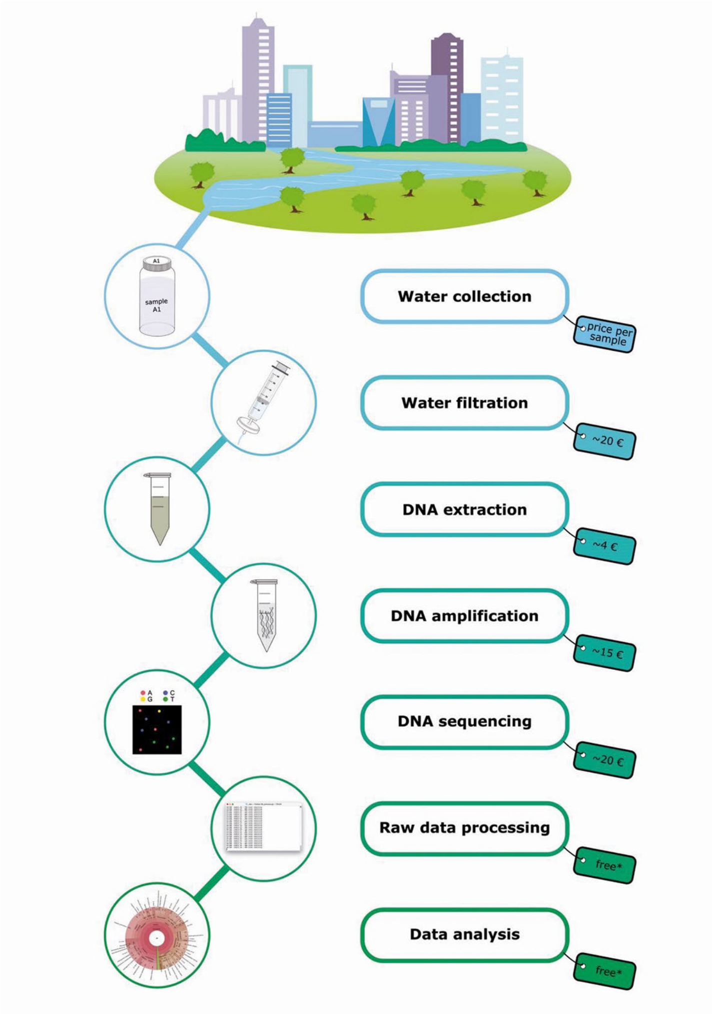
Fig. 3: Water samples for eDNA analyses are collected in sterile bottles

When collecting environmental samples (fig. 3), contamination with other DNA traces should be avoided. Thus, the usage of sterile gloves and sterile field equipment is of extreme importance. Not only can contamination between samples occur (cross-contamination), but also human DNA traces originating from the sample handler can potentially enter the sample. The starting point of all water-based eDNA methodologies is the collection of a water sample in sterile 1–2 l bottles or bags that are placed in the water body. Alternatively, eDNA samples can be directly taken from the water using sterile pipes and specialized pumps (Thomas et al. 2018). The volume of water and the number of samples depends largely on the type of water body (flowing/standing), its depth and number of available microhabitats present.

Fig. 4: The collected water is pumped through a special encapsulated filter to isolate the eDNA from the water

After the collection of the water samples, the eDNA needs to be isolated from the water and collected on a dedicated filter (fig. 4). Finally, after the water is filtered, the sample consisting of a filter with collected eDNA requires preservation. Depending on the preservation method chosen (e.g., in highly concentrated ethanol), the collected eDNA sample can be stored at cool temperatures (4°C or -20°C) or even at room temperature. In conclusion, the required sample replication and filter volume depends on the choice of target organism, the research question and the water body. Depending on the approach chosen, including the number of replicates and types of filters used, cost estimates per sample can vary between 20 and 100 Euros, excluding personnel expenses (fig. 5). That being said, when planning for eDNA research, one has to bear in mind that sometimes a trade-off between sampling sufficient amounts of water and cost and time efficiency has to be made (Macher et al. 2021).

Fig. 5: Metropolitan freshwater biodiversity can be assessed quickly and on a large scale using eDNA metabarcoding, while retaining comparably low costs. However, the costs per sample scale with the total number of samples/replicates that are sequenced simultaneously (see Buchner/Macher/Beermann/Werner/Leese 2021). (*) Most bioinformatic tools to process and analyze the eDNA metabarcoding data are free of charge but can require the acquisition of computing power



3.4 Molecular Laboratory

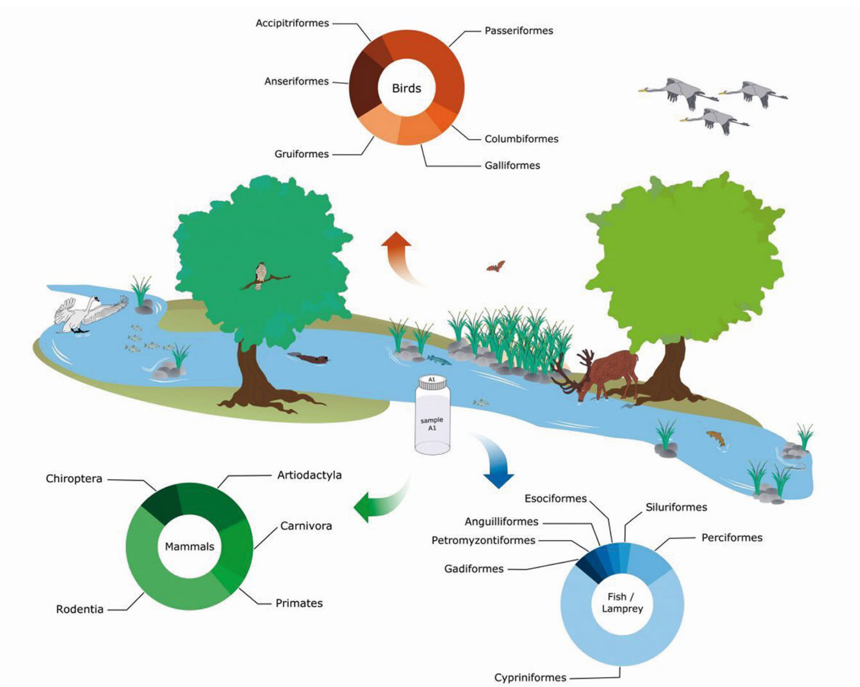
The laboratory processing of eDNA samples (fig. 6) with a focus on animal and plant (and not microbial) species usually implies working with a low concentration of target DNA.

Fig. 6: After the fieldwork, the eDNA is extracted from the filters and prepared for sequencing in a sterile laboratory

Thus, significant precaution measures have to be taken to prevent contamination of the samples. Usually, eDNA samples should preferably be processed in a dedicated sterile lab with a unidirectional workflow. Here, the working places for the two major steps of DNA extraction (low amounts of DNA) and DNA amplification (high amounts of DNA) are spatially separated and samples only proceed forward. This mitigates potential contamination from already PCR-amplified eDNA samples. Furthermore, working places have to be decontaminated either with UV light or bleach after each working step. To prevent contamination with human DNA, the usage of a single-use, sterile overall suit and long gloves is an established good practice.

The initial laboratory step is the DNA extraction. Here, many different laboratory protocols and various commercial kits are available, but all follow a similar principle. First, the captured eDNA has to be separated from the filter. Open filters can usually be removed from the housing and are then ground or partitioned either with beads in a bead mill or with sterile scissors. Encapsulated filters, on the other hand, are filled with a buffer that is removed from the capsule and used for the DNA extraction. The next step is the lysis, where the DNA is isolated from cells in the sample. A lysis can either be performed enzymatically, chemically or mechanically. Then, the DNA is extracted from the sample, which comprises the removal of all organic and inorganic components except DNA. The following step is the amplification of the target DNA with a polymerase chain reaction (PCR). Here, the amount of target DNA copies is exponentially increased. The choice of target fragment, however, largely depends on the research question and the target species. For the assessment of whole communities, universal primers that can target DNA fragments ('DNA barcodes') characteristic for certain taxonomic groups, e.g., fish or invertebrates, are amplified in PCR reactions. Depending on the questions, various other organismal groups can be targeted, e.g., fungal, algal and bacterial communities. Interestingly, the eDNA information collected from water samples can also inform about the surrounding diversity as DNA traces shed by terrestrial organisms in the water bodies can be successfully detected (e.g., Macher et al. 2021; fig. 7). To ensure a high reliability of obtained results, the implementation of multiple extraction and/or PCR replicates is strongly recommended. Afterwards, the eDNA samples have to be prepared for high-throughput sequencing (HTS) and are subsequently converted into millions of sequence reads. The HTS is performed on the machines that are capable of transforming the PCR-amplified products into the letter codes (ACGT) using fluorescent chemistry, which then form the end DNA sequences. The raw data then obtained from the HTS machine is basically a large text file with millions of lines that represent the letter code of the sequences ('reads') as well as ASCII codes that denote the quality of the sequence.

Fig. 7: Overview of a freshwater associated vertebrate community including some of the detected species. The OTU (operational taxonomic unit) richness among the classes of birds, mammals and fish/lamprey found in this study are illustrated in pie charts (Source: Macher et al. 2021)



3.5 Raw Data Processing

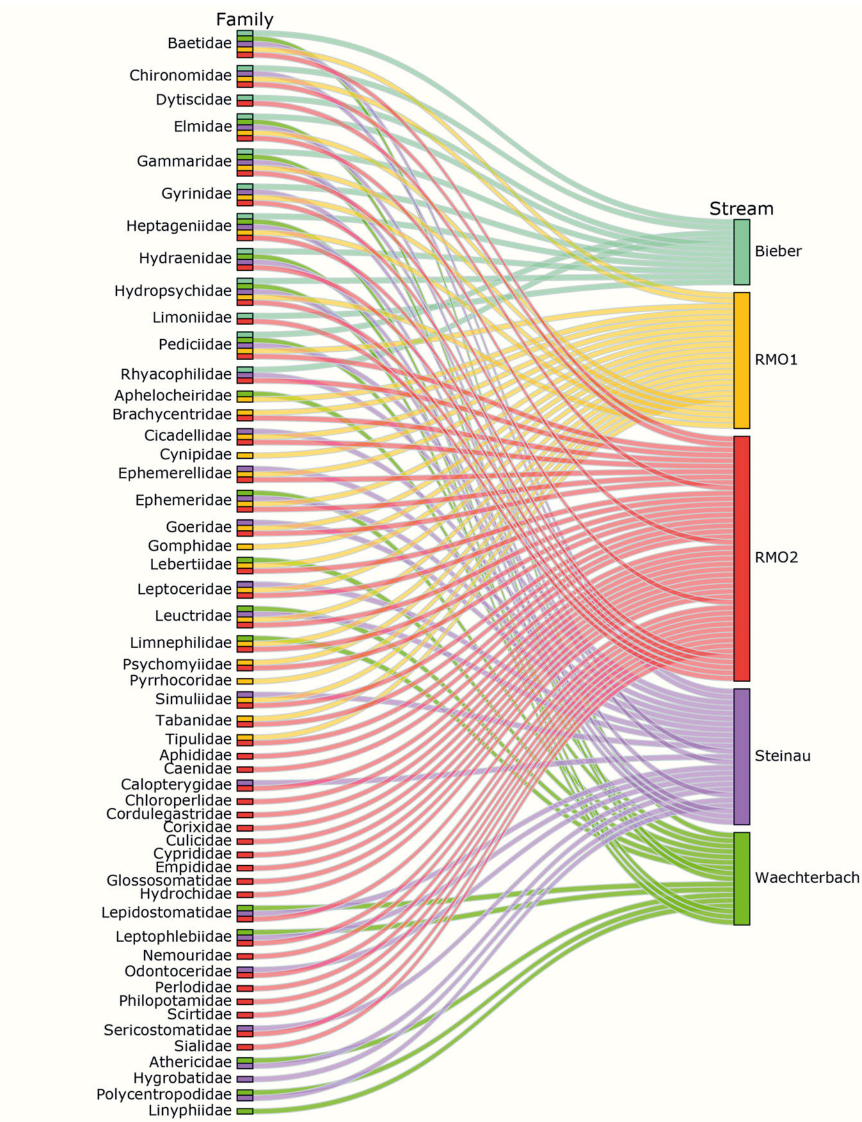
After sequencing, the multitude of DNA sequences obtained (usually millions of reads per sequencing run) have to be processed bioinformatically prior to scientific analyses. Initially, all reads of a sequencing run are stored in a single file and since they usually contain information from multiple sampling sites, require a demultiplexing step. Thus, the reads are divided into single files according to their sample-specific tagging sequence. This allows the simultaneous sequencing of dozens and even hundreds of samples on a single sequencing run, which drastically reduces costs. Nowadays, most DNA metabarcoding studies apply paired-end sequencing runs where the DNA sequences are read from both directions. This increases the quality of the reads and allows the sequencing of longer reads. After demultiplexing, the forward and reverse reads are merged and their quality is subsequently evaluated. When all high-quality reads are assigned to their respective samples, they can then be joined into biological entities. Here, two main approaches can be distinguished: clustering and denoising approaches. Clustering groups together all sequences within a certain threshold into a single entity (i.e. the operational taxonomic unit – OTU). Denoising approaches, on the other hand, aim to remove sequencing errors from the dataset and retain all correct biological sequences, without clustering them. These entities are referred to by various abbreviations, such as ASVs (amplicon sequence variants), ESVs (exact sequence variants) or zOTUs (zero-radius OTUs). Both approaches have their specific strengths and fields of application and can be used in parallel: OTUs are a proxy for species and should preferably be used for diversity measures (e.g., local or regional species diversity [alpha and beta diversity]), ecological indices and biogeography, while denoised sequences should rather be used for population genetics, connectivity and haplotype indices (Antich et al. 2021).

The final step of the raw data processing workflow involves taxonomic assignment (identification of a single sequence to a taxonomic, preferably species level). Therefore, the sequences are matched against a reference database. The choice of database depends on the target marker used in the study. Various online databases exist that host reference sequences of different markers and organisms, including NCBI GenBank, Barcode of Life Data Systems (BOLD), UNITE or R-Syst. In most cases, due to incompleteness of reference databases, not all reads can be reliably assigned to a reference species and the obtained taxonomy table requires additional filtering steps. Furthermore, it is recommended to manually check the assigned taxonomy for plausibility and potential errors (replicate consistency, negative controls).

3.6 Data Analysis

The final product after data processing is a taxon list with species names and associated read numbers per site. This table is the basis for downstream analyses. With the final taxon table, one can perform statistical analyses to investigate patterns of observed diversity and use multiple tools to visualize the data (fig. 8). Different software tools exist to perform statistical and ecological analyses, such as the R package vegan, the web-based tool MicrobiomeAnalyst, or the graphical-user interface-based software TaxonTableTools that was specifically developed for the processing and analysis of DNA metabarcoding data (Macher/Beermann/Leese 2021). The choice of analysis strongly depends on the design of the study and researchers' preferences. In most cases, the occurrence over space and time will be the most relevant dependent variables, as well as analyses that link the occurrence of species or taxa with ecological traits to, e.g., assess ecological status.

Fig. 8 a): Exemplary eDNA metabarcoding data analysis results: Parallel category plots are a comprehensive method to visualize biodiversity of a dataset and illustrate differences in taxonomic composition between samples.



3.7 Shortcomings of eDNA Metabarcoding

Undoubtedly, eDNA metabarcoding data hold many strengths. However, the interpretation of eDNA-derived data always needs to be taken with caution because, contrary to traditionally derived species lists, taxa that are found in eDNA datasets were not nec-

Fig. 8 b): Exemplary eDNA metabarcoding data analysis results: Krona charts are hierarchical, interactive pie charts to explore the detected taxa inventory of a dataset on different taxonomic levels.

essarily present at the site at the time of sampling. Particularly in anthropogenically influenced ecosystems, such as metropolitan areas, wastewater effluents can introduce signals of marine food fish, while in agricultural areas many terrestrial domestic animals can be found. This poses a challenge of false positive (species reported as present while it is not) and false negative (species reported as absent while it is present) DNA signals. Although false positives might occur due to the transportation of the DNA signal in lotic ecosystems or its persistence, still the most common cause of false positive DNA signals is contamination. False negative results are of paramount importance for detecting species of interest, particularly rare, threatened or invasive taxa, where their absence in the data could be deriving from lack of their DNA rather than their actual absence in the ecosystem. False negative results often derive from insufficient water sample volume to retrieve the DNA signal, often from rare, underrepresented species. While its implementation is beneficial for producing reliable and comprehensive presence and absence data, up to now eDNA metabarcoding does not offer reliable information about species abundance or the population structure (e.g., sex or age distribution). Although in some cases, quantitative interpretations of read counts and biomass have been reported, e.g., for fish (Hänfling et al. 2016; Ushio et al. 2018), they still should be treated with caution. A final major concern is the incompleteness and reliability of reference databases. As described previously, reference taxonomic information is crucial to translate the sequencing data into a species list. The gaps in public DNA reference databases are unequally distributed among taxa groups and regions worldwide. However, with the ongoing efforts towards curating those databases and the addition of substantial amounts of new molecular data, the databases continue to improve constantly. Until the goal of having curated fairly complete DNA reference databases is achieved, we advise that the taxa lists should be verified by a specialist of the respective taxonomic group to further limit the shortcomings of reference material.

The shortcomings described above have to be taken into consideration when working with eDNA data. However, as also highlighted, there are several approaches that currently exist to reduce the impact of most of them. With the eDNA field rapidly improving, it is likely that most of those issues will be of a lesser concern in the foreseeable future. Overall, eDNA metabarcoding has been proven to be a reliable, comprehensive and reproducible approach for species bioassessment and would prove a promising solution also for metropolitan aquatic ecosystems.

4. Potential Applications of eDNA in Metropolitan Research

Environmental DNA-based methods are non-invasive and time-efficient ways of studying aquatic biodiversity, providing information about the presence of single species or even entire communities inhabiting aquatic ecosystems. In recent years the application of eDNA-based biodiversity assessment has expanded beyond simply assessing species composition towards more targeted and specific approaches. From monitoring invasive or elusive species to evaluating the success of restoration initiatives, eDNA metabarcoding has shown great promise for detecting aquatic life. Various studies have successfully applied eDNA-based biodiversity assessments in metropolitan research, for example, by initiating citizen science projects, the monitoring of reintroduced species or assessing pathogenic activity. Here, we present examples of eDNA-based approaches already tested in various environments that could readily be adapted to metropolitan aquatic research.

4.1 Monitoring Species of Interest

Metropolitan ecosystems, even though seemingly hostile for native fauna and flora, often harbor unexpected taxa often recognized as rare and threatened (Dearborn/Kark 2010; e.g., in the Ruhr region: Rhine sculpin, fire salamander, midwife toads). On the other hand, mainly due to anthropogenic activity, many invasive species have been thriving in city environments. Here, eDNA traces have been successfully used to detect rare, threatened taxa as well as invasive alien species (e.g., in the Ruhr region: signal crayfish, invasive gobiids, American bullfrog; see, e.g., Jerde et al. 2011; Thomsen et al. 2012; Thomas et al. 2020). This species detection approach has considerable advantages over traditional assessment methods, mainly because of its non-invasiveness and easy scalable application. No need for disturbance of the target organism to prove its presence is of paramount importance, particularly for threatened taxa. Contrary to traditional monitoring methods, eDNA-based surveys can avoid the handling of specimens (e.g., electrofishing, preservation in ethanol), but are still in agreement with the conventional approaches. Moreover, in some cases species were found in sites where they were not previously detected with traditional methods, which further supports eDNA-based approaches as a highly sensitive method of species detection. The sensitivity of eDNA methodology, along with time and cost efficiency, was the reason why it was proposed for application in routine biomonitoring of threatened aquatic species of high importance like the Eastern hellbender, the European weather loach or the great crested newt. In all of the cases mentioned, eDNA-based identification outperformed traditional detection, revealing targeted species' presence even at low eDNA molecule concentrations. Further development and validation of eDNA protocols has been conducted in recent years to further enhance the detection reliability of endangered taxa, additionally aiming to also provide information on quantities and abundances (Thomsen et al. 2012; Harper et al. 2018; Kusanke et al. 2020). The further development of eDNA methodology has led to the implementation of eDNA-based biomonitoring of endangered taxa in standard national legislation, similarly to routine monitoring of great crested newts in the United Kingdom. The detection of aquatic invasive species via eDNA has also proven highly efficient. Studies on several candidate vertebrate invasives, like the American bullfrog, the Bluegill sunfish and the Asian carp as well as smaller organisms like invertebrates proves the high efficiency of eDNA-based species detection even at very low abundances of target organisms. However, with some freshwater arthropods, eDNA-based detectability was difficult, arguably due to low abundances and presence of chitin exoskeleton likely hindering the DNA release (Thomsen et al. 2012; Tréguier et al. 2014).

Keeping in mind the shortcomings of the method, eDNA-based approaches have certain advantages that could be useful in monitoring species of interest in metropolitan environments. It could certainly help planning reasonable conservation actions towards protecting those species and provide a cost-efficient and non-invasive way of informing local authorities about species' presence and dynamics. For example, eDNA metabarcoding may be a desirable solution for informing both city conservation agencies as well as the citizens about highly endangered species living in their vicinity like axolotl populations within Mexico City or rare leeches living in the metropolitan ecosystems of Warsaw (Koperski 2010; Recuero et al. 2010). The eDNA methodology could be equally useful for controlling the dispersal of invasive species thriving in human-altered metropolitan environments. It has recently been proposed as an effective tool aiding in estimating the presence and impact of invasive mollusks in metropolitan areas in Spain (Clusa et al. 2017).

4.2 Assessing Pathogens in Metropolitan Waters

Water security is one of the top priorities of metropolitan ecosystem services. Among the main threats to clean water access is water pollution, caused mainly by sewage discharge, stormwater runoff or animal fecal input, resulting in the presence of pathogens affecting the well-being of the city inhabitants. Health risk deriving from pathogenic exposure was confirmed in several studies from metropolitan recreational waters as well as sources of drinking water (Craun et al. 2005; Wullings/van der Kooij 2006; Sterk et al. 2015). In the field of microbiology, eDNA metabarcoding has been a well-established method for estimating diversity of various pathogenic organisms. An eDNA-based detection has also been implemented for successfully detecting dangerous animal pathogens, such as *Batrachochytrium salamandrivorans* or *Ranavirus*, threatening endangered amphibian species (Miaud et al. 2019; Sieber et al. 2020; Spitzen-van der Sluijs et al. 2020). Data collected from eDNA traces have also been used for extensive research on improving the detectability of the fungus *Aphanomyces astaci* responsible for the crayfish plague decimating threatened native crayfish species throughout Europe (Wittwer et al. 2018b; 2018a; Strand et al. 2019).

Genetic information retrieved from aquatic environmental samples has recently been proposed as a very promising solution for detecting human pathogens. It has proven particularly efficient in detecting and monitoring local outbreaks of SARS-CoV-2. Here, environmental viral RNA signals were identified both from air samples as well as from wastewater from multiple locations (Ahmed et al. 2020; Hart/Halden 2020; Lednicky et al. 2020; Street et al. 2020). Detection of SARS-CoV-2 virus from wastewater has already been thoroughly evaluated, in some cases detecting a higher rate of infections compared to the number of confirmed clinical cases (Wu et al. 2020; Farrell et al. 2021). Using aquatic eRNA for detecting SARS-CoV-2 virus has also been tested in a metropolitan setting in the region of Valencia in Spain. Here, the viral signal from the urban wastewater was detected even before the number of reported cases started to indicate a local outbreak, highlighting that eRNA-based detection could serve as an early warning system for monitoring pathogens in metropolitan areas (Randazzo et al. 2020).

Even though eDNA metabarcoding has been recognized as a promising tool that could be used in stormwater and wastewater management, it has not yet been widely implemented in urban environments. Thanks to increased sensitivity, eDNA could provide a valuable tool for reliable estimation of the microbial community, which could lead to a better understanding of the potential pathogenic risks present in metropolitan waters. By using eDNA/eRNA-derived data, one could improve the monitoring of drinking water sources or sewer discharges with increased possibility of tracing potential pollution sources. An eDNA-based approach has already shown great promise for tracking fecal contamination in metropolitan recreational areas (Staley et al. 2018). It could also largely facilitate understanding harmful cyanobacterial blooms taking place in urban recreational waters by better understanding the diversity and dynamics of communities responsible (Y. Jiang et al. 2020). Establishing eDNA-based research in cities could also be of paramount importance to metropolitan freshwater diversity by analyzing the pathogens affecting both local diversity, e.g., fish in local aquacultures and threatened amphibians as well as the citizens.

4.3 Evaluating Metropolitan Restoration Initiatives

To counteract continuous degradation of freshwater ecosystems and slow down, halt or even reverse ongoing biodiversity loss, various restoration initiatives have been proposed for riverine ecosystems worldwide (Bernhardt et al. 2005; Pander/Geist 2013; Muhar et al. 2016). Restoration activities typically comprise various modifications to river course and adjacent riparian zones as well as the habitats within, sharing the common aim of improving the hydrologic and ecological status of a degraded riverine ecosystem, which could then increase community, biological and utilitarian values. Gradually, the need for river restoration has been recognized by policy- and decision-makers, which resulted in its implementation in the legislative acts on local as well as international levels (e.g., EU Water Framework Directive, US Clean Water Act). Although there are certain benefits from restoration projects, one of the main issues discussed is the lack of standardized evaluation of the restoration success. Although several approaches to evaluating the success of restoration initiatives have been proposed (Palmer et al. 2005; Woolsey et al. 2007; Jähnig et al. 2011), there is still a lack of standardization and robustness. The potential of using eDNA-based approaches in restoration ecology has been thoroughly discussed and proven to be a promising solution for a future way of assessing biodiversity in restored sites. Similarly, eDNA metabarcoding has been acknowledged as a highly promising tool for biodiversity assessment, also in the context of ecological restoration (Williams et al. 2014; Ruppert et al. 2019). However, to date very few studies have applied eDNA-based evaluation of restoration success and only from a single-species perspective. In metropolitan environments, freshwater ecosystems are subject to substantial degradation and deterioration of their ecosystem functions due to gradual urbanization. Thus, a multitude of actions were proposed to initiate stream restoration initiatives within urbanized areas. To evaluate the success of many metropolitan stream restoration projects, the composition of macroinvertebrate communities is investigated (Purcell et al. 2002; Selvakumar et al. 2010; Violin et al. 2011). However, since all of those assessments are based on morphological determination, some of the organisms can only be assigned to family level, which could possibly hamper interpreting the richness of observed diversity. Here, eDNA metabarcoding could provide a higher taxonomic resolution and thus enhance the reliability of the biological evaluation of metropolitan stream restoration initiatives.

4.4 Engaging Metropolitan Society

Recently, the number of research projects involving the engagement of the public is constantly growing, with more and more benefits of so-called 'citizen science' being acknowledged. Acquisition of large volumes of data collected voluntarily along with high coverage, otherwise difficult to achieve, have been primary advantages of communities' involvement behind a plethora of environmental monitoring initiatives. Public activity seems to be a particularly effective solution for biomonitoring in residential ecosystems like metropolitan areas. Citizen science has already proven useful for obtaining environmental data from city ecosystems, e.g., regarding urban biodiversity (Wang Wei et al. 2016; Anton et al. 2018; Mason/Arathi 2019). It has also been proposed and tested as a promising solution for measuring metropolitan environmental pollution (Q. Jiang et al. 2016; Longo et al. 2020). In metropolitan aquatic ecosystems, citizen science has been validated to deliver valuable environmental data, mostly concerning water quality, which are comparable to those obtained by trained professionals. However, engaging the public has not yet been implemented in studying metropolitan freshwater biodiversity, even though some solutions have already been proposed (Rae et al. 2019). On the other hand, there are more and more initiatives engaging the public by studying biodiversity using eDNA metabarcoding. eDNA-based citizen science research was proposed, e.g., to enhance the knowledge about diversity of amphibians living in residential ponds in Austria ("Frosch im Wassertropfen" project; http://www.uibk.ac.at/350-jahre/veranstaltungen/frosch-im-wassertropfen/), to assess the freshwater macroinvertebrate biodiversity of selected watersheds in Canada (STREAM initiative; http://www.stream-dna.com), to assess biodiversity in local BioBlitzes (public event focusing on collecting and identifying as many species as possible in a specific area over a short period of time) in the USA (CALeDNA; http://www.ucedna.com) or even to enhance nationwide biomonitoring of the endangered great crested newt in the United Kingdom. Citizen science has also become an important part of the outreach activities undertaken by scientific institutions and commercial companies focusing on eDNA analyses like NatureMetrics in the UK or EnviroDNA in Australia, offering easy-to-use kits that can be readily applied by non-scientists for straightforward eDNA sampling. The value of eDNA-based biodiversity records gathered through local community-derived initiatives are also considered as one of the crucial input data underlying new global initiatives like eBioAtlas by the IUCN and NatureMetrics (www.ebioatlas.org). There is a growing concern that eDNA studies will disattach the public from nature by translating it into numbers and letter codes. However, as shown above, the eDNA approach provides a promising straightforward solution for raising interest in nature and life in the immediate vicinity. Thus, implementing eDNA-based research in city freshwater ecosystems engaging the citizens would not only provide a valuable method for monitoring species of interest, assessing pathogens or evaluating local restoration initiatives, but might possibly also have a profound educational value in increasing scientific literacy and biodiversity awareness of metropolitan citizens (Box 2).

Box 2: Urban BioBlitz Using Aquatic eDNA – Assessing Biodiversity and Educating Citizens

Since freshwater biodiversity is in peril with the number of freshwater species being in decline, it seems of high importance to better engage researchers, decision-makers and the public on the way to protect aquatic organisms. This seems particularly true for biodiversity of metropolitan freshwater ecosystems, which on the one hand is heavily impacted by urban land use and on the other is poorly known. To create awareness and educate the citizens about local freshwater biodiversity, a rapid survey ('BioBlitz') using environmental DNA is proposed (Hupało et al. 2021). In only two days of sampling performed by two people at 15 sites in the city of Trondheim in Norway, 435 taxa, representing at least 265 putative species, were detected. The results of this study demonstrate the usefulness of eDNA metabarcoding for rapid biodiversity surveys and its value for educational purposes. The authors also point out the relative ease and cost effectiveness of generating and analyzing a large biodiversity dataset. When combined with openly available services and software, eDNA information can be a powerful educational tool for expanding scientific literacy, increasing citizen inclusiveness and raising awareness about the importance of the diversity living in the close surroundings.

5. Conclusions and Outlook

To assess and monitor metropolitan biodiversity is an important task in times of biodiversity loss, invasive species spread and the emergence of pathogens. Environmental DNA is a very suitable tracer that allows an assessment of animal and plant but also unicellular bacterial and viral diversity from water samples. The collection of eDNA samples is simple, straightforward and analyses are cost-efficient. It is important that the collected data are analyzed appropriately and made accessible to managers, researchers, but also to the interested public. Therefore, the next urgent steps are less about method development but rather about the installation of common platforms for data access and visualization (similar, e.g., to GBIF – Global Biodiversity Information Facility, http://www.gbif.org) as well as the implementation of quality control and quality assurance routines to improve the reliability of new data for global biodiversity monitoring. Dedicated regulations, standardized protocols as well as unified personnel training with a high degree of automation have to follow to ensure the reliability and reproducibility of eDNA-based metropolitan biomonitoring. With that in place, novel solutions can be implemented in the cities of the future including, e.g., screening for invasive species detection in ballast waters in city harbors, early warning detection of harmful pathogens in recreational waters as well as drinking water sources or routine DNA-based biomonitoring of restoration initiatives. Those solutions based on environmental DNA support a pathway for future sustainable development of urban areas including metropolitan biodiversity.

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Concept and Methods in Urban Public Health

Susanne Moebus

1. Preliminary Remarks: Urban Public Health as a Research Subject

The description of (urban) public health is normative, and although public health in its literal meaning as health of the population appears to be a stable construct, it is a moving target shaped by a range of influences, systems, and ideas (Mold et al. 2019). Yet, four key elements can be emphasized:

1. According to the UN Declaration of Human Rights (UN General Assembly 1948) and the WHO Jakarta Declaration on Health Promotion (WHO 1997), health is one of the fundamental human rights and essential for the social, economic and sustainable development of societies.
2. Health is different from the mere absence of ill-health (Moebus/Bödeker 2000).
3. Public health is concerned with the health status of the population.
4. Public health includes the practice of interventions aimed at populations to lower the risk of disease and mortality by reducing the burden of health as well as strengthening health resources through nonmedical interventions (Mold et al. 2019, Rosenbrock 2001).

Health itself unfolds in places and settings of daily lives. It is almost a truism to say that the urban environment has a strong leverage on health and on the distribution of health promoting resources – already known and written down in the *corpus hippocraticum* around the 5th century BC (Capelle 1991). However, population health in the urban context is still far from being mainstreamed. For this reason, urban public health was initiated to fill this gap by expanding the field of public health through spatial approaches from disciplines like spatial planning, geography, biology/ecology, engineering, logistics, social and political science.

In view of global urbanization trends and climate change, the question how to shape and design urban environments therefore must be closely related to the promotion and maintenance of the health of their inhabitants – each with respect to different population groups. This requires a much better and evidence-based understanding of how cities both create and undermine health chances. Understanding cities as complex systems, characterized by an entire ecology of innumerable interlinked structures, functions, networks, concepts and (non)knowledge, it becomes immediately clear that evidence-based knowledge can only be achieved through broad interdisciplinary joint efforts – of both research and practice. This is one of the reasons why the toolbox of scientific methods used by urban public health is typically characterized by its recourse to a multitude of methods from different disciplines.

Nonetheless, prevailing methods in public health are based on epidemiological concepts which focus on the population and use a quantitative approach (Beaglehole/Bonita 2004). For urban public health, the empirical methods of epidemiology are still a major approach. However, issues of problem-solving or evidence-based implementation are not necessarily addressed using the quantitative approaches of epidemiology. An important consequence is the need for quantitative methodological approaches, which makes urban public health an almost bewildering research field with a multitude of methods available. The inter- and transdisciplinary approach of urban public health cannot (so far) rely on methods specifically tailored to or developed for this particular research field. However, the complexity of urban public health research questions deserves a wealth of methodological approaches and accordingly a wealth of analytical methods – and skills. For this reason, research in urban public health relies on a broad interdisciplinary spectrum of methods derived mainly from planning, epidemiology, biometry, geography, urban, social, and political sciences including both qualitative and quantitative methods.

2. Theoretical Framework

To that end – and because urban public health is just an emerging branch of public health – this chapter addresses conceptual approaches rather than describing one specific urban public health method in detail. Accordingly, the aim here is to give initial insights into methods and instruments of urban public health with a focus on basic concepts and applications of urban public health. Still, a brief outline of main epidemiological concepts are given to illustrate the important opportunities for urban public health research.

2.1 The Plurality of Health

Human health is commonly thought of as the absence of disease. Consequently, with regard to health research, the focus is mainly on the study of disease origins and causes, often called pathogenic approach. However, the reverse conclusion from knowledge of diseases to knowledge of health and health causes works quite rarely. Health is not merely the opposite of disease, and impossible to determine with certainty: it is difficult to describe; it is perceived differently, and yet it is intuitively familiar. Health usually only comes to people's mind in case of ill-health – the SARS-CoV-2 pandemic has blatantly brought this phenomenon to the world's attention. In this sense, there is a "hiddenness" of health (Gadamer 1994) that does not stop short of science. A central health model trying to address the pitfalls of the pathogenic approach is the salutogenic concept, which explores health in terms of a "health and disease continuum" (Antonovsky 1987). Importantly, due to the constant interaction of humans with their physical, social and psychological environments, health is not dichotomous. Rather it is a dynamic process affecting the closely related individual, social and ecological levels. What is decisive in all these approaches is that the individual is not regarded as a sum of arbitrarily and individually modifiable characteristics, habits and vices, as is the case in the predominantly behaviourist oriented "lifestyle" prevention approach (Rosenbrock 2001). Rather, in addition to its intrinsic value, health is a means of personal and community development.

Moreover, many diseases are known, but only one health, just as the knowledge of a great number of risk factors, but only a few indicators of health. As a result, the opportunities for individuals to actively maintain their own health are very limited – in contrast to what is still widely believed. Even more, the same groups and social classes of the population that are most at risk of disease, disability, or premature death are also the least able to control their lives and self-help economically, socially, and culturally (Rosenbrock 2001). In this sense, the old paternalistic focus on individual prevention, care and health education needs to be replaced – wherever possible – by strategies of target group mobilisation, and a more specific approach that is more concerned with the everyday life and conditions of the target groups. Overall, the study of the risks to and the promotion of health are therefore complex processes relevant at all levels of society and in a broad range of contexts (Barton/Grant 2006).

2.2 Health and Urban Environments

The urban environment, through its physical design and functionality, daily affects the health and well-being of the population – be it a strong or weak effect, a health-promoting or a harmful health effect. Cities, or in a more general sense, urban environments, are not self-contained, homogenous entities, but complex systems characterized by a number of different urban fields and structures (e.g., education, economy, mobility, politics, buildings) interacting with each other in a complex urban grid. Improving health and preventing disease in urban environments requires evidence based knowledge taking into account this urban grid. The complexity of interactions between urban environments and human health is already conceptualised in several models and frameworks from different disciplines. The most widely recognized are probably the

- joint urban planning and public health framework (Northridge et al. 2003),
- framework for urban health (Galea et al. 2005),
- health map for human settlements (Barton/Grant 2006),
- urban health niche model of multi-level risk clustering and risk pathways (Sarkar/Webster 2017),
- framework to study built environment and health (Gullón/Lovasi 2018),
- model of resources and pressures of urban health including urban governance (WBGU 2016).

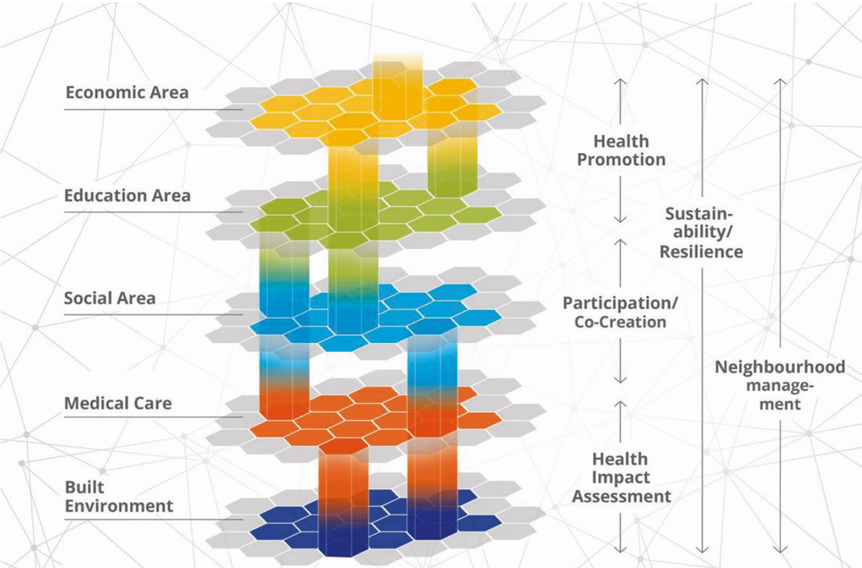
As cities form an entire ecology of infrastructures, institutions, services, and built structures, each of these, and in combination, affects health. It is for this reason that social, economic, cultural and (urban) spatial living conditions have a strong influence on health. Even more, it is internationally undisputed that these structural effects are even stronger than the effects of any kind of lifestyle (Holifield et al. 2018). People who face poverty, unemployment, environmental pollution, poor housing conditions, crime and/or lack of social networks thus experience great difficulty in successfully implementing behaviourally targeted prevention interventions (Vlahov et al. 2007). The challenge for communities is therefore to create and maintain such living conditions that enable health chances for all. For a successful implementation of urban health promotion and urban prevention measures, such an understanding of health is a basic prerequisite.

2.3. "A Place for Place in Public Health": Urban Public Health

As Frumkin pointed out, there is a need for "[a] place for place in public health." (2003, 1452) Thus urban public health is a conceptual and methodological complement to the research and practice field public health relying on the basic approaches and models of public health. One of the most well-known definitions describes public health as the science and practice of preventing disease, prolonging life, and promoting health through the organized efforts of society (Acheson, 1988), which means that public health addresses the entire population or population groups exclusively. However, what is often most difficult to understand about public health is that it is often confused with the objective of clinical medicine, which addresses the health problems of individuals only (Beaglehole/Bonita 2004).

Despite the old-as-the-hills knowledge that urban environments affect urban populations, not all public health is urban public health. For instance, urban public health explicitly addresses a spatial perspective. Two of the fundamental issues of urban public health in designing cities or urban environments as a health resource for all, are to consider (i) the concurrent variability and malleability of urban life's impact on health and the longevity of the built environment; and (ii) the complexity of urban systems. Generally speaking, urban public health complements the public health approach by acknowledging the primacy of sustainability, emphasizing environmental health inequalities and explicitly integrating a spatial dimension – all in the context of the specific characteristics of urban systems. The corollary of the above is mutuality of the relationship between multiple populations in urban areas and the urban environment itself. Indeed, the urban features can affect the health of the urban population, but of course it is the urban population that shapes its environment. In fact, this has crucial implications for the way we analyze the multidimensional and multilevel relationship between cities and their role in population health, taking into account the often neglected close link to governance as well as political and social action and vice versa. Fig. 1 attempts to illustrate these links by referring to the overlay analysis widely used in geographic information systems (see section 3.3). The manifold structural and functional layers or areas of a city, such as built, environmental, economic, transport, social, cultural, educational domains or also healthcare, are stacked and analysed as layers of the same region.

Fig. 1: Layers of public health in urban regions.
The figure illustrates on the one hand the interrelationships between functional and structural layers of a city, and on the other hand indicates the manifold thematic topics within a level by means of the tile. The slender connecting lines in the background are intended to indicate the (future) digital connectivity between all layers and functions.



Urban public health is particularly responsive to the specifically urban characteristics of (1) density and diversity, (2) social and human resources; (3) built structures; (4) large health disparities within the city due to environmental and socio-spatial inequalities; and (5) contextual complexity, as systems of the physical, social, economic, and political environment interact with each other. That is why urban public health closely links to resilience, sustainability, and governance, influenced by political and social action and vice versa. In this respect, urban public health needs to bring together many disciplines, ways of thinking, and methods. However, the interaction between structural urban intervention measures and health has hardly been considered so far. Viewing urban health through a structural lens places more emphasis on health conditions than on individual health behaviours, also avoiding the perils of *blaming the victim*.

As public health is an inter- and transdisciplinary field of research and action, this is inherently true for urban public health. The inter- and transdisciplinary approach of urban public health cannot (so far) rely on methods specifically tailored to or developed for this particular research field. As discussed above, the complexity of urban public health research questions deserves a wealth of methodological approaches and accordingly a wealth of analytical methods – and skills. For this reason, research in urban public health relies on a broad interdisciplinary spectrum of methods already derived mainly from traditional public health disciplines like epidemiology/biometry, sociology, anthropology, health economics, health services research and health policy analyses. However, for urban public health, the interdisciplinary cooperation with spatial and urban planning, geography, architecture, ecology/environmental research, logistics, engineering, as well as urban studies, social, and political sciences is imperative.

3. Empirical Approaches: Data Acquisition and Common Sources

3.1 Starting Points

The advantage of using highly sophisticated interdisciplinary methods in urban public health is simultaneously a challenge, as the large number limits their straightforwardness, comprehension, and accessibility. Further challenges are that a high level of experience and methodological expertise is required for the application and in-depth understanding of this broad interdisciplinary spectrum. Furthermore, their relevance for urban public health issues has by no means been specified in detail so far.

Therefore, in order to launch empirical approaches from urban public health, the following sections can only outline a tiny fraction of the existing plethora of methods, models, instruments, their areas of application, along with their strengths and limitations. The following sections thus limit themselves to presenting examples of opportunities for data acquisition and data analyses with a focus on urban epidemiology.

For reasons of space, in the following only an empirical perspective is presented, which of course is a serious limitation as the highly relevant research issues, findings, instruments, and approaches in qualitative research on urban public health as well as the emerging field of mixed-method approaches are not included. These would be methods such as systematic reviews, critical-constructive analyses or comparative case methods, communication and analysis methods such as process tracing, co-creation, and impact chain analysis.

Sound urban public health research requires a comprehensive understanding of research approaches and a methods-literate access to urban public health problems. Like in all research areas, a clear and competent understanding of research design, sampling or case selection, data collection, and data analysis is required. Since the choice of empirical research design depends on the nature of the intervention, knowledge of randomized and nonrandomized approaches, prospective and retrospective study designs, clinical trials and observational studies is useful. However, the aim here is not to present in detail cutting-edge techniques for evaluating interventions. Furthermore, not all kinds of regression analyses, instrumental variable, interrupted time series and sensitivity analysis are introduced. In this regard, useful basic information is provided in relevant academic literature.

Empirical studies of public health research often use different terms for central concepts like health factors, health traits or outcomes for health issues or risk factors, determinants or exposures that potentially influence health. In the following, these terms are used synonymously.

3.2 Primary Data – Surveys

Information or data for research can be collected in a number of ways. Primary data are newly collected data that are best suited for a given research purpose. Since urban public health is about population health, data from people are essential. Primary data in health research are collected mainly through surveys, for which numerous research designs have been developed. Manifold are the distinctive features that more or less apply to specific research questions and specific ways of conducting a survey. There are also many ways to categorize the distinctive features to facilitate their basic understanding. For example, the temporal perspective refers to prospective, retrospective, and cross-sectional studies; practical procedures refer to experimental and observational approaches; types of analyses refer to description and association studies.

Prospective or retrospective designs include a wide array of study types, including the classical cohort and case-control studies, but also specific ones like case-cohort, nested case-control, case-crossover, case-time-control, case-specular or genetic-epidemiology-case-only approaches (e.g., Gordis 2008).

The sample size differs markedly between study types. For example, a case-control study may include fewer than one hundred participants, while nowadays international longitudinal cohort studies follow thousands to hundreds of thousands of participants over several decades, with the epidemiological Framingham Cohort Study one of the oldest and most famous ones. Sources of exposure and outcome data vary between study types, but typically encompass, e.g., medical and employment records, interviews, questionnaires, medical examinations, environmental measurements. Data from medical records, death certificates, physical examinations, and/or questionnaires, for instance, are often used to verify or specify the reported outcome. For instance, in case a study participant in a medical interview or self-administered questionnaire reports having had a myocardial infarction, diabetes mellitus or cancer, these reports are validated through medical records. Also, in case a participant of a longitudinal study dies during follow up, death certificates are useful to determine the cause of death more accurately. As an example, say, the main objective of the study is to analyze the effect of traffic-related noise (exposure) on myocardial infarction (outcome). To estimate a possible effect, it is necessary to determine the outcome exactly. This means that not only the exact number of participants with a first myocardial infarction must be known, but also the number of participants who died of myocardial infarction during the follow-up.

Longitudinal Cohort Study Design

Longitudinal cohort studies are challenging among other factors with regard to duration and organization of the fieldwork as well as data analysis. The effort is worthwhile as temporal aspects allow for analyzing causal relationships or improving knowledge about long-term developments and longevity. The concept of a longitudinal study, simply put, is that participants without the disease of interest are followed over a given period of time to observe which of the participants develop the disease. Appropriate statistical analyses can then be used to investigate whether and to what extent the exposures of interest (often risk factors) differ between participants with and without the disease. In this way, and bearing in mind many of epidemiologists' most often discussed obstacles like confounding and bias issues (s. below), causes for the development of the disease can be identified. Longitudinal studies allow researchers to follow their participants during a part of their lives. The approach also allows for repeated observations as well as implementation of new study objectives over time – valuable for many research questions. The measurement of health outcomes and exposures (risk factors) can be collected with a high degree of reliability, and modelling cause-and-effect relationships is possible. For instance, exposure measurements should be as free as possible from recall bias, i.e. the issue that participants do not remember past events or their experiences precisely, or leave out details (s. section 4.3). Recall bias is particularly important in environment-related studies, as the extent of inaccurate recall is associated with characteristics of the exposure of interest (Coughlin 1990). One example of a long-lasting established German cohort study is the Heinz Nixdorf Recall Cohort Study. A short overview of the design, study location, assessment methods and main assessed variables is given in the following.

The Heinz Nixdorf Recall Study is an ongoing population-based, prospective cohort study initiated in 2000. It is based on a random sample of the general population of the metropolitan Ruhr area, aged 45–74 years. The former primary study objective was to determine if imaging techniques can be used to improve the risk prediction of myocardial infarction. Overall, 4,814 participants were recruited for baseline examination (participation rate: 55.8%). Extensive follow-ups were conducted in 2006–2008 (response 91%) and 2011–2015 (response 86%). On-site examinations at the study centre, lasting about five hours, included a self-administered questionnaire and a personal interview regarding socio-demographic characteristics, lifestyle factors, and assessment of the medical history, e.g., heart diseases, cancer, allergies, mental health. Additionally, recordings of medications and in-depth risk factor assessment, physical examinations including anthropometric and blood pressure measurements, and comprehensive laboratory tests as well as genetic analyses were performed. Also, mailed questionnaire-based surveys have been conducted annually for 23 years to assess the health status and specific health outcomes of the participants. Thus, relocations, deaths, and causes of death are systematically recorded.

According to environmental/urban public health research, extensive and detailed recording of participants' environmental exposures was performed, including chemical-physical environment (e.g., traffic, air quality, noise, acoustic environment, green spaces), socio-economic environment (indicators of socio-economic status of urban districts), as well as occupational and personal stressors. Environmental factors are assigned to subjects via geocoded residential addresses.

For the coverage of particulate and gaseous air pollutants, an area-wide daily modelling was performed in the entire study area using the dispersion and chemical transport model EURAD (European Dispersion and Deposition Model). This model is particularly suitable to represent urban background pollution and its short- as well as longer-term temporal changes. In addition, source-specific pollution (e.g., pollution from traffic and/or industrial emissions) was modelled. Exposures to fine particulate matters (e.g., PM10, PM2.5, PM2.5abs to measure the proportion of soot in fine dust, or the concentration of nitrogen oxide) are also available and allow in particular the recording of traffic-related particulate matter and the exposure to nitrogen oxides with a very high spatial and temporal resolution.

Chronic traffic pollution is recorded by using the residential address and distance and traffic density indicators. Chronic exposure to traffic noise was assigned as another physical environmental factor according to EU Directive 2002/49/EC. To derive the exposure to traffic noise present indoors, data were collected on both the sound insulation of the apartment and the ventilation behaviour of the participants. Green areas are, e.g., calculated via satellite-based data (Landsat 5 for 2003, 2006, 2009, Landsat 8 for 2013, 2015) as Normalized Difference Vegetation Index (NDVI) for the whole study area. This measure quantifies the presence of green vegetation based on reflected light in the visible and near-infrared bands (s. below). Neighbourhood social status was surveyed on a small scale using the proportion of unemployed, social assistance recipients, and median income in district, as well as the number of relocations.

A hexagonal sampling grid created a walkability measure across each study region covering the municipal boundary of participants' home address and a buffer of one kilometre beyond. Sampling hexagons with sides of 1000 m were used. The granularity of measurement with computational complexity had to be balanced; a larger hexagon would have led to more potential error in interpolation, but a smaller one would have been more intensive to calculate. By selecting the 1000 m hexagons and using the centroid of each hexagon as a sample point as well as the six vertices, a distance of 500 m between each point was used. This interpolation estimation appeared to be scaled appropriately, as a short walk was determined as little over 500 m.

Due to its fine-grained and detailed description of exposure to different environmental and social factors in the study area, the Heinz Nixdorf Recall study offers excellent opportunities to investigate associations with diverse health outcomes, mental and general health as well as risk factors. The variety and depth of both the recording of environmental factors and the pheno- and genotypic characterization of the subjects allow further investigation of important questions beyond the existing study results. Furthermore, through the use of highly standardized assessment and database tools, data of this study is still used in big national (e.g., Kieback et al. 2019; Bächle et al. 2018; De Las Heras Gala 2016) and international research cooperations (e.g., Locke et al. 2015; McClelland et al. 2015). Overall, many important results regarding environmental issues could be achieved (e.g., Lucht et al. 2020; Kartschmit et al. 2020; Orban et al 2017; Fuks et al. 2016; Hoffmann et al. 2015; Hertel et al. 2010).

Case-control Study Design

A substantial trade-off of longitudinal studies is that they are often not suitable for studying the causes of rare diseases, as this requires very large sample sizes and long durations to achieve sufficient statistical power. In this case, case-control studies are often very useful alternatives. Put simply, patients with the disease of interest are identified and their history of exposure to suspected etiologic factors is compared with that of control subjects who do not have the disease. Case-control studies are particularly suitable for investigating outbreaks, as they are fast, inexpensive and comparatively simple, e.g., generally requiring a small sample size. As with all study designs, this approach has several constraints. "Although easier to do, they are also easier to do wrong" (Schulz/Grimes 2002, 431). To mention only a few, case-control designs are prone to biases, e.g., anamnestic information has limited reliability due to long exposure history. Most importantly, a case-control study is not able to detect very small risks, which is an important issue especially in environmental epidemiology studying, e.g., hazardous exposures and cancer outcomes.

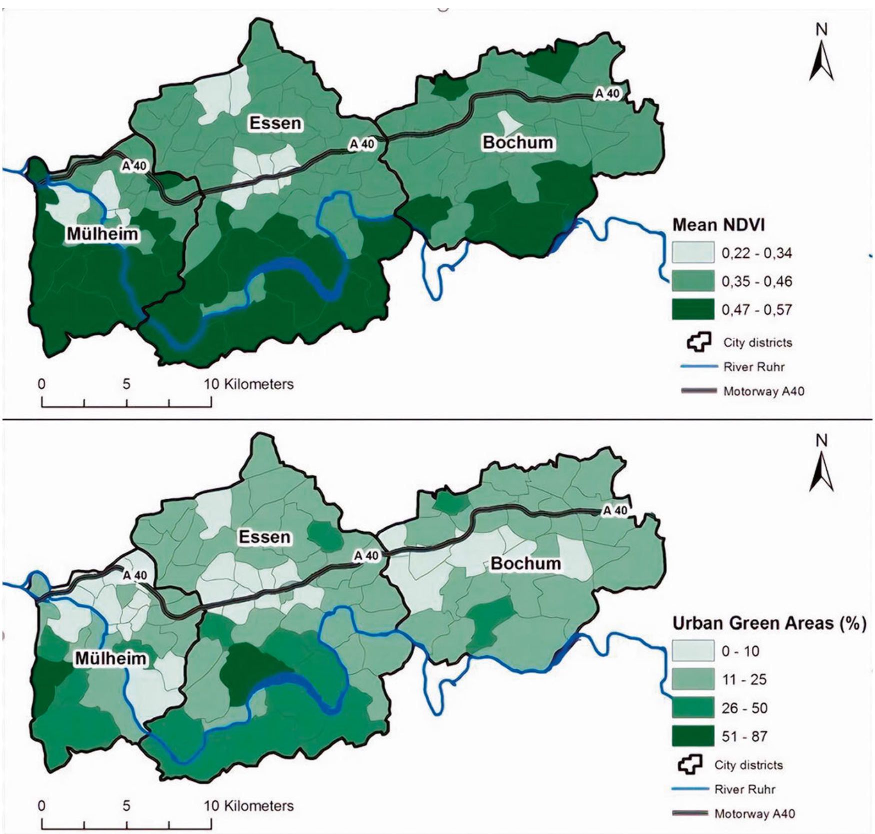
3.3 Secondary Data Sources

Secondary or second-hand data is data often routinely collected for a different purpose than the research question at hand. Secondary data commonly used in epidemiologic health studies include death registers, health- and environmental reports, census data, official statistics, administrative records, medical records or health insurance data. Secondary data analyses are widely used in healthcare system studies or pharmacological studies, to name only two. For urban public health, information on the quality and quantity of features of the built environment are of course crucial. So far, mainly used secondary data in urban public health are those about green and blue areas like parks or lakeside swimming pools for recreation. Many studies investigated pathways linking green space with environmental justice, health outcomes, physical activity, or social interaction.

Urban planning already uses well-known data sources like densities (population, buildings, traffic, …), development structure, street design and open space network, number and types of land uses, plot ratios, ground conditions or redevelopment, public transport, and many more. However, these data sources so far have rarely been linked to urban public health research objectives. One reason for this seems that conceptual approaches in public health incorporating explicit spatial perspectives from scientific disciplines such as spatial planning are still in their infancy.

Similarly, the tremendous potential of satellite remote sensing data has not yet been sufficiently appreciated in urban public health research. As a first satellite data application, the use of the *Normalized Difference Vegetation Index* (NDVI) was recommended as a standardized measure of green to investigate association with human health (Gascon et al. 2015). Several satellites, such as Landsat 5 to 9 are available as data sources for the calculation of the NDVI, providing a 30 m^2 resolution. The NDVI is calculated according to the level of reflectance of near-infrared and visible red wavelength spectra followed by the calculation of the distribution of NDVI (like mean, standard deviation) within buffers of interest using a geographical information system (GIS). However, although easy to access and convenient to work with, the conceptual implication needs critical appraisal. For example, objective exposure to green space is commonly measured either as surrounding greenness or access to green space (e.g., distance to nearest park), which are two different concepts. Applying the concept of surrounding greenness, the exposition can be measured within a certain area, often with a buffer around a residence or on district level using either land-cover data to calculate the percentage of green space or satellite imagery to compute the NDVI. Figure 2 illustrates the differences of the distribution of green space when applying the indicators of NDVI or proportion of urban green space. These differences require a thorough interpretation of their impact in terms of exposure markers as (positive) health factors.

Fig. 2: Distribution of the Normalized Difference Vegetation Index (NDVI) from 2015 and proportion of urban grean areas (2012) in 108 districts in Bochum, Essen and Mülheim/R, Germany. The figures depict the different results of the distribution of green when applying the indicators of NDVI and proportion of urban green areas. However, main hotspots of urban areas with less green are identifiable



The inclusion of secondary data in qualitative research has also been proposed for grounded theory approaches. An advantage identified is that these data sets might be helpful to build a theoretical understanding of complex social processes (Whiteside et al. 2012).

When using secondary data, it is necessary to find the most useful data set given the research question. Further, one needs to make sure the retrieval is feasible and the quality of the data sets is sufficient, e.g., with regard to missing data or methods of their collection. Lack of timeliness, or lack of sufficient detail to address the problem under surveillance are further challenges when using secondary data, as well as possibilities of record linkage with other data sources.

The following example from urban public health research describes a study that uses a set of secondary data sources. The *Acoustic Quality and Health in Urban Environments* (SALVE) project aims to measure spatial-temporal differences of the urban acoustic environment, taking into account the built environment, defined as land use types, and temporal changes. Sounds of urban regions have been a concern of architecture and construction engineering for years. In the context of health research, however, sound has been restricted to the risk factor 'noise', thus reduced to sound decibel levels. Accordingly, noise mitigation measures aim exclusively at the reduction of the noise level below a certain threshold. Soundscapes on the other hand, comprise all acoustic events of the natural and physical environment, which are determined by sound level, frequency, time and space. Soundscape ecology, which includes the study of spatio-temporal heterogeneity of sounds in different landscapes, provides a suitable methodical approach to analyse the relationships between soundscapes, the built environment and human health.

The projects started in 2018 as an interdisciplinary pilot project in the frame of the University Alliance Ruhr (UAR), involving researchers from public health and spatial planning. By taking year-long direct and automated auditory measurements of a robust land-use sample in the city of Bochum, located in the highly urbanized Ruhr Area of Germany, one of the largest multi-seasonal urban soundscape datasets has been established including more than 1.5 Mio minutes of sound recordings. The sound data is categorized into various soundscape metrics as well and is combined with comprehensive spatial data from various data sources of environmental agencies. Lastly, health and social data from the georeferenced longitudinal Heinz Nixdorf Recall (HNR) study (see above) will be used.

A random stratified sample that prioritizes polygons with participants of the Heinz Nixdorf Recall study locations was applied to locate all measurement field points. The target population for field recordings was chosen to maximize the spatial proximity of health reporting with field sound recordings so as to capture the soundscape of participant locations. Using 24 automated recording devices placed stationary in the field, the surrounding sound was recorded for five minutes each hour for 365 days.

Spatial parameters such as proximity of recording points to different features such as highways, city centers, and airports, availability of surrounding green areas and land-use mix were incorporated into the data set. In addition, other spatial datasets may include built area index (NDBI), park and recreation areas, road and rail corridors, urban density gradients (Corine Urban Atlas), natural ecoregion units, soil and geological units, elevation, physiographic regions and sub-regions, demographic and economic data of the general population, open water and streams, and bus and mass transit stations.

The novelty of this study derives from the idea of treating urban land use as a so-called "human habitat", and attempting to use sound as an indicator of habitat quality, similar to the use of bio-acoustic indices as a measure of the quality of non-human habitats. Furthermore, a temporally longitudinal set of recordings will be systematically gathered from the urban environment with both automated and direct recordings, which will ultimately become one of the largest soundscape datasets ever recorded in Europe, and can be used for a wide array of follow-up studies (Haselhoff et al. 2022;

Hornberg et al. 2021). Overall, the application of soundscape metrics in urban environments and their association with health information of the population will provide a deeper understanding of sound than tradition decibel-focused metrics used in noise-related studies.

3.4 Specific Tools for Urban Public Health Research

The following section briefly outlines specific tools for urban public health research that cannot be clearly assigned to one of the above specific categories.

Assessment Checklists and Surveillance Instruments

Overall, checklists are often designed as step in processes to identify health issues in urban environments and to determine if further assessment is needed (Pope et al. 2016). One of the most powerful tools, but also a challenging one, is the *Health Impact Assessment* approach using several different assessment checklists (Kemm et al. 2004) or the less voluminous *Healthy Urban Development* checklist (New South Wales Department of Health 2009). The checklist includes the systematic assessment and description of the urban environment as well as the resources and risks of the population, in some cases even the health status of the population group of interest.

A reporting or assessment level on the smallest possible monitoring/spatial scale should be aimed for, e.g., to be able to identify intra-urban characteristics of environment-related inequalities. In this regard, a newly emerged instrument seems promising: The *Healthy Streets* approach tries to cover what is almost the smallest urban entity, the street, and aims at a "human-centred framework for embedding public health in transport, public realm and planning" (healthystreets.com/what-is-healthy-streets 2021). The concept is based on ten evidence-based indicators representing the human experience with streets in different aspects (Saunders 2021). Besides directly addressing residents, the approach is helpful for designers and engineers to assess their work. *Healthy Streets* provides several publicly available resources like the *healthy street design check, healthy street index, how healthy is my street* and *qualitative street assessment*.

Often these instruments rely on using tailored comprehensive indicator sets, which are briefly depicted in the following.

Health Indicators, Health Indicator Indices

In urban public health research, classical topics include the analysis of spatial and geographic distributions and variations in health and environmental exposures. However, explicit small-scale intra-urban differences are rarely examined. The question of which small-scale urban health indicators or even indicator indices are best suited for systematically capturing the – especially small-scale – spatial distribution of urban health risks and health opportunities is currently under debate. The basic idea behind an index of urban health indicators is to bring together metrics from different disciplines to describe health and multiple contextual variables influencing health in an urban context. Choosing an indicator needs knowledge about its role and link to health.

Indicator frameworks can help to systematically structure the complexity of environmental health. For example, emissions of fine particular matter as part of air pollution is associated with multiple health outcomes. These emissions not only distribute unevenly geographically, but can also originate from traffic, agriculture or industry. This indicates different air pollution sources, which also necessitate different targeted measures. Moreover, in the case of traffic-related air pollution, traffic noise is an important concurrent risk factor for health.

As an example, known theoretical frameworks about environmental health indicator development and monitoring health vulnerability are the *Driving Forces, Pressure, State, Exposure, Effect and Action* (DPSEEA) with its extension *Multiple Exposures-Multiple Effects* (MEME) frameworks (Corvalán et al. 2000).

Exposure and Disease Mapping

Maps are an essential feature in the spatial depiction of specific health outcomes, diseases, and health related indicators, or exposures. The modern advanced possibilities of mapping, however, have only recently found their way into the field of public health. An important application field is health reporting on national and community levels. Here, maps are potent tools in documenting, understanding and advocating the health of the population and population groups. By mapping the distribution of health on a small-scale, e.g., inequalities can be visualised (as an example, see fig. 3). This information source is not only relevant for health reporting and (urban) planning but also for health policy measures in all policy areas according to the "Health in All Policies" framework of the WHO (2014).

Geographic information systems (GIS) are a well-known tool for merging, visualizing and analysing spatially heterogeneous data sources. A fairly new feature of GIS is the so-called "SoftGIS" approach, which combines quantitative and qualitative data assessment, allowing users to annotate positions on a map based on their own spatial perceptions and preferences, e.g., in their neighbourhoods (preferred paths, avoided or favourite places) and also to comment on them. Additionally, questionnaires included in the system allow users to collect additional non-geographical individual characteristics, such as health status, satisfaction, demographic information, or socio-economic status. In Helsinki, for example, the development of a master plan showed the potential of using SoftGIS for promoting participation (Kahila-Tani et al. 2019).

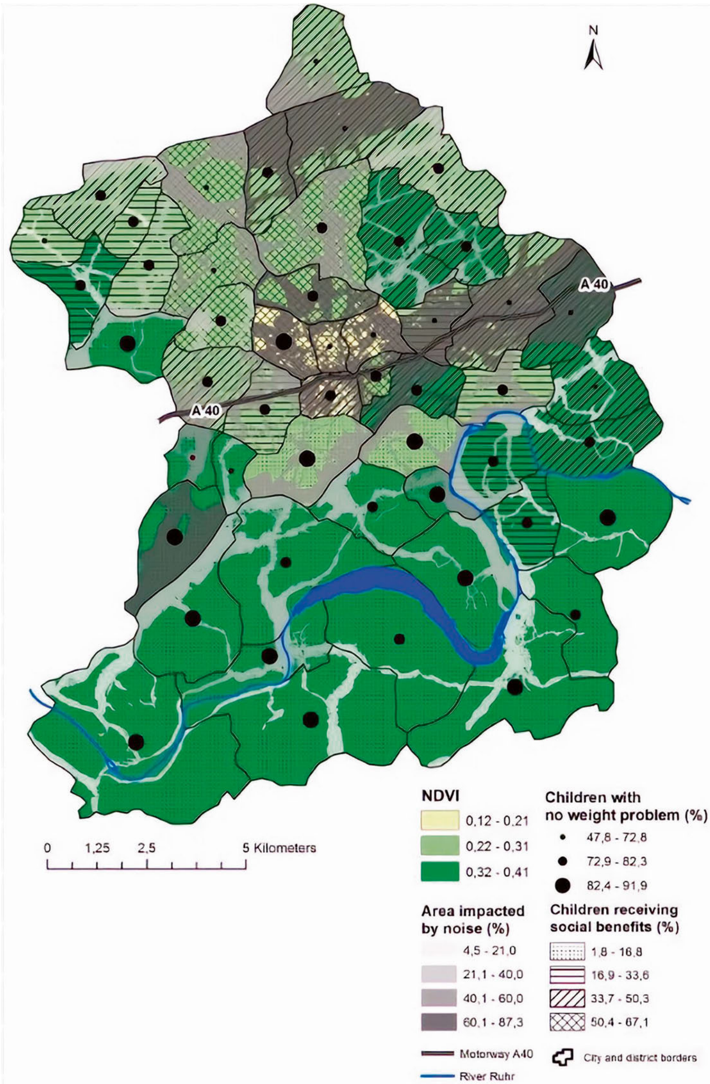
4. Empirical Approaches: Data Analyses

4.1 Measures and Rates

In very simple terms, epidemiology counts cases or health events, describes them in terms of time, place, and person, divides the number of cases by an appropriate denominator to calculate rates, and compares these rates over time or for different groups of people (CDC 2012). The basic aim of epidemiological studies is the analysis of the distribution and determinants of health and disease. Typically, main questions refer to one or all of the five "Ws": Which, Who, Where, When, Why – and how to change.

In principle, studies aim at a comparison either between subjects with and without disease (when interested in how subjects differ with respect to determinants) or

Fig. 3: Multi-layer map using the indicators 'greenness' (NDVI), 'noise' (>55 dB (A)), 'unemployment' and 'children's health'. Sources: Geodata and noise map, socio economic and children's health from City of Essen (2013–2017), NDVI (2015): U.S. Geological Survey (//earthexplorer.usgs.gov/). Cartography: Sutcliffe (Sutcliffe 2018)



between subjects with and without an exposure (when interested in how subjects differ with respect to diseases). To do so, subjects can be enrolled in a variety of study designs aimed at capturing diseases present (prevalence) or emerging (incidence) in a given time period. Prevalence measures the occurrence of a disease without regard to when the disease developed. The time period used varies and often even a day or other short period is the reference, the so-called point prevalence. Incidence in contrast is focused on newly developed disease cases in a given sufficiently long time period. Thus, e.g., subjects already diseased at the beginning of the study will not inform the incidence but will be counted as prevalent cases. Incidence therefore plays a crucial role in attributing a disease to a determinant, since a causal association implies the cause to happen before the outcome.

For quantitative analysis, disease occurrence is related to the study population. When the size of the study population is used as denominator, then the disease rates are termed "risk" and proportions are reported, e.g. 10 % of population is diseased. When the denominator is chosen as the time subjects were at risk of developing a disease, then rates or densities are reported, e.g., 10 cases per 100 person years.

$$\text{Prevalence} = \frac{\text{No of subjects with a disease in a given period}}{\text{No of subjects in the study population during the same period}}$$

$$\text{Incidence} = \frac{\text{No of newly diseased subjects in a given period}}{\text{No of subjects at risk of developing the disease during the same period}}$$

To cope with the principal aim of comparing disease occurrence across populations, the risks or rates will be calculated for each population separately and then combined in disease measures. Table 1 gives the three most important disease measures in epidemiological studies. The risk difference compares populations on an absolute scale, can be negative when diseases occurrence is higher in the unexposed population and is thought to highlight the public health impact of an exposure. In contrast, the risk ratio, often also called the relative risk, can never be negative. It is especially suitable for estimating the strength of a relationship between an exposure and a disease outcome. Risk differences and risk ratios do not necessarily lead to the same conclusion. For instance, the risk difference between exposed and unexposed subjects can be the same for two populations, but the risk ratios may differ vastly. Odds ratios finally differ from the other disease measures as the number of diseased subjects is not related to the total population (giving the risk), but to the number of subjects not diseased (giving the odds). Odds ratios in general overestimate the risk ratio but are a good approximation when the prevalence of the disease in question is small (e.g. 10%).

Tab. 1: Measures for population comparison

Subjects	***Diseased***	***not diseased***
exposed	a	b
not exposed	c	d

$$\text{Risk difference} = \text{disease rate exposed} - \text{disease rate not exposed} = \frac{a}{a+b} - \frac{c}{c+d}$$

$$\text{Risk ratio} = \frac{\text{disease rate exposed}}{\text{diesease rate not exposed}} = \frac{\frac{a}{a+b}}{\frac{c}{c+d}}$$

$$\text{Odds ratio} = \frac{\text{odds exposed}}{\text{odds not exposed}} = \frac{\frac{a}{b}}{\frac{c}{d}} = \frac{ad}{bc}$$

In environmental health research, effect sizes of a risk factor on a health outcome are often very small, implying little importance of the risk factor. However, since environmental exposures, like environmental toxins, air pollution or noise, often affect very large proportions of the population, even small risks can be of great health relevance. The SARS-CoV-2 pandemic drastically demonstrated this effect: Although hospitalization rates due to Covid-19 infection were relatively low, the sheer number of people 'exposed' to the SARS virus caused, e.g., the health care system to partially collapse, which in turn led to drastic measures being taken. Although prone to conceptual problems in its definition and interpretation, the *population attributable risk fraction* (PAF) is a widely used measure in epidemiology to assess the public health impact of exposures in populations. It can be interpreted as the proportion of disease cases that would be prevented following elimination of the exposures (Greenland/Robins 1988). The PAF thus relates the observed number of cases to the expected number of cases under no exposure.

$$\mathrm{PAF} = \frac{\text{Incidence in the whole population} - \text{Incidence in unexposed population}}{\text{Incidence in the whole population}}$$

4.2 Statistical Approaches

Given the multidisciplinary approach of urban public health, the full spectrum of statistical tools is utilized. However, regression analysis has become the most important and variable approach to data analysis. Regression analysis aims specifically at the quantification of the association between diseases and their determinants. In addition to the simple linear regression model, more complex associations are usually modelled within the framework of Generalized Linear Models, which offers a great variety of functions. Disease measures like risk and odds ratios can easily be estimated, e.g., by logistic regression or Poisson regression. Specific research questions can require more specific approaches like hierarchical or spatial regression models. However, finding the most appropriate model and statistical tool can be challenging, but can be guided by flowcharts directing users through stormy waters. For example, decision trees are currently provided to select the best multilevel modeling approach for longitudinal (and cross-sectional) spatial data based on changes in characteristics of the contexts. The best approach is decided on by asking questions about evidence of spatial confounding and changes in the characteristics of areas over time. The decision tree is helpful in navigating diverse statistical models when participants are nested within geographical areas or for which all variables are initially measured at an areal level or aggregated to a common spatial resolution that might be of interest to health research. The methods are based on a tradeoff between accuracy to retrieve regression coefficients, a model's goodness of fit, and time needed to complete the fit. These tools are accompanied by information to help applicants to choose the appropriate software packages when analysing data using regression analysis, particularly when a spatial effect is possibly present (Djeudeu et al. 2022).

4.3 Bias

The validity of empirical studies rests on many assumptions. Study results can deviate systematically from the 'true' results for various reasons. This bias leads to either an overestimation or underestimation of the 'true' exposure-disease relationship. Three types of bias are of general importance: selection bias, information bias, confounding. Selection bias is said to occur when the study population is different ('not representative') from a population originally targeted, e.g., subjects eligible for inclusion in a study might have refused to participate. Information bias is the general term for many bias sources like, for instance, a differential remembering of exposures between diseased and not diseased subjects (recall bias) or the inexact identification of diseases (misclassification). Confounding is a bias occurring when an association between exposure and disease is distorted by another known or unknown variable. A confounder therefore is a factor that partly accounts for the observed effect of a risk factor. Avoiding confounding is a central topic widely discussed in empirical studies and is addressed by a great number of methods in all phases of the study course. A helpful tool, especially for the analysis of causal effects, are directed acyclic graphs (DAG). These support epidemiologists in selecting *a priori* relevant confounders for their association models, avoiding both overfitting and potential unintended consequences of commonly used methods such as conditioning on mediators (simplified examples for using DAGs to gain important insights in neighbourhood health effects research are given in Fleischer/Diez Roux 2009).

Further methods and instruments are methods for modelling complex systems, e.g., agent-based modelling, optimizing stochastic techniques (based on the use of random numbers and probability statistics to investigate problems) and verbal models (cf. the chapters by Rienow; Westerholt; Weyer et al.; Gönsch/Gurr in this volume).

5. Remaining Issues and Perspectives for Further Research

Overall, how to identify which characteristics of the urban context are modifiable, and under which circumstances, is an important theoretical and empirical (urban) public health question. Often, more content-related topics relate to the impact of spatial context and neighbourhoods on resident's health. These concerns have developed into a major research focus in recent years (Diex Roux et al. 2010) with research on physical activity, green space, and various health outcomes coming to the fore. Thus, research on the processes through which the urban context may affect health and on further elucidation of these processes still remains a major issue (Galea/Vlahov 2005). Likewise, the best measures to assess the physical environment relevant to health need investigation, accompanied by the research question how these measures relate to health in urban and suburban environments.

One focus of urban public health research is to deepen knowledge of how urban social characteristics, structures, migration flows, and interaction patterns affect health. There is already an enormous amount of knowledge about how poverty affects health. However, information on the association of economically deprived urban populations is still missing (O'Campo/Yonas 2005). For instance, although concerns regarding the impacts of gentrification are increasing, few studies to date have analysed gentrification effects on health. First studies show that gentrification is associated with worse self-rated health and higher risk for preterm birth for Black residents, but not for all residents (Diez Roux 2021, 97). Similar to this is the issue of environmental justice with its human health implications relating, for instance, to degraded urban landscapes and environmental quality.

An emerging concept relates to the urban microbiome, a complex ecosystem including a myriad of microorganisms – from sewers to roof (gardens) – that interact with the environment as well as with humans. In combination with the roles of, e.g., the immune system and the growing understanding of epigenetics (meaning the study of heritable phenotype changes that do not involve alterations in the DNA sequence, Bird 2007) and environment-gene-interactions, an intriguing research field arises. For instance, gaining an overview of the situation of the local antibiotic resistance situation by sampling and analysing wastewater is a promising approach providing complementary health data at lower costs compared to testing an equal number of individuals living in the same area (Schmiege et al. 2021). Using the example of antibiotic resistance, identified by the WHO as the greatest challenge to global health, urban wastewater epidemiological methods are developing to analyse the spatio-temporal variation of the resistome in urban wastewater (which means the collection of antimicrobial resistance genes in the wastewater), taking into account small-scale socio- and environmental diversity. The innovative approach of wastewater-based screening creates an evidence base through short and long-term monitoring and mapping of temporally and spatially varying health-related conditions – at neighbourhood, community and regional levels. This is of great interest especially from the perspective of planning and public health (cf. also the essay by Hupało et al. in this volume).

Common epidemiological methods so far have failed to address the complexity and dynamism of urban systems due to their narrow problem definitions and mainly reductionist, often linear analytical representations. Systems thinking in general and systems dynamics in particular are relatively new approaches in public health. These methods for modelling and analysing the complexity underlying urban processes seem promising for effectively designing urban public health interventions (Tozan/Ompad 2015). This concept has not yet been linked to one of the most challenging new research concepts, which aims at analysing the so-called exposome. The exposome is supposed to address the complexity, dynamics, and contextuality of environmental and societal influences as a whole from a life course perspective. In that, this approach aims to overcomes the traditional epidemiological approach of one exposure-one outcome at a given time period (Haddad et al. 2019). Furthermore, novel methodologies and tools are currently considered for better assessment of the human exposome, including approaches using –omics technologies (genomics, proteomics, transcriptomics, and metabolomics), personal samplers and wearable sensors. As a result, new biometrical and computational methods have emerged, such as the environment/metabolome-wide association study approaches. The metabolome refers to a whole set of chemical compounds found within a biological sample (like nucleotides, aminoacids, lipids). However, their applications and interpretation are still in their infancy and need careful and thoughtful refinement. By targeting urban areas, the exposome framework could lift urban public health studies to a new, more complex level. First large EU research collaborations use diverse data sources (including data from participatory processes), apply statistical methods according to the complex data structure (e.g., machine learning), pursue both a pathogenetic and a salutogenetic view (health-promoting environmental resources), and systematically integrate aspects of social inequality. Their results will show whether the expectations of modelling complex and dynamic exposure patterns is feasible, and it remains to be seen if the challenging concept will establish new methods of data collection and analysis.

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IV Metropolitan Culture(s)

Storytelling

Julia Sattler

1. Preliminary Remarks

Since the 1980s, the concept of storytelling has moved beyond the literary and cultural arena into other dimensions of public life. It has become a subject of interest in fields of research and application beyond the Humanities, among them Design, Management, Marketing, Economics, Geography and Urban Planning. Starting from an outline of the so-called 'story turn' in these disciplines as well as from a short reference to the 'spatial turn' in the Humanities and Social Sciences that makes for much potential for interdisciplinary cooperation, this contribution outlines the potential and challenges of storytelling as a tool and as a practice for the metropolitan context and metropolitan research.

Highlighting the role of stories and storytelling for spaces, specifically urban spaces, it focuses on the importance of storytelling in relation to the constitution of space and the creation of a locally specific spatial identity. Context-wise, it looks at the work that has been done in the area of Urban Planning in relation to storytelling, both in research and in practice. This also means that, outside of the more general approximation to the topic, storytelling here will be defined mostly in relation to functional storytelling in the public arena, leaving out other dimensions usually subsumed under the same term, such as storytelling in the family context, the religious or ritual contexts, and so on. In its analytical part, the paper addresses examples from the United States and from Germany before concluding with questions and recommended literature for further consultation.

2. Framework and Contexts

In the past three decades, several disciplines, including the Social Sciences as well as Architecture and Urban Planning, have gone through a conceptual and methodical shift that is sometimes referred to as the 'discursive turn' or 'story turn.' As these descriptors suggest, the shift points to an openness toward ideas from the Humanities, which traditionally work with concepts and ideas such as discourse, narrative, story and image creation. With special consideration of the urban fields of inquiry, Goldstein et. al. (2015) suggest that there has been a "cultural turn" among urban scholars, which has led to a more nuanced and flexible understanding of the city and of urbanity, both of which are now conceived of as more than empirical, quantifiable entities. Stories and the engagement with storytelling as a cultural practice offer alternative ways to conduct research as compared to the work with data and hard measurable facts. This leads to "a mode of planning that is based on 'being-in-the-world' rather than being apart from it" (Throgmorton 1996, xix).

Stories and approaches shaped by storytelling give access to an affective domain of the city, to its psychogeography and its multiple historical, cultural and social layers. It also enables an insight into the construction of urban narratives, which are larger patterns or units of discursive construction, and basically the result of multiple stories working together to create specific ideas about the city more generally, or one particular city. Building on that, Urban Planning, Architecture and related disciplines can make use of this knowledge when developing new projects, or in the context of urban regeneration efforts. In these fields, a careful analysis of the storytelling behind a project can also contribute to explaining why an approach may have been less well received or why it may even have failed.

Pauwels places the emergence of the "story turn" at the origin of the "era of emotional capitalism" (113) in the United States of the mid-1980s. This shift in thinking was the result of business and politics beginning to take storytelling more seriously following "the influence of European intellectuals like Mikhail Bakhtin, Roland Barthes, Umberto Eco and Paul Ricoeur" (2020, 112), who all emphasize the importance of stories in the creation of meaning. The interest in storytelling first emerged in Marketing as part of a new form of "aesthetic capitalism" (Pauwels 2020, 114) that aims to convince the audience of a product via the directed use of stories, thus making use of the functional aspects of storytelling. Similar shifts occurred in other fields, transforming areas of research that had previously defined themselves via their strict use of quantifiable data into fields occupied with the human creation of meaning. It is evident that in the contemporary era, every dimension of public life is shaped by storytelling. This includes the stock markets, for example, which undergo changes depending on expectations voiced in the form of storytelling (e.g., Shiller 2019).

Christophe Mager and Laurent Matthey (2015) attribute the emergence of the idea of the "urban planning narrative" to Secchi (1984), who "drew […] the attention of planners to the production of myths." This shift contributed to changing the understanding of the planning discipline toward one "centred around the production of images" (Mager/Matthey 2015, 2), and enabled a focus on stories. By the second half of the 1990s, James A. Throgmorton had established the idea of urban planning as a type of storytelling under the header of the "argumentative" or "rhetorical turn in planning" (1996, 36). Building on Martin Krieger (1981) and other scholars who had commented on "the importance of storytelling in planning, analysis and the social sciences" (Throgmorton 1996, 46), Throgmorton states that the crucial recognition leading to an interest in texts and in storytelling was that planners and planning as a profession can profit from knowledge about storytelling both financially as well as in terms of their dealing with fieldwork

(1996, 52ff.), again pointing to the functional understanding of storytelling that shapes the discipline's approach to and work with it.

Still, the approaches developing out of the 'story turn' in the arena of Urban Planning and connected fields ranging from Urban Design to Human Geography speak to the importance of imagining the city beyond its mere constructed spaces (Sandercock 2010, 18). Working with spaces via storytelling takes into account "the relationship between personal experience and expression, and the broader contexts within which such experiences are ordered, performed, interpreted and disciplined" (Cameron 2012, 573). Evidently, Michel Foucault's findings on discourse and discipline play an enormous role in the shift that is often termed the 'story turn.' According to the French philosopher, knowledge and meaning are produced via so-called discursive formations that are in turn shaped by power and power dynamics (Armstrong 2012, 29). Via their constant circulation, discourses create meanings and normalize certain behaviors or approaches as opposed to others and thus intervene into all possible areas of the real world. To work with storytelling in any capacity presupposes an (at least implicit) understanding of the workings of discourse and of narrative.

A discussion of storytelling in relation to urbanity and Urban Studies cannot do without the turn in the opposite direction, however briefly, and focus on the development referred to as the "spatial turn" in the humanities. Döring and Thielman (2008) argue that the term "spatial turn" originated in geography, specifically in the research of Edward Soja in *Thirdspace* (1996). In this work, Soja called for the renewed inclusion of the spatial dimension in research conducted in the Social Sciences as well as in geography itself. The suggestion was picked up by other fields, and especially in the humanities, which led to the recognition how developments and processes manifest themselves spatially (Presner et. al. 2014, 69). Many of the studies undertaken under the header of the "spatial turn" in the Humanities have remained curiously disciplinary instead of establishing a research agenda interlinking the Humanities and the built environment or planning practice, and "the perceived gap between a supposed 'urban fictionality' and a supposed 'urban reality' persists" (Sattler 2018, 124).

Taken together, these two developments – the 'story turn' and the 'spatial turn' – have led to a greater openness of various disciplines towards each other and to new approaches in all fields involved, but especially in those relating directly to the urban arena. They have contributed to the emergence of new conversations in relation to sustainability (e.g., Eckstein and Throgmorton 2003), urban design and landscape planning (e.g., Childs 2008), public housing (e.g., Vale 2013 and 2018) and the development of the post-industrial city (e.g., Eisinger 2003; Doucet 2018). In studies of this kind, a focus on storytelling and communication has led to conscious engagement with questions of power and knowledge, as well as with the stories' specific roles in urban contexts. They have also resulted in the increased visibility of approaches in research and in practice that highlight storytelling as a tool in Urban Planning and as a way to improve planning practice.

3. Story and Storytelling: An Approximation

The practice of storytelling is deeply engrained in human history and identity – the human being is often referred to as a storytelling animal. Humanity is here defined by stories and by storytelling. Still, there are different understandings of what a story is, what kind of information it should contain, and how it should mediate this information: "For some story is an object of knowledge, for others a form of practice, and for others it is a mode of academic expression" (Cameron 2012, 575). This makes it difficult to come up with one definition of story or of storytelling. The same is true for the effect of stories, which is the subject of an ongoing debate in the Humanities and Social Sciences alike: While it is possible to examine stories circulating in the public arena to come to conclusions about discursive formations at a defined moment in time, such conclusions are not automatically given, nor are they ultimately required for every process of storytelling (cf. Cameron 2012, 580).

One factor that is common to storytelling despite the heterogeneity of definitions is that storytelling is always an act of volition. Stories cannot tell themselves, there needs to be an individual or a collective telling them. In this way, stories are passed on from one person to another, or from one group of people to another. The process of passing on a story can transgress boundaries, such as generational or national ones. Stories can contribute to building communities and to the establishment of a shared identity and shared knowledge. Stories can, but do not necessarily have to, go beyond those facts and "produce ethical relations between otherwise distant and unequally positioned subjects" (Cameron 2012, 583). For the purpose of a definition, the stories and texts addressed here may be oral in form, they may be constituted of written words, but they may certainly also come in different media formats, including representations in films and on websites. Storytelling is increasingly being undertaken in relation to forms that are usually considered non-narrative, such as data and statistics. In this context, storytelling serves to make data accessible (Vora 2019, 17) and to support data-based processes of decision-making (Vora 2019, 14).

Sandercock (2010) has shown that storytelling contributes to the production of urban knowledge. It establishes the city or the region from a more subjective perspective than statistics would, thus linking up to the idea of converting data and facts into "stories" mentioned above: Empirical data only assumes meaning in the context of a story. Storytelling can thus contribute to practices of placemaking (de Certeau 1974; Rose 1993). In the urban or metropolitan context, storytelling is one way how the past, the present and the future of a site – a neighborhood, a town, a city, a region – are constructed and conveyed to others; stories are indeed constitutive of perceived "realities'" (Throgmorton 1996, 46). An action in the past and its consequences become imaginable via the use of words combined into storylines that provide an answer to the question how the site has become what it is. Stories can also point out potential paths towards a site's future developments. This does not mean that telling a story about something automatically makes it 'real.' But especially when using stories in order to further certain arguments, e.g., relating to the use of a structure or an urban area, these stories will need to be able to connect to the perceived 'reality' of that site to be understood, or, to speak with Throgmorton, they need to be "persuasive" (1996, 38ff.).

Certainly, in the context of a community, this also means that not everyone can tell every story, or that every story will be heard to an equal degree, or by the same listeners. Barbara Eckstein goes so far as to say that "[m]ost storytelling – arguably all storytelling – is about setting community boundaries, including some audience members within its territory and excluding others" (2003, 13). Hence, storytelling and personal and community agency are closely intertwined. In the postmodern era, debates about which story should be told, and how, and by whom, have moved to the public arena and form an important part of the ongoing debates about visibility and about social justice. Storytelling and identity politics are intimately interlinked. Recent social movements such as Black Lives Matter show that urban space is loaded with oftentimes unrecognized and implicit meaning, and that the question of who can take ownership of the city is strongly linked to such construction of meaning.

Every story depends on interpretation; and personal experience plays into this process (Cameron 2012, 574). While generally, a story aims to convince the reader of a certain reading and the author can try to support a specific reading, it is not possible to predict how readers may perceive a story and whether they may have a completely different understanding of it as compared to what the author envisioned. In the literary fields, approaches such as reader-response theory and reception aesthetics answer to this gap.

In relation to the audience, stories need to make use of an accessible language. The wording must be age-appropriate and amenable to readers and/or listeners in a way that keeps them interested. A good story pays attention to this on several levels: "An effective story […] fully exploits the materials of time (duration, frequency of repetition), time-space (chronotope), and space (scale, perspective, remoteness), deliberately arranging them in unfamiliar ways so that they conscript readers who are willing to suspend their habits of being and come out in the open to engage in dialogue with strangers" (Eckstein 2003, 35–36).

There is no prescribed length for a story, but those stories used in the planning-related field are often brief. For the purposes here, a story is understood to be a construction which makes use of methods and tools as well as conventions, such as those relating to the establishment of one or more specific points of view, as well as the use of metaphors, symbols and other forms of imagery. These kinds of stories can certainly be generic, especially when used in the context of marketing and branding efforts, or to communicate the effectiveness of a suggested plan, but that does not mean they cannot be sophisticated at the same time. Ben Highmore (2013) has explored the significance of metaphors in relation to urban spaces. He has shown that images relating to health are crucial not only to talk about urban spaces and their inherent qualities (e.g., the park as a "lung" of the city), but also regulate who has access to these spaces, and what will happen if such limits of access are transgressed.

In addition to imagery, emplotment is crucial to storytelling. This is also the case even in its mostly functional form as used in plans or marketing documents: While stories can be voiced in any arena, not every utterance is a story and "[t]elling stories is not just listing events" (van Hulst 2012, 300). The so-called plot, in which events build on each other (e.g., via a pattern of cause and effect), connects "story elements in such a way that they form a coherent whole" (van Hulst 2012, 300). Storytelling commonly means that there is a defined setting for the events to happen, and that there are characters who react to and interact with their environment and with each other as part of the plot. Like this, for example, different groups of actors (the characters) can become included in the story in the interest of promoting more diversity. It also enables readers to imagine what a future scenario might imply for different interest groups, such as different minorities living together in the shared space of a densely populated urban quarter. This suggests that at least ideally, stories attain to a democratic quality of dealing with urban space and offer potential for discussion.

Thus, stories and storytelling processes in the context of a planning project can help to establish a dialogue between different groups in a population (e.g., different groups of inhabitants in a neighborhood undergoing urban renewal) and may lead to heightened empathy and trust between those involved (van Hulst 2012). But this factor also impacts what kinds of stories can be told. Traditionally speaking, a 'good' storyline will come in the shape of a conflict, a crisis, and ultimately, its resolution. This represents an instance where the characters undergo a development and fundamental change (Throgmorton 1996, 49). A positive outcome, i.e. ending – for example the acceptance of a proposal and its positive results for the future of a neighborhood – is already part of the process of storytelling in this particular context. Thus, these kinds of stories come with a particular agenda or goal and are by implication limited in their potential for unexpected outcomes. They are in that sense always results of a compromise.

Still, not all storytelling is inherently good or leads to more inclusiveness and diversity. It bears remembering that there will never be a situation in which everyone's story can be told and taken into account. By implication, storytelling practice should only be used if there is indeed space to include what is learnt in the process, so as to avoid misunderstandings and false expectations on all sides involved. Throgmorton stresses the ethical aspects relating to the idea that stories are constitutive in the creation of spaces and beyond. It is crucial, then, to ask how a community should develop, and which stories should be used in these contexts (1996, 52).

Moreover, since it steps beyond the rational paradigms of traditional planning, storytelling and storytelling research can support or even enable interdisciplinary dialogue between the planning-oriented disciplines and fields in the humanities. This can be productive in the context of the emerging discipline of Urban Cultural Studies. Here, the publications of Buchenau and Gurr (2015, 2018) and Eckstein and Throgmorton (2003) bear mentioning. At the same time, the focus on storytelling has led to a myriad of complex questions relating to urban culture, such as whether cities can indeed be "read" like texts (as claimed by Throgmorton 1996) and what such a reading process may mean in relation to the built environment and its semiotics (Hassenpflug et. al. 2011).

4. Storytelling and/in Urban Planning

In his monograph *Planning as Persuasive Storytelling*, James A. Throgmorton calls for an entirely new understanding of Urban Planning as a field of research and practice. He suggests for those in the planning profession to take into account that "planning can be understood as a fragmented and heterogeneous mix of stories and storytellers in which no one rhetoric has a *prima facie* right to be privileged over others" (1996, 38, italics in the original). Following this understanding and interlinking it with knowledge about storytelling, those who plan for a site are creating texts (maps and plans, for example) which "interpret the city *and* planning" (Throgmorton 1996, 38, emphasis mine).

This suggests they are authors engaged in a dual process. In this process both an understanding of the city-as-text as well as of the process of its development (via planning) is shaped. The resulting text – a second-order text, as according to Throgmorton it is a text about another text, namely the city – is then read and interpreted by others: by citizens, but also, for example, by political authorities or the sponsors of a project. Planning becomes a field inherently concerned with texts of various kinds. This also concerns its dealings with maps and with treating data like a narrative text.

Since Urban Planning focuses on the creation or re-creation of sites at a point of time in the future, it is especially the future-directed form of the story that helps envision a situation that is not there yet: "[W]e can think of planning as an enacted and future-oriented narrative in which the participants are both characters and joint authors" (Throgmorton 1996, 47). Here, stories can serve to inspire and motivate change in those reading, watching and/or listening. Storytelling and related activities create space for citizen participation: Citizens working with planners become authors of their own planning-texts. Via such activities, planners can support trust and empathy. This may lead to a higher acceptance of spatial changes. Storytelling can contribute to successful facilitation processes and to building stronger networks and alliances (Goldstein et. al. 2015, 1299).

At the same time, stories need to be composed bearing in mind that there is an audience who will either be persuaded by them or not. In what Throgmorton terms a "rhetorical approach to planning" the focus would have to be on finding those elements which are especially persuasive to the audience. This suggests that there are specific characteristics of a planning story that make it convincing. These can be learned by planners and their affiliates and then used for this purpose: "[P]lanning can be likened to good fiction and […] planners are future-oriented storytellers who write persuasive and constitutive texts that other people read (construct and interpret) in diverse and often conflicting ways" (Throgmorton 1996, 46). From a Humanities perspective, it is debatable whether one can indeed 'learn' to write a good story building on one's knowledge of writing techniques and conventional storytelling elements alone. In addition, everybody is embedded in their own story and identity, which is sometimes difficult to recognize and disassociate from in the process of writing a story with a specific purpose.

In the context of Urban Planning, it is possible to differentiate between efforts to "combine the urban planning narrative with storytelling and to establish storytelling as a prescriptive or descriptive model for planning practice" (Mager/Matthey 2015). While some approaches focus on "storytelling as a model *of* the way planning is done", others concentrate on "storytelling as a model *for* the way planning could or should be done" (van Hulst 2012, 299). The first approach equates processes of planning to storytelling, while the second looks at how planning practice can be made better via stories (van Hulst 2012, 302–303).

According to Throgmorton, who has also served as mayor of Iowa City, planning as a practice can be equated to the practice of storytelling. His statements link planning with persuasive storytelling about the future. The stories planners work with are not isolated from their social settings, but rather, for a plan to be successful, planning stories need to resonate in them. Throgmorton's approach stresses the likeness between the practice of Urban Planning and the practice of storytelling and helps consider planning-related documents from their conception to the finished masterplan as stories following defined guidelines. This understanding, which does not investigate that a planning process also contains other parts, such as finance planning or environmental considerations, at least indirectly suggests that for planners to become better at persuading their various audiences – from the city council to the company holder to the general public – they need to tell better and more convincing stories. Planning practice thus can improve its persuasiveness by taking its lesson from storytelling. It is important to note that this improvement in and of itself does not say anything about the role of social justice or equality in the context of a project.

Still, such 'better' stories can potentially help different interest groups in a planning process to be able to follow each other's arguments and counterarguments in relation to a plan. This understanding is representative of storytelling as a model for a better planning practice. Leonie Sandercock argues that "planning is performed *through* storytelling" (2003, 12, emphasis mine). Storytelling can be useful where conflict resolution is needed or where several parties need to be heard in order to carry out a project. In this instance storytelling becomes a model *for* planning, a 'tool' that can be employed by the experienced practitioner to be more effective in working towards positive change. In practice, both conceptions of storytelling work hand in hand and share many characteristics. Any approach in Urban Planning that centrally focuses on storytelling – be it as a model *of* planning or as a model *for* planning – is likely not an instance of bureaucratic planning but one that involves the community and necessitates a dialogical approach (van Hulst 2012, 303f.).

While there are different ways of telling a story, "[i]n planning, like in politics, if you want to persuade actors of the necessity of change, it seems that you first have to tell a story about decline" (van Hulst 2012, 310), which can then be followed by a story of hope. This suggests that there is a formula for storytelling in relation to Urban Planning, and that there are indeed storytelling rules to follow: "Collaborative planning stories are both descriptive and normative, making sense of the world while providing guidance for change amidst turbulence and uncertainty" (Goldstein et. al. 2015, 1297). This comes with ethical implications – storytelling about decline, as a force constitutive of reality, can also contribute to the very production of decline, for example (e.g., Beauregard 1993).

5. Storytelling and Planning Practice

Storytelling has been used in planning practice for a long time, though it has not always been referred to in this way. Rubin (2010) has shown how the use of detailed imagery of the living conditions of the poor in New York City in the famous work of the Danish-American journalist Jacob A. Riis has contributed to social reform and a betterment of the living conditions in the tenements of large metropolises (*How the Other Half Lives*, 1890). One potential question is how contemporary ways of including storytelling relate to earlier such efforts at social progress—in how far Riis may be read as an early advocacy planner—especially when it comes to the correlation of storytelling with contemporary identity politics.

In his 1996 study *Planning as Persuasive Storytelling*, Throgmorton uses the electrification of the city of Chicago as an example of how planners used storytelling to carry out the project of modernizing the city. In this context, storytelling is used to forward technological progress and to promote social equality. In *The History of Forgetting: Los Angeles and the Erasure of Memory* (1997), Norman Klein points out the imagination and construction of Los Angeles via storytelling. He emphasizes, for example, the strategic use of "classic booster language" (2008, 27) across several decades and shows how carefully designed promotional stories shaped the city's layout and its policies of public transportation, but also the development of its industries. Here, studying past instances of storytelling and its uses enables today's planners and others to recognize the intended and unintended effects of the practice and can make for a more careful dealing with the subject of storytelling, but also with questions of equity.

Storytelling and storytelling practices in an urban context also come into play when advocating for urban regeneration and redevelopment projects. With regard to the city of Detroit, storytelling has been used in the context of urban renewal efforts in the 1950s in order to make space for a highway and erase a predominantly African American neighborhood (Thomas 1997). Thus, while storytelling and the use of stories bears much potential for bottom-up processes including the citizens, there are examples where stories have been used in the context of top-down projects and where this has led to less acceptance of a plan despite its inclusion of a story.

The use of storytelling in the context of top-down processes is still relevant in the contemporary post-industrial setting of Detroit, for example in relation to the *Detroit Future City* plan, which, as Daniel Clement and Miguel Kanai show, is not citizen- but corporate-oriented and "may exacerbate the racialized spatial injustices" (Clement/Kanai 2015, 369). This is evident, for example in relation to the designation of the city's most disadvantaged neighborhoods as "'innovation landscapes'" (Clement/Kanai 2015, 369), which in the long run may enable their clearance for new purposes, much akin to the erasure of the "Black Bottom/Paradise Valley" neighborhood during urban renewal. A similar focus on economic progress can be detected in relation to the storytelling of investment projects by private individuals, such as those of Dan Gilbert. These projects work using powerful slogans of "opportunity" while not taking into account "social justice and educational possibilities" (Sattler 2018, 131) for all citizens alike. It is certainly not a coincidence that in recent years, in the context of large-scale and oftentimes private redevelopment efforts in the city that do not follow a holistic plan or "story" for Detroit, investors have been compared and linked to colonizers (Sattler 2018, 131).

In terms of contemporary projects, the European Capital of Culture (ECoC) is an urban regeneration project that explicitly makes use of storytelling and larger narratives about the future of a post-industrial region. For ECoC 2010, the idea of the German Ruhr Region turning into a 'new kind of metropolis' was established. Here, the organizers developed a larger narrative about urban regeneration using many local and localized stories to build a new post-industrial identity for the region. While the participatory approach of the ECoC was recognizable in the program and contributed to the citizens' feeling pride in relation to their local history, the idea of a 'metropolis in the making' was by and large rejected. This was due to the already existing structure and identity of the region, which consists of more than fifty larger and smaller cities and townships and does not fit the established definition of a metropolis (see Sattler 2020; Reicher et. al. 2011). While the ECoC, which is funded by the EU, is always evaluated, a relevant study with regard to storytelling and the ECoC has been undertaken in Matera in Italy (Iaffaldano/Ferrari 2020).

In relation to storytelling and its use in projects, a critical question to ask relates to citizen agency and the uses of the practice. If storytelling becomes a tool for advertising a planning project, citizens may react very differently as compared to a situation in which they feel their own stories matter and become represented in the plan. Storytelling as used in relation to the Creative City established by Richard Florida could be one example of how stories are utilized in the context of large-scale investment projects, also on a global scale.

6. Further Points of Connection and Contention

Now that stories and questions of storytelling have become recognized as a productive source for research as well as an idea to be used by planners in their daily work, there is plenty of material to focus on in the urban context, but certainly also beyond. Much potential lies in asking how exactly urban planning documents include local and other stories. There may be much to gain from a study of how these documents convey and establish urban knowledge, and how this can be used in different disciplines working with cities and practices of city-making. Similar questions can be asked in relation to 'unusual' formats of storytelling and their potential for planning: filmic documentaries, for example, or poetry, would be genres needing further inquiry.

The emergence of digital formats and digital tools of urban research and exploration opens up new possibilities for planning in conjunction with storytelling. Sandercock and Attili (2010) call for an investigation of how voices that usually remain unheard in planning processes might become included, and how the new media may contribute to such processes. Investigations in this direction have been undertaken by Hallenbeck (2010) for Vancouver and by Wagner (2010) for New Orleans. Any planning process including storytelling and community inclusion necessarily needs to address questions of power, and of the complexities emerging in planning processes where planners are outsiders in relation to the communities they plan for. Here, many questions remain open in relation to the ethical complexities of speaking for others (Sandercock/Attili 2010, 326) – this is especially true in the 21st century, when speaking has become very politicized again.

With regard to planning education, Sandercock (2010) calls for a detailed discussion of storytelling and its potentials for a more interdisciplinary curriculum in the field. Already in 2003, Barbara Eckstein had argued for the establishment of better and more analytical tools for planners to critically re-examine storytelling. She remarks that the equations that have been established linking storytelling to planning processes are often not as clear at a second glance, for example because, while the author of a story or other publication is often one particular individual, in reality "[g]roups or institutions produce plans" (Eckstein 2003, 15) rather than individual persons. In addition, plans are written with a specific aim in mind and thus the "storyteller is narrating to control the action of others" (Eckstein 2003, 20). The kind of storytelling that matters to planning is storytelling with an intention, which is less deconstructive compared to the type of storytelling fiction focuses on. Eckstein warns planners to be more careful in dealing with the material and argues for the need to introduce planners to "explicit knowledge about how stories work as narrative forms" (Eckstein 2003, 23). That said, one should not neglect the potential of storytelling or of the planner as a kind of storyteller who can acknowledge heretofore untold stories, once more advocating for the inclusion of this kind of knowledge into planning education.

In the Humanities, there has also been encouragement to include plans and maps in teaching (Sattler 2018). Vormann (2018) and Wendt (2018) wish for greater recognition of interdisciplinary research and teaching in American Studies, a field that has traditionally understood itself as interdisciplinary, but tends to stick close to other Humanities instead of engaging with such fields as Architecture, Urban Planning or Engineering.

What unites these approaches and appeals is the quest to find the right words and a new terminology: If "storytelling claims to be politically and theoretically transformative, we need a better vocabulary and critical framework with which to assess such stories, and to determine whether they deliver on their political and theoretical promises" (Cameron 2012, 586). These findings call for both greater attention to detail, but also for more investigation of the process of storytelling and its potential for urban development and related fields. Such research will need to clarify how storytelling is related to processes of urban scripting at large. Storytelling will also have to be regarded in close relation to larger narratives and their formation.

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Narrative Analysis

Julia Sattler

1. Preliminary Remarks

While narratives and storytelling are closely intertwined and have contributed to the "story turn" or "narrative turn" in Urban Studies, it remains difficult to delimit the terminology that has emerged in this context. There is as yet no comprehensive theory on the use of story and narrative in Urban Studies.

Following an approximation to the terminology shaped by its understanding in the Humanities and Social Sciences, narrative will here be discussed in relation to the urban arena. Examples are taken from Europe as well as from the United States, where the idea of foundational cultural narratives shaping the nation and its identity as well as the citizens' understanding of their role in it via these narratives is rather established. The outlook points out further potentials of an engagement with narrative in urban research, in urban practice as well as in teaching.

2. Narratives: An Approximation

In recent years, the term "narrative" has become rather fashionable – it is used in many different contexts, and it is also attributed more than one meaning. Bearing this in mind, it is unsurprising that a discussion about "narratives" has also gained foothold in Urban Studies, Metropolitan Studies and other fields engaged with the construction and analysis of urban spaces. In the literature, there are several instances where the term "narrative" is used interchangeably with the term "story" and where it appears that storytelling is the same as constructing a narrative, which contributes to the dilution of terms, and to the difficulty of finding a comprehensive and precise working definition for these and other fields of research and practice.

A narrative, briefly defined, is a collection of stories. It is the result of processes of storytelling, a kind of discourse that can contain several different medial forms and several different storylines. It is a significantly larger entity as compared to a singular story – a collection of stories builds a narrative, and not the other way around.

Here, a "story" does not necessarily have to be a written text or the kind of story that is told at the dinner table in a family. Media reporting also engages with storytelling, as does film, as do processes of mapping, and so on. A narrative is the result of such different stories merging with each other and shaping into a new 'whole.'

It is possible to differentiate story from narrative on the basis of the different degrees of complexity offered by a story versus a narrative. A singular 'simple' story, while it is, in terms of its literary properties a 'narrative' text – meaning it represents "*an event or a series of events*" (Abbott 2002, 12, italics original) and moves through them – is usually limited in outlook. It has a defined set of characters that remains the same throughout. These characters, in the world of the story, do certain things to achieve certain ends, lending closure to it. A story can be generic, especially when this is a 'functional' story such as the kind often used in planning proposals or marketing brochures. Here, a 'story' would be a short narrative text that is included in a hand-out for the public to advertise a certain plan, for example. In this generic form of a story, an urban area could be introduced, including a problem such as pollution, or an abandoned structure. In the course of the storyline, the positive consequences of remedying the problem could be pointed out – for example, the neighborhood becoming a healthier place to live for families. This is the process that is usually termed "storytelling" in urban planning (e.g., Throgmorton 1996).

On a textual level, a 'complex story' – for example the storylines told in a novel, a film, or a comic – would not be as generic as the 'urban planning story' framed above. First, it would add in more characters. It would address not just one but several hindrances to overcome for the characters, and contain several storylines overlapping with each other (Ameel 2021, 78–79). A complex story can also move back and forth between different layers of time, or different spaces, or both. It may contain flashbacks or fast forwards or other devices generating suspense; it may open up more layers and more options for characters to interact with each other. It might not be linear, either.

Still, by contrast to this kind of story, even if it were a complex one, the 'larger' category of the narrative is closely intertwined with the idea of myth. It produces a larger meaning beyond itself, beyond its 'story.' The American Dream is a powerful cultural narrative, and F. Scott Fitzgerald's *The Great Gatsby* (1925) – likely the most famous novel about it and its failure – is a story contributing to its construction and perpetuation as well as negotiation in the public arena. Narratives certainly do not only arise from novels, or fictional genres, but reporting, art, activism, and even statistics all feed into them. Since narratives are larger entities, they can have significant authority in a society, or among members of another group, and significant reach and power.

In Literary and Cultural Studies of the Anglophone world, it is rather common to work with the idea of the so-called cultural narratives, which can be defined as the narratives a culture perpetuates about itself – such as the American Dream already mentioned, or the idea of being able to rise from 'Rags to Riches' in the US context. These cultural narratives share their visibility both within the culture in which they originated and beyond. For the United States, these two cultural narratives have been and continue to be powerful forces in relation to immigration, but also in the context of the ideas of social mobility and progress.

Narratives of this kind lend stability and a common orientation to a community and continue to do so in the face of difficulty. They can be a powerful source of motivation. In this regard, the crucial factor is not whether the narrative at large or any of its singular constituents is objectively true or attainable, but rather that it has the power to fuel the imagination of a group.

In relation to the entity of the nation as a community of people who do not know each other personally and are all different from each other but still practice solidarity and share common beliefs, the British anthropologist Benedict Anderson has shown that collective identity is supported by master narratives legitimizing it. These master narratives are not always stable, but they appear logical and useful to a community at a specific time. They also contain a story of origin that justifies the way the nation has developed. Narratives are closely intertwined with processes of identity formation and with power relations: While they certainly help people understand the past, their true power lies in the present (Humlebæk 2018) – Anderson (1983) connects this idea of power in the present directly to the rise of nationalism.

In the field of German Cultural Studies, Wolfgang Müller-Funk has contributed to the establishment of the topic of narrative in relation to questions of cultural memory and identity. He assumes that narratives render abstract units, such as the nation, the region, or a 'culture' experiential to its members (Müller-Funk 2008, 13). Those narratives which have become self-explanatory within a nation or other community are most powerful because they are part of every interaction and do not need to be made explicit at all times (Müller-Funk 2008, 14).

Narratives establish their meaning because they construct an order of events, and thus contribute to their own stability. But at the same time, because they give meaning to these events – even if they are described as negative or traumatic – they create attachments and trust (Müller-Funk 2008, 29–30).

3. Narratives and/in Urban Studies

Especially in the Anglo-American world, an interest in narratives and narrative structures is established in many different disciplines and goes beyond the more traditional fields affiliated with such inquiries, such as the Humanities and Social Sciences (Müller-Funk 2008, 17). Despite the lack of comprehensive theory building so far, questions of narratives are brought up in Urban Studies as an interdisciplinary field both in research as well as in practice.

Generally, the idea of engaging with narrative is perceived to be part of a movement towards "[being] more inclusive, democratic, more compatible with local experiential knowledge, and aware of the various layers of meaning in the city" (Ameel 2021, 16). This observation is well in tune with the perception that traditional approaches in Urban Planning will over time be replaced by new ones and will contribute to a different understanding of the role of the planner in the modern intercultural city, which has been described as the role of a "translator" (Fingerhuth 2019, 43). While this understanding takes into account the cultural factors shaping planning (Fingerhuth 2019, 43) and in fact considers the cultural responsibilities of those involved with a project, this observation does not necessarily go hand in hand with a unified understanding of the potential roles and definitions of narrative in this context, or with the ways in which narratives can also contribute to counteracting democratizing tendencies.

At times, the term "'narrative' [is used] predominantly as a metaphor" (Ameel 2021, 17) by planners, architects and others in affiliated fields, meaning that a site speaks a specific 'language', e.g. via its structures and layouts, its buildings and their relation to each other. It is also possible to look to narrative in order to imagine the different ways a neighborhood or other site can potentially turn out following a process of transformation; or to think about how narratives relating – locally – to a site can be used in planning. This latter approach can be transferred into practice and would mean citizen participation in a project in order for planners and others involved in the process to get to know the narrative complexities of a site. This links back to the concept that, via 'stories' or 'narratives', planners, architects and others shaping the form of the city should pay attention to the social layers and human dimensions of a site (Ameel 2021, 17). Yet others ask of planners as well as policy makers – those working with the city in practice – to learn more about narrative because of the power it contains. There are warnings to be wary "[i]f we cannot distinguish policy argument from sales talk" (Fischer/Forester 1993, 3).

Certainly, there is significant interest in the idea of narratives in their relation to the city or the metropolitan region among those in Urban Studies who address these questions from a perspective shaped by Literary and Cultural Studies and/ or the Social Sciences. The approaches here also vary but are unified by their intense focus on the textuality of the city, and by the narratives which are used in order to advance specific ideas of the city in planning or marketing documents for urban areas. This kind of research is well in tune with the concern voiced above that at times plans may sound more like sales concepts, especially in instances where planning and marketing become intertwined with each other.

In the emerging field of Literary Urban Studies, which is concerned with questions of urban complexity and its representation, with urban texts and their various forms as well as interventions in the urban context. It also addresses the question of what more traditionally 'urban' disciplines can potentially learn from cooperation with scholars from fields where narratives and their analysis are central: "What literary and cultural studies […] can contribute to an understanding of precisely those elements of urban complexity that cannot be measured, modelled, classified or studied in terms of information theory" (Gurr 2021, 22) is central to this emerging arena of research. In addition, the expectation is that the inclusion of qualitative approaches into contexts that are usually approached with quantitative studies may work well in order to deal with planning under uncertain conditions, but also to forward the understanding of urban complexity (Gurr 2021, 22).

This approach and its allusion to shared properties and interests between very different fields calls for a more explicit and ground-level cooperation and a process of shared theory building. But since, despite a shared interest in narratives, these disciplines use different methods and theoretical conceptions in their focus on the city, urbanity, or metropolitan regions, such cooperation does not come easily: "literary strategies and urban planning do not coincide without conflicts and contradictions" (Gurr

2021, 142). Nonetheless, this dealing with conflicts and contradicting ideas is part and parcel of interdisciplinary research and work in practice and will likely contribute to sharpening and developing all three, (1) the understanding of and theory building in relation to narrative, (2) the parameters of successful collaboration across disciplines, and (3) the transformation of the role of planners and other practitioners in a context that is intensely shaped by cultural factors. All of these are central issues of consequence for the field of Urban Studies.

4. Narratives in Urban Research and Urban Practice

Narratives are not only the subject of research in Urban Studies, but they are also used by practitioners in efforts such as urban redevelopment, urban greening, or planning for a more sustainable city. Here, they are especially used as part of communication strategies, meaning in the context of attempts to move urban development or planning practice forward in a particular direction.

The example of urban renewal in the United States makes clear that narratives, while they are generally associated with strategies of progressive planning at the present time, have not always been used to perpetuate ideas of inclusiveness, diversity and heterogeneity. By contrast, during the 1950s and 1960s, urban decline, fear of decaying cities and 'slums' were produced and perpetuated via narratives of decline (Beauregard 1993) that led city governments to 'erase' certain parts of cities in the interest of 'blight removal.' This effectively meant the removal of certain parts of the population – African Americans and other marginalized groups – from the city in the interest of constructing supposedly more desirable spaces, or even highways that sped up the process of suburbanization and thus perpetuated the downfall of the US inner city throughout the 70s and 80s.

Turning decline and the ongoing threat of "blight" – a term that became heavily "infused with ethnic and racial prejudice" (Pritchett 2002, 6) – into a powerful narrative supported not only via statistics, newspaper articles and government reports, but via political speeches addressing urban problems and their resolution through strategies of urban renewal, supporters of this program established and perpetuated the view that the supposed 'slums' needed to be cleared to avoid a general process of urban decline that would spread like a disease. Infused with moral arguments proposing the idea of a "finer city" by way of the erasure of certain neighborhoods as the "Black Bottom" neighborhood in Detroit, for example (Thomas 2013), urban renewal in this city as well as in many other industrial cities across the United States added to the tenuous relationship between urban planners, urban planning and the African American community in the 20th century.

Research in relation to these kinds of narratives of decline and 'blight' has led to critical views of urban renewal and its workings in the US to this day, but has also added an awareness that such kinds of processes may repeat themselves in the contemporary post-industrial city (e.g., Hyra 2012), for instance when a powerful narrative of 'blight removal' is made the primary objective of contemporary proposals to regenerate the city. Urban renewal and other experiences of 'removal' from neighborhoods and cities has by the same token – despite the oppression and neglect that is certainly a part of it – turned African Americans into activists for building a more just city with opportunities for all residents, such as via the efforts of the National Urban League (Thomas/Ritzdorf 1997, 10–11). In cities which have gone through urban renewal, the future of the city is still a point of contention, especially in relation to necessary transformation and regeneration efforts in the context of de-industrialization. How the Rust Belt's cities will develop is certainly also a question of narratives and their use to perpetuate or fight certain ideals of what the city should be and whom it should belong to.

It is possible to trace the legacy of earlier narratives of decline into the present time. The contemporary depiction of Detroit and many other Rust Belt cities in the United States is simultaneously shaped by narratives of failure and ongoing decline as well as by narratives of rebirth, comeback and the American Dream. This is a stark contrast with one narrative, supported by statistics, newspaper articles, official reports, but also artistic formats such as ruin photography pointing to decline, and the other newspaper articles and reports, supported by yet other statistics, pointing to rebirth. Both types of narratives are not a reflection of the – ambivalent – situation on the ground but have been pushed onto the city by outsiders in the efforts to push for new investment, or, potentially, a new phase of urban renewal. Both narratives can be made useful in this particular context of de-industrialization, social challenges and a high number of abandoned properties: A declining city provides many opportunities and little resistance to unconventional ideas, and a "comeback city" is an attractive place to build new businesses – a potential site of the American Dream. Critically dealing with such narratives in the urban context necessitates "deconstructing dominant narratives through an engagement with those whose experiences do not fit neatly within them" (Doucet 2020, 635) and thus necessitates work with local communities.

The analysis of the application and role of narratives across a variety of such practical contexts as mentioned above is the subject of much research in Literary Urban Studies. Here, the focus is on such topics as the exact use of narratives of rebirth following urban decline, or on the ways in which narratives are used to change the image of a city or a region. The narrative of decline and rise via creative industries and strategies is paradigmatic in this context, especially in instances when urban planning and marketing efforts become closely intertwined. It is evident in the US Rust Belt, but also in other contexts across the Western hemisphere. It is supported by such ideas as Richard Florida's "creative class", based on the assumption that the presence of artists and other 'creatives' (entrepreneurs, investors, freelancers in the media and other sectors) will forward economic development and large-scale investment, as well as by the expected rise of property values via the impact of gentrifiers (Herscher 65). Both of these ideas of economic improvement feed into narratives of the rebirth of formerly heavily industrialized sites under the pressure to re-invent themselves. The rebirth narrative of course necessitates the earlier downfall.

It is also evident that some of the narratives that were in the past considered typically American, such as the idea of the *frontier* that continuously moves westward and brings new opportunities and new ways of life to the settlers, have transgressed their national context, especially in relation to post-industrial regions and the narratives associated with them. This may be because there is as yet no blueprint for how to develop these sites (Sattler 2019, 206).

In the marketing materials advertising the European Capital of Culture RUHR.2010 – simultaneously an effort at promoting the Ruhr area as well as redeveloping its cultural, social and economic infrastructure via investment – it becomes evident that the narrative of the *frontier* is internationally readable and applicable. In the material, the region, formerly shaped by the heavy industries, was described as a sort of *frontier* landscape providing new ways of living together, e.g., for those affiliated with the "creative" industries. It was constructed as a site of unlimited and new opportunities, and a place that can re-invent itself freely. One can certainly argue that, while the strategy of local redevelopments to improve the infrastructure after the decline of the heavy industry that were a part of the 2010 efforts are in line with earlier such efforts to stimulate investment in the Ruhr region, the use of these larger, internationally known narratives of re-invention and rebirth specifically point to the idea that such marketing concepts aim at global readability and visibility rather than at local development alone (Sattler 2016, 18). Such a narrative first and foremost promotes economic (rather than cultural or social) investment, and investment into particular economic sectors.

It is also evident that careful analysis of such a *frontier* narrative necessitates taking into account all its dimensions, including the imbalances of power that shaped the *frontier* dynamics and the supposed 'Wild West' of the 19th century, and which populations will suffer from these dynamics in the present time. Here, an engagement with urban activism and anti-gentrification movements is a fruitful undertaking, also to understand the ambiguities continuously shaping the role of narrative in urban contexts (Gurr 2021): The narrative of the 'gold rush' in relation to former centers of the heavy industry certainly has to be taken with a grain of salt.

5. Outlook

With regard to communication in planning, it can be argued that an engagement with narratives and narrative patterns has brought forward and can continue to bring forward new understandings of sites, but also of the workings of urbanity and its contentions at large. Urban planning's engagement with both storytelling and narratives has by now indeed become part a larger-scale effort to include not only different sites, but also different people and their knowledge and concerns, but it has at times also been used in the interest of perpetuating selling efforts alone. Thus, the turn towards more communicative approaches in fields dealing with the city on a practical level can bring forward a more progressive, socially just and open way to deal with the city, as was already suggested almost thirty years ago (Healey 1993, 243–244). At the same time, not every engagement with narrative in the context of a project is necessarily and at all times inclusive and democratic.

On a less abstract level, it could be productive to work on further ways to include narratives in planning as well as in teaching in the field. This concerns, e.g., the idea of narrative mapping as a way to explore a location in detail before projects for it become designed and are ultimately turned into reality (Ameel 2021, 114ff.). Ideally, such an effort could also turn into an arena for ground-level cooperation between the different disciplines that form a part of Urban and Metropolitan Studies. This area of planning might lend itself specifically to cooperative projects, because the result of a narrative mapping would be a multiplicity of voices; texts for those in the literary and cultural fields to analyze and make fruitful for those working with the site from the perspective of planning, designing and building (Ameel 2021, 215ff.). Spaces built bearing this polyphony in mind might then lead to structures that refer to and take into account the past of a site, but could also place these references into new contexts and thus lead to different interpretations of the past and of the present and future – a practice that is very different from the type of erasure that parts of the city of LA have experienced (Klein 2008), for example, or from the results of urban renewal in cities such as Detroit or New York in the 50s and 60s (Thomas 2013).

For planners to work with narrative and for those in the literary and cultural fields as well as in the Social Sciences to be able to cooperate with planners on the ground would, if it is to be taken seriously, have to be accompanied by implementation into curricula. If it is arguable that "literary and narrative perspectives can be much more than a vague form of inspiration for planners, but can help provide a toolbox to draw consciously on narrative and rhetorical structures when drawing up plans for the future" (Ameel 2021, 121), then narrative ideas and approaches need to be included in the planning curriculum. At the same time, students from the Humanities and Social Sciences would also profit from more explicitly learning about how to support processes of planning with knowledge about narratives and stories, but also about how they can profit from understanding the quantitative layers of cities, working with maps and plans in order to get to new readings of urban literature and other urban texts. Such classes, which can be undertaken in cooperation between instructors from different fields, can lead to new interpretations of spaces, but also to different ways of looking at the built environment for all participants (Grünzweig/Reicher/Sattler 2015).

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Interdiscourse Theory and the Analysis of Collective Symbols

Rolf Parr

1. Preliminary Remarks

In the following, we begin firstly with a few basic premises to outline the theory of interdiscourse, forming the constitutive framework for the analysis of collective symbols. We then proceed to present the system of collective symbols characteristic of Western Europe. Such an arsenal of symbols plays an important role not only for the way metropolises regard themselves, for how others view them and for the images of metropolises conveyed by media and politics. It is also a key to constituting metropolitan research concepts, used quasi terminologically and analytically, such as 'urbanity' or 'metropolitaneity'. We then discuss a concrete example to illustrate the analytical method used on collective symbols, demonstrating the specific efficacy of this analysis for metropolitan research. The chapter ends with some references to other terms and methods of metropolitan research.

2. Theoretical Framework

Interdiscourse theory is based on the observation that, since about the middle of the 18th century, modern societies and their cultures have not only differentiated themselves into specific fields of knowledge, each with its special discourse, but in response to this, forms of speech have also developed, which, in turn, establish new connections between the specializations (see Link/Link-Heer 1990; Parr 2008; 2011; 2013; the relevant research is listed in Parr/Thiele 2010). Interdiscourse theory thus essentially understands the social cohesion of modern societies as defined by the sum of the links that imaginatively transform "the practical division of labour into life lived in its totality" (Link 1983, 27, my translation), even if this totality must always remain fragmentary and fragile. Entire cultures are then shaped, firstly, by the special discourses, or groups of special discourses (e.g., those of natural sciences, humanities and social sciences) they have developed, secondly, by the formations, and especially the hierarchies in which these are arranged, and thirdly, by the elements connecting discourses by bridging the gaps between discourses relevant to particular cultures.

This function is fulfilled by analogy-forming processes such as metaphors, comparisons, allegories, and, not least by such symbols as can be understood and used collectively by everyone. Thus, for example, the expression 'urban jungle', links the areas of 'culture' and 'nature'; that of the 'urban melting pot' links the process of steel production with the ethnically diverse structure of a metropolis, and that of the Ruhr area as the 'armory of the nation' links traditional craftsmanship with modern industrial production (cf. Parr 2011). In all these cases, we are dealing with an imagery (*pictura*) that stands for something else, the meaning of which it is, in fact, seeking to convey (*subscriptio*).

One of the most important functions of such collective symbols is to make highly specialized facts generally understandable, which, in turn, explains why they are frequently used in the media and in politics as a 'glue'. This is especially true when complex issues need to be formulated under constraints of space or time, yet as concisely as possible at the same time. Collective symbols are, therefore, not only found in literary, essayistic and journalistic texts (including films and other audiovisual materials), as well as in political speeches and announcements, but often also in introductions, greetings, and in the forewords to (popular) scientific and programmatic texts, such as those of urban actors and authorities, regional organizations and district and state governments. Being heard in the media-political public sphere seems to almost demand a resort to collective symbols. Such compulsion can be demonstrated by, among other things, the fact that radio, television, and newspapers usually select and quote only those collective symbols suitable for condensation from complex announcements, extensive brochures, and long speeches. Consequently, when we speak of and discuss metropolises, central aspects are commonly framed by collective symbols.

2.1 What are Collective Symbols and What do They do?

An interdiscourse-theoretical approach demonstrates how collective symbols represent couplings of specialised discourses and fields of knowledge, which, viewed semiotically, then appear as complex, iconic and paradigmatically expanded signs. In the first place, these unite the imagery (*pictura*) with the meaning it seeks to convey (*subscriptio*, 'sense'), so that collective symbols display a bipartite construction (for terminology see Link 1978; Drews/Gerhard/Link 1985; Becker/Gerhard/Link 1997). Secondly, an image consists of several partial images, which are nonetheless related and can continuously produce even more complex and longer text/image correlates. From a syntagmatic point of view, a *pictura* element is thus assigned to a *subscriptio* element (e.g., the *pictura* element 'teeming' to the *subscriptio* 'big city'), while the *pictura* and *subscriptio* attributes of a collective symbol are paradigmatically expanded into – at least rudimentary – isotopes. Hence, collective symbols display a multiple layering that distinguishes them from classical metaphors. Thirdly, we can define the relationship between *pictura* and *subscriptio* more precisely, because it is not completely arbitrary, but semantically motivated. A city laid out in a chessboard pattern with very wide, clearly laid out streets can hardly be symbolized as a 'jungle', but as a 'concrete desert'. Fourthly, collective symbols fulfill the criterion of iconicity, i.e. the *pictura* elements can be depicted visually. A simple test of whether one is dealing with a collective symbol is, therefore, the question whether a text can be transformed into a caricature. Finally, a fifth characteristic is the tendency to polysemy, i.e. different 'meanings' with varying significance can be formed under an image (but not arbitrary ones!).

Thus, specifying collective symbols means that it is no longer single metropolitan metaphors (in the double sense of: 'Which single metaphors stand for metropolises?' and its obverse: 'What does the metaphor *metropolis* stand for?') that claim our interest, but rather the quite diverse, competing, sometimes even frictional discursivisations of the object 'metropolis', which are made possible by the collective symbol system as a whole, and for which this system of symbols is regularly used. In its entirety, the synchronous system of collective symbols represents something like a 'filter' of visualization and is, therefore, to be understood as a medium *sui generis*, with the discourses on the thematic object, 'metropolises', always constituting 'metropolises' as a social and discursive object.

2.2 Systems of Collective Symbols and Spatial Contexts

Collective symbols as a whole constitute a closely related system of visual forms subject to modification over time but remaining, synchronously, relatively stable and coherent and thus enabling the relevant discussions and events in a culture to be coded. This characteristic function results from collective symbols tending to form classes displaying paradigmatic equivalence in both *pictura* and *subscriptio*. On the one hand, image elements from different social areas can be exchanged while retaining the same 'meaning'. Thus, a metropolis can be described as an 'organism' (with 'head', 'heart', the various 'limbs', the 'blood circulation' etc.). On the other, it can also figure as a 'swarm of insects' or as a 'complex machine', or, just as well, thermodynamically, namely as a 'boiler under extreme steam pressure'. This results in chains of images (*picturae*) that can in principle be substituted for one another without changing their meaning (*subscriptio*). Here, an example would be (from a Western perspective): 'Shanghai is the heart of Chinese industry; it is the engine of a capitalist machine running perfectly, in which one cog engages another; it is an organism constantly growing at the core of the Chinese economy'. Another chain of interchangeable *pictura* elements deals with the standard attributions attached to the 'threatening big city', for example, the images of 'cloaca', 'kraken', 'moloch', 'jungle', 'thicket', and 'labyrinth' (cf. Henning 2020).

This is the first dimension of interconnected collective symbols; the second structural dimension means that different circumstances can also be subsumed under one image, i.e. the same *pictura*; for example, that of the 'imbalance' of a metropolis can denote different circumstances (subscriptions) meant by it: 'too many inhabitants in too small a space', 'not enough hospitals', ' rents too expensive', 'unbalanced age structure' or a 'very bad ecological balance'.

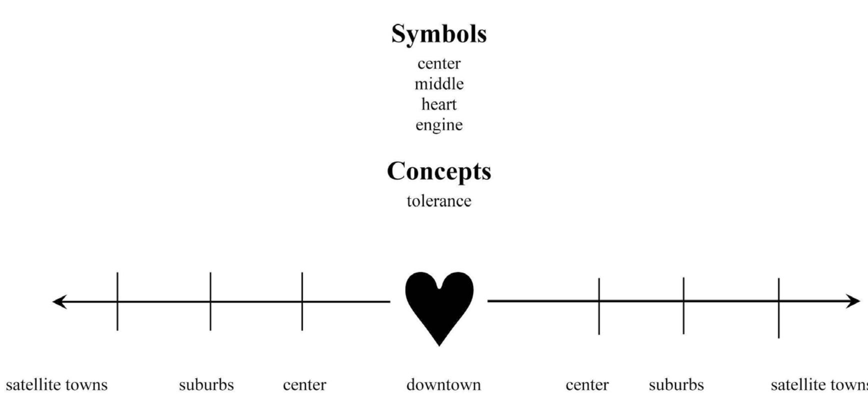
These two structural dimensions – chains of images with standard subscriptions, as well as different subscriptions sliding in under one image – result in the character of collective symbols as a synchronous system. In Western Europe, this system consists of many single symbols, of which about 100 to 150 are relevant. However, they relate closely to each other through the two dimensions of interchangeability and repeatedly work to encode events of all kinds in media-political discourses.

One can, therefore, trace the interplay of collective symbols constantly being used in medial and political discourses, and equally in the arts, as a closely interconnected system of axes, equivalences and value hierarchies, through which our cultural self-understanding is given perspective, as through a filter. It then becomes obvious that systems of collective symbols always also represent a form of cultural construction in spatial contexts. This means, however, that systems of collective symbols are closely linked to ideas of spatiality: Systems of symbols constitute collectively shared representations of social relations in spatial form, and these can, nevertheless, be individually accentuated (not least in the arts, where there is great scope for aesthetic representation). In the terminology of the more recent sociology of space, systems of collective symbols construct 'mental maps' "through which […] not only perceptions, images and experiences, but also cultural knowledge can be produced and organized" (Berking/Löw 2005, 9, my translation). Just like cognitive maps (cf. Downs/Stea 1982; Werlen 2008, 259), the symbol systems that can be visualized as spaces are also culturally constructed and simplified spatial representations referring to a reality, which is – *de facto* – much more complex.

2.3 Collective Symbols and Their Systems as Media of Perceiving the Metropolis

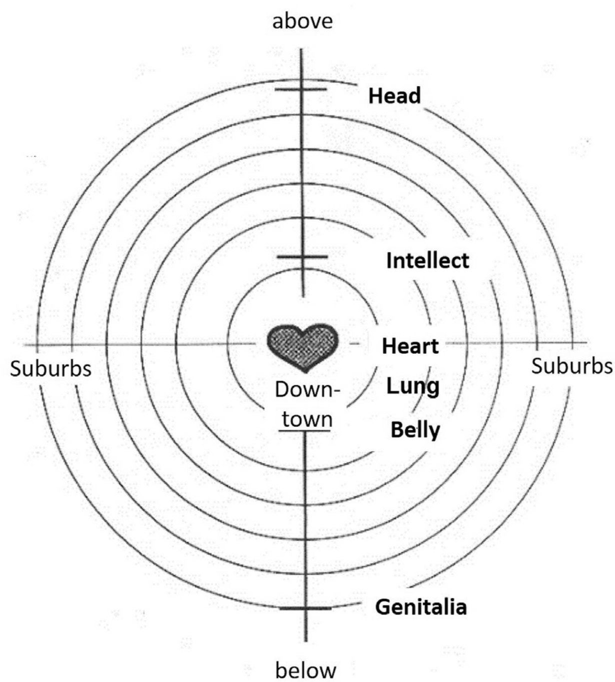
Thus, when systems of collective symbols construct models to denote spaces, and these models are applied to metropolises, what exactly do they look like? Since the beginning of the 20th century, a relatively consistent reservoir of symbols has developed for speaking about cities, metropolises, and regions. Empirical analyses of the relevant material reveal that three axes constitute this reservoir and that these are, at the same time, cultural constructions of space. The first of them is the taxonomic right/left axis (see fig. 1), familiar from, for instance, the symbolic positioning of political parties. It is based on the symbol of the 'scales' (as in the zodiac sign) and favors the place of the 'heart-center', which is particularly positively valued for its 'stability'.

Fig. 1: The taxonomic right/left axis (based on Parr 2001, 27)



The second axis is that of top/bottom (see fig. 2), which is often realized in the form of body symbols ('head', 'heart', 'lung', 'belly').

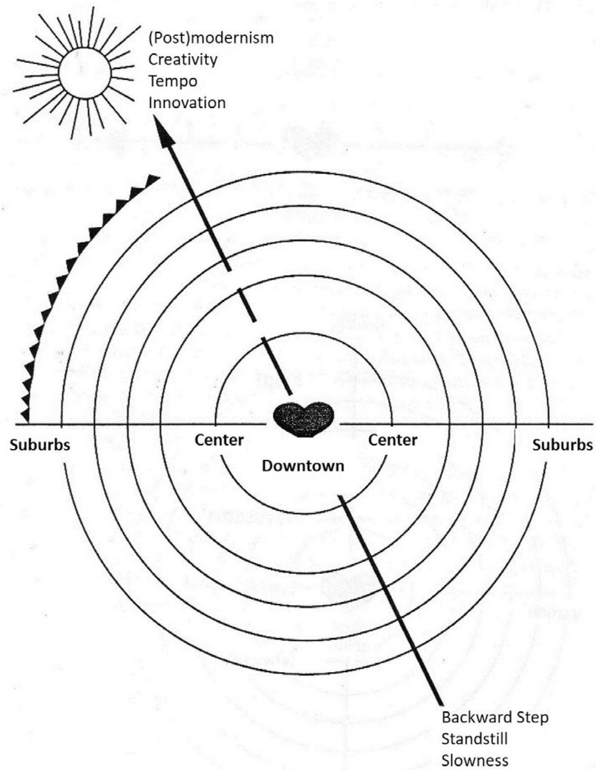
Fig. 2: The upper/lower axis (based on Parr 2001, 27)



The third, dynamic axis (see fig. 3) is that of 'progress', '(post)modernity', 'creativity', and 'willingness to innovate' vs. 'regression', 'stagnation', and 'slowness' (cf. Disselnkötter/Parr 1994; Parr 2001, 31; Parr 2013, 24–30).

These three axes together form a system of coordinates (right/left; up/down; forward/backward), a spatial model – albeit still abstract – which nevertheless can be concretized for entities of various kinds, not least for metropolises or metropolitan regions imagined as subjects with an individual 'character' (cf. Löw 2011; 2018). From the self-perspective of metropolises and their marketing, this yields particular potential if they can occupy the positively evaluated places on all three axes: on the right/left axis the integrating 'center'; on the top/bottom axis the 'heart' correlated with 'center' (not only 'head', not only 'belly'); and on the dynamic axis the pole of 'progress', which can be read as the 'top' or 'front' of a ranking list ('because we have the power for dynamic development, we will soon be world leaders' [cf. Peck 2008]). A small experiment quickly shows how effective collective symbols are in encoding metropolises: If you ask a group of test persons to pinpoint the capital city of Berlin on an empty map of Germany, then it will usually be placed in the middle of the map, in contrast to its rather peripheral actual

Fig. 3: The dynamic (progress) axis (based on Parr 2001, 28)



geographical location. This placement reflects the perception of Berlin as the cultural and political 'heart' of Germany.

The respective positions in the system of collective symbols have come to favor specific symbols, concepts, terms, emotive words, and ideologies, as well as their connotations: the 'center', for example, favors mainly 'heart' symbols, which connote regional authenticity, but also 'tolerance' ('we can look left from the center, but we can also look right') and 'maturity in one's actions' ('we are not dependent on either left or right', 'we are the zero point from which measurements are taken'). Debates on metropolises, cities, regionalism, and globalization repeatedly emphasize the urban values of 'tolerance' and 'openness to the world', and how they can apply in a cosmopolitan coexistence, so that such concepts become particularly relevant to conurbations as both topographical and symbolic 'integration centers' for regions.

Conversely, the symbolic 'center', as a site fostering integration, depends on its relation to what are defined as the 'edges'. If they are vague or – as they are often called in debates on regionalism – 'frayed', the 'center' becomes more difficult to define, and its existence may even be called into question completely. This is precisely what the celebrated author Heinrich Böll stated early on in the existence of West Germany. In

1958, he wrote that the Ruhr area "has not yet been discovered", as "the province that bears this name", that it "cannot be precisely determined either in its borders or in its form", "because no other name has been found for it" (Böll, quoted in Schütz 1976, 41, my translation).

Finally, the dynamic axis represents concepts such as 'modernity', 'innovation', and 'creativity' (including the corresponding symbols of progress) at one end, while the other denotes 'backwardness' or, at least, 'the past'. The particular importance of this third axis emerges in the current discourses on the "Ruhr metropolis" (see Parr 2010a), where they struggle to not only acknowledge the relics of industrial culture in retrospect, but also to develop future prospects. This dilemma, however, prompts us to assess how far discursivisations of the Ruhr Area can claim any lineage also enabling a perspective for the future, i.e. the 'valorization in the future of origins'. In terms of the analysis of collective symbols: On the dynamic axis, 'progress' must be accentuated more strongly than 'retrospection', and 'regression' must be redirected to, and reinterpreted as, 'progress'. 'Monuments' of industrial culture, for example, would be freighted with 'semantics denoting the future' and 'semantics denoting progress' (see the examples in texts from Regionalverband Ruhr/RVR 2010). Slogans, such as 'creating something new from the old' or 'from industrial region to tourist destination', correspond to this on the narrative level. To put it differently: The view onto the past must be designed in such a way that it is always also a view onto the future, and one that, ideally, can be conceptualized as a concise collective symbol. Here it would indeed be possible to posit 'cultural conversion'.

Based on the three-axis model, we can simulate possible symbolic positions carrying positive connotations for metropolises: 'We are the middle' (on the right/left axis) 'because we have the heart' (on the top/bottom axis), 'and since we have both, the heart and the middle, we are far in front (on the dynamic axis of progress). Similarly, various metropolises such as New York, London or the Ruhr area, sport the label of 'melting pot': here, we are dealing with the remnants of a topics deriving from an industrial process and standing for the integration of a disparate periphery into a center (the 'center' or 'heart'). However, as an identity formula oriented towards the future, the symbol has also to be located on the dynamic axis of progress, since the topics of 'melting' connotes a processual momentum, which can also be seen as progress, so that the symbol of process can become one of progress. Conversely, a position composed of the 'outer edge' of the taxonomic axis, the 'bottom' of the vertical axis and the 'regression' of the dynamic axis, would be coded particularly negatively ('If the outskirts of Paris continue to deteriorate, the whole city will soon be degraded into a cloaca and end up back in the conditions of past centuries'.)

At this point, it has already become apparent that, in the interplay of these three axes, oppositions like 'center vs. periphery' or 'metropolis vs. hinterland' emerge and then structure those regions under discussion. However, they can also receive very different accentuations, namely when treated spatially, temporally, and hierarchically. This opens up options for transitions between discourses on space, time and competition (rankings), so that, for example, sporting and artistic successes can be offset against the economic success of a metropolis. At the same time, this process stabilizes the respective identity conceptions, since they can then be related to the diverse social subareas.

One of its additional effects allots metropolises character traits consistent with the collective symbols assigned to them. This can be observed whenever the symbols involved are correlated with typical actions or when typical actions (such as 'being tolerant', 'understanding', 'being able to come to terms') can be generated from symbols (such as 'heart'). Thus, metropolises become active in generating narratives (cf. Parr 1999). Collective symbols are, therefore, important in circulating narratives for cities, metropolises, or regions.

We can demonstrate how literature, the press, politics and the various scientific disciplines (see the references in Parr 2001) have been promoting such circulation of the symbols for metropolises since about 1900. Three groups, in particular, recur with striking regularity: firstly, there are 'organism' symbols such as 'head' and 'heart', secondly, 'machine' and 'industry' symbols such as 'melting pot', thirdly, taxonomic relations of the type 'we stand at the center of things'. The juxtaposition of opposing 'organism' and 'machine' and, respectively, 'construct' topics to each other is an important rule for relating the different symbols together.

This results in a four-zone scheme (see table 1) for coding metropolises according to collective symbols. The first zone (read from left to right) denotes 'nature' as something looked upon negatively, as 'threatening' and, therefore, negatively connoted, the second zone indicates a positively valued 'good nature', the third zone a 'good culture/technology' evaluated positively, and the fourth one a 'threatening and bad culture/technology' accordingly evaluated negatively (cf. Parr 2001, 35).

The two middle zones result in a space of urbanity being positively evaluated twice over in a 'center' itself denoted equally positively. Some symbols and taxonomies oscillate ambivalently between 'good culture/technology' and 'good nature', and even have the capacity to integrate the two central paradigms into a single zone (see the lower half of the diagram; cf. Parr 2001, 34).

2.4 Collective Symbols in Narrating Metropolises

This stock of symbols relevant to regions or metropolises is ordered in such a way that it further enables the production of different types of journalistic, literary, and filmic narratives. These then transfer the paradigmatic juxtaposition of symbols into the narrative succession produced by combining them.

The first form of narration has the extreme zones colliding to create tension. Furthermore, stories of incompatibility or, conversely, stories of the mythical mediation of 'good nature' with 'good culture/technology' become plausible (for the connection between collective symbols and narratives, see Parr 1999). The aesthetics of imagery and text in metropolitan travel guides often work with such mediations, and, at the same time, implicitly with their always latent opposites. Such guides then display a penchant for correlating nature and urbanity, to offer, for example, visitors to New York the prospect of Central Park as a 'green oasis in a sea of concrete'. In Stockholm there is the possibility of fishing for dinner in the middle of the city, or, in the case of the Ruhr area, the promise of the 'Pott you can swim in' (cf. Merian Extra 2006, 39ff.), a play on the demotic label of "Pott" for the whole area with its allusions to griminess (reflected in the negative connotations of the pejorative adjective "pottdreckig": dirty like the quon-

Tab. 1: Perception of cities, conurbations, and regions through Collective Symbols

<table>
<tr><th colspan="2">nature and organism symbols
(semantic characteristic ‘nature’)</th><th colspan="2">machine and construction symbols
(semantic characteristic ‘culture/technology’)</th></tr>
<tr><td>‘bad nature’</td><td>‘good nature’</td><td>‘good culture/ technology’</td><td>‘bad culture/ technology’</td></tr>
<tr><td>desert
uncontrolled growth
proliferation
illness (i.e cancerous ulcer)
wasteland
desolation
swamp
jungle
thicket
standstill</td><td>organism, soul
(creative) brain
(pulsing) heart
(green) lung
sane growth</td><td>engine, machine
bustling technical rhythm
melting pot
progress
dynamism
acceleration</td><td>city machine
concrete desert
Babylon
whore
cloaca
prison
labyrinth
moloch
swarming
frenzy</td></tr>
<tr><td>periphery</td><td>suburb</td><td>center, headquarters</td><td>satellite city</td></tr>
<tr><td>imbalance
nature chaos
superficiality
the back of beyond</td><td colspan="2">a sea of stone, a sea of houses
city as ‘ship’
order, depth
the cherry on top
center, core, heart of hearts, motor
the nodal point in supra-regional networks
rhizome
creativity, tolerance</td><td>imbalance
arid sea of stone
leaking ship
cultural chaos
superficiality
end of the line</td></tr>
<tr><td>extreme(s)</td><td colspan="2">center(s)</td><td>extreme(s)</td></tr>
</table>

dam Ruhr region). In our example above, a negatively evaluated symbol, the “Pott” can be linked to the positive natural element ‘bathing’ in such a way that the latent paradoxical effect here initially created can be resolved diachronically (on the dynamic axis of the system of symbols): where *once* there was the dirty “Pott”, *today* one can bathe in beautiful nature.

A second contrasting type of narrative form reverses the matrix and conflates ‘bad/dangerous culture’ with ‘bad/dangerous nature’ in negative scenarios. Such combinations appear in literature and they stand out particularly in the Hollywood genre of urban disaster films, whilst in politics, governing authorities also invoke them for disaster scenarios. The technique can also shape narratives depicting processes of decay, where ‘mixture’ turns into ‘segregation’, ‘urbanity’ into ‘barbarism’, ‘unity’ into ‘multiplicity’, ‘wholeness’ into ‘disruption’, and ‘center’ into ‘periphery’. And finally, a dialectical contrast by way of illustration: success stories reverse this polarity to narrate how ‘disunity’ turns into ‘unity’, ‘periphery’ into ‘center’, and ‘regression’ becomes ‘progress’ (cf. Parr 2001, 36–38).

3. Methodology: Key Steps in an Analysis of Collective Symbols

Collective symbols can be analyzed most easily using a two-column scheme. The first step involves continuously entering all *pictura* and *subscriptio* elements found in a text into such a schematic diagram. This usually results in gaps in both *pictura* and *subscriptio*. The second step attempts to fill the gaps in the *p*(*ictura*) and *s*(*ubscriptio*) elements, relying on the already existing ones to show whether this form of making sense works.

Making sense involves a certain leeway (the criterium defining ambiguity), but operating only within the limits allowed by the symbols in totality. The deciphering can run from the *pictura* to the *subscriptio*, as well as vice versa. It is rare for texts to deploy a *pictura* without themselves referring to a corresponding *subscriptio*. The analysis thus unmistakably demonstrates the specific use of a collective symbol (or several combined ones). To use a journalistic text as an illustration:

> The fight against traffic congestion
>
> If the A 40 is the carotid artery of the region, then it has been suffering from vascular constriction for years. Traffic jams form as dependably as the sun comes up. Beginning in mid-July, the NRW (North-Rhine Westphalia) State Roads Authority will remove the bottleneck between the Gelsenkirchen (AS 28) and Bochum-Stahlhausen (32) junctions. The four-lane section will expand into six lanes, for 96 million euros. In this, Michael Gebert is the chief surgeon, as it were. […]
>
> The regional branch has taken precautions to prevent the traffic flow from finally collapsing. It is responsible for the 4.5 km long section from the boundary between Essen and Bochum to the Stahlhausen junction. Last year, it extended the stretch's hard shoulder in the direction of Essen by enabling it to support heavy trucks. (Wahl 2008, my translation)

So, to present the above as a two-column scheme (deduced elements are shown in square brackets):

	pictura		***subscriptio***
s 1	traffic congestion	p 1	total breakdown of traffic
s 2	carotid artery	p 2	highway/autobahn A 40
s 3	[patient]	p 3	region
s 4	vasoconstriction	p 4	bottleneck
s 5	chief surgeon	p 5	Michael Gebert (Roads NRW)
s 6	collapse	p 6	[mega jam] [total breakdown of traffic

Carrying out such analyses on more extensive bodies of text, then generates statements about the recurrent use of symbols, but it also identifies which symbols stand for the same fact and vice versa, as well as how contrasting facts can connect by recourse to the same symbols, or – often at least as interesting – which ones do not.

Also, considering the positive or negative values assigned to chains of symbols in a concrete case further enables statements about the discursive positions respectively taken: Does the discourse position taken confirm an already existing one? Is an alternative being developed? Or does the position generated via collective symbols even represent an intervention? Knowledge of such discourse positions is, in turn, the prerequisite for tactical considerations applied to discourses: Which symbols are applicable in which – for example, cultural or political – context, and for what purpose? What is the best way to react to symbols that have been successfully circulated, but are not compatible with one's discursive position? If one also asks who maintains which discursive positions through which symbols, then, last but not least, statements can be made about those espousing them.

4. What can the Analysis of Collective Symbols Offer Metropolitan Research?

The analysis of collective symbols can reveal the unspoken – but highly effective – discursive schemes that play no small part in speaking about metropolises, as well as figuring in any concomitant actions. In other words, the analysis of collective symbols and their systems illustrates one of the cultural practices producing, circulating and establishing discursive constellations about spatial contexts. In particular, such analyses make it possible to differentiate specialized discursive elements from interdiscursive ones.

Furthermore, such analyses of collective symbols are important components in developing theoretical approaches to metropolises. The reason lies in the extent to which they relate "culturally prefigured (and premeditated) spaces and spatial conceptions" and their "configurations, prefigurations (and remediations) within cultural reality" (Hallet/Neumann 2009, 22, my translation), i.e. "the conceptual and empirical relationship between discourse and space" (Galze/Mattissek 2009, 8, my translation). The analysis of systems of symbols is, among others, one approach, equally capable of investigating both the over-semanticisation of actual geographical spaces and the semanticisation of medially imagined spaces, and it culminates in demonstrating the interplay of both. Moreover, this approach enables "both an application to concrete spatial conditions and a" semantic-structural "description of non-spatial phenomena, in which the terms for spatial relations are used metaphorically" (Dennerlein 2009, 29, who thus takes up Lotman's double view of *topological* and *topographical* structures [1972, 311–329], my translation). Thus, both the semantic-analytical and the symbol-analytical approaches can very precisely relate media textures, along with the semantics of their internal spatial constructions, not only to cultural and social spaces outside of fictional texts but also to real spatial topographies. From a diachronic perspective, the analysis of collective symbols, metropolises, and the regional spaces in which they are situated allows us to understand them as cultural and social spaces that change with the various symbolic discourses applied, and are accentuated in ever-new and different ways.

In the case of an object, a topic, or a discussion, collective symbols also make it possible to take up different positions in the discourse, given that the same symbol can be evaluated positively or negatively. The coherent use of whole clusters of symbols then results in equally coherent discursive positions. And in turn, the precise knowledge of these clusters enables targeted discursive intervention in discussions and disputes. For example, in 2010, when Essen was the European Capital of Culture for the Ruhr region, even cities on the geographical periphery of the Ruhr region were manifestly able to present themselves as 'center' and as 'a piece of the center'. By contrast, opponents of the Capital of Culture took up the 'center/heart' symbols actually carrying a positive evaluation and deemed the most important motorway connection in the region a rather 'calcified main artery' for a metropolis. By introducing this notion of a discursive position, the interdiscursive theoretical approach thus allows for a much more convincing description of ruptures and interferences than do, for example, approaches derived from the history of mentalities. While theories from this latter focus on the homogenizing disparities, interdiscourse theory demonstrate interference, ruptures, distortions, and their diachronic development.

Furthermore, comparing systems of collective symbols from different cultures opens up a comparative perspective for spatial and metropolitan research, because, for example, the US-American symbol system is structured completely differently from the Western European one (see Link 1991; Parr 2010b). Finally, the analysis of collective symbols offers a thread to trace the proliferation of discourse elements, as well as the concepts and narratives linked to them (example: 'Big Apple' narratives in New York and the Ruhr area).

5. Connections to Other Methods and Approaches

Connections to other terms and methods in the field of metropolitan research arise from the analysis of collective symbols applied to research into urban modelling (cf. Gönsch/Gurr in this volume), storytelling (cf. Sattler in this volume), and the analysis of narratives (cf. Sattler in this volume) (since narratives can be generated from collective symbols by attributing characters). If texts can be understood as qualitative models for municipalities, then collective symbols, in, for example, planning texts, contribute significantly to their character as models, and as ones sometimes tending towards prognosis, sometimes towards simulation.

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V Interdisciplinary and Mixed-Methods Approaches to Urban Complexity

Comparisons

Julia Sattler

1. Preliminary Remarks

The notion of the comparison or the comparative approach to a topic is omnipresent across much of the Social Sciences, in Literary and Cultural Studies as well as in Urban Studies and related fields. Textbooks addressing the topic of comparative research as a way to link research and practice are evidence that the topic has reached the educational system as well. Still, there is no singular comprehensive theoretical or methodological approach that clearly defines the comparison. What unifies comparisons is "the aim to test, and to change, theoretical propositions" (Robinson 2015, 193). In Urban Studies, Robinson attests a track record for innovation to comparative approaches and praises the effect of comparison, which she describes as the extension of any conversation or research "beyond the single case" (2015, 194).

This contribution outlines the emergence and development of comparative approaches in Urban and Metropolitan Studies from a perspective including but not limited to the Humanities. Pointing to the chances and challenges comparative approaches pose in theory and practice, it reflects on different types of comparisons and their contribution to developing and testing new ideas around interdisciplinarity and generating new forms of urban knowledge. The outlook suggests possible further developments of and challenges for working with comparisons in Urban and Metropolitan Studies.

2. Comparative Approaches in an Urban Context

Generally speaking, a comparative project, study or approach takes "into account more than one event or object" (Ward 2010, 473). Such a format is defined by its comprehensive examination of at least two events or objects, not just by adding sweeping references to other possible examples. The mere mentioning of the existence of other relevant cases or contexts does not make for a comparative format either.

Throughout the past decades, comparative formats and approaches have emerged in such different urban research arenas as sustainability studies, the study of different types of informal housing, the role of the financial markets, or urban governance. Still, there is no one particular theoretical approach unifying all these projects, studies and approaches under the heading of "comparison," but rather, "[d]efining comparative urban studies is not straightforward" (Ward 2010, 475). Due to the lack of a comprehensive theoretical approach or toolbox for comparative studies, "theory generation is at the heart of comparative urbanism" (Robinson 2015, 194) at the present time.

By implication, in urban and metropolitan contexts, comparisons contribute to the building of theory from many different angles, leading to a great diversity of approaches in the field of comparative research (Robinson 2015, 194). This is significant because in an interdisciplinary field such as Urban Studies, research approaches and project formats may be both qualitative and/or quantitative, may use methods from a variety of fields including but not limited to statistics, textual analysis, historical investigation, or infrastructure analysis, and may work on a micro- or macro-level of analysis (cf. Goensch/Gurr, Terfrüchte/Frank and Frank et al. in this volume).

Comparative approaches in Urban Studies and related fields first emerged out of the attempt to globalize the field and to look beyond the Northern hemisphere. The popularity of such approaches in urban contexts has varied over time, however (Palmer/Simon 2020, 20). Very explicit comparisons between different cities in fields building on urban inquiry and research have existed at least since the 1960s and became rather popular in the 1970s, while in the 1980s such kinds of studies declined in popularity again (Ward 2010, 476–477). These developments are part of larger trends in research and opportunities for funding.

Jennifer Robinson credits the work of Louis Wirth (1938) as the first comparatist work in the field of Urban Studies (2015, 189). Wirth, in his essay "Urbanism as a Way of Life" does not only try to define what makes a city, but also recognizes "the great variations between cities" (1938, 6) and that they can be classified into "a typology of cities based upon size, age, and function" (ibid.). Suggesting that research should "lend itself to the discovery of their variations" (ibid.), Wirth paved the way for city comparisons of various sorts, and also recognized that it is worth noting the effects of industry and capitalism on cities when examining their characteristics in different settings (1938, 7).

Over time, different approaches to comparative studies in the urban arena have been brought forward. In turn, the ideas behind comparative studies potentially contributed to phenomena such as the emergence of a division "between analyses of wealthier and poorer cities in the wake of developmentalism" (Robinson 2015, 189). In the 1960s, the idea prevailed that through globalization – meaning by way of more intercontinental travel, new opportunities to conduct commerce and communication, as well as by way of the emergence of global financial markets – cities would become increasingly similar to each other (e.g., Murphy 1966). Here, studies with a comparative approach have been able to show that even global phenomena such as capitalism produce different local outcomes and have thus enabled a more profound understanding of both, capitalism and cities.

For the studies conducted in the global context today, such comparisons analyzing in detail the local effects of global phenomena are still useful to understand cities in detail in their networks. They contribute to an understanding of how global pressures or tensions, but also new opportunities, may manifest differently in different local settings, and which parameters might shape such differences. They can also highlight the long-term consequences of colonialism or other systems of oppression. Building on this idea, comparative studies can support particular groups in gaining political agency, or can help to make the long legacy of the past visible. In order for this to be achieved, researchers will need to be open to the other forms of urbanity they may encounter once leaving the West and its analytical practices behind. Its by and large Western focus is an ongoing challenge for urban theory in comparative and other arenas: "[t]here is an urgent need in urban studies to build cultures of theorizing which appreciate and foster diversity of theoretical starting points" (Robinson 2015, 192). For practitioners and researchers, observing how cities elsewhere address shared problems very differently may lead to crucial new insights as to how the 21st-century city can develop, but may also generate less Western-centric theoretical approaches to the analysis of urban and metropolitan areas.

Generally, "whether policy-oriented, structural or historical, comparative studies rely on the idea that key cities have something in common with each other, and that international comparison can provide fresh insights into when, how and to what effect local differences emerge" (Kwak 2008, 317). In the long run, comparative urbanism "might help to develop new approaches to understanding an expanding and diverse urban world, [...] being respectful of the limits of always located insights" (Robinson 2015, 194). Essentially, a comparative approach establishes new networks and enables different ways of looking at the urban at large. The popularity of such approaches has helped make urban research a key actor in the co-production of knowledge (Simon et al. 2020a) 4): "it is precisely the variation across the cases that has provided the grounds for conceptual innovation and invention" (Robinson 2015, 194). Thus, there are many arguments for comparative approaches to the study of urbanity, urban complexity and urban phenomena at large.

In many cases, the basis of a comparison between cities is perceived to be a kind of "formal equivalence" (Ward 2010, 475), which then proves to be misleading and is analyzed in detail: Comparisons are specifically useful in contexts where such pronounced differences become clear as "[u]nderstanding the potential uniqueness of cities and the specificity of the local are essential for knowledge production" (Palmer/Simon 2020, 18). At the same time, comparative studies have contributed to the establishment of a supposed hierarchy between those cities that are taken into account in studies and those that tend to be left out. This contributes to the visibility of some cities and urban phenomena and the invisibility of others (Palmer/Simon 2020, 21). This may add to some cities being perceived as secondary cities in relation to others. Further, comparative studies potentially contribute to enforcing binaries such as North/ South, East/West and thus those involved with them need to be aware of this risk.

3. Types of City Comparisons

Depending on the setup of a project, it is possible to differentiate between types of comparison which are used in Urban and Metropolitan Studies, as well as in related fields when comparing cities or metropolitan areas and their characteristics.

The most obvious strategy to classify comparisons is via numbers – here, the crucial factor is how many items are compared to each other in a study. Paired comparisons build on the comparison of just two entities, such as cities or regions. This type of comparison does not necessarily mean a simplification of facts, a strengthening of binaries or the production of simplified dichotomies which must be avoided (Grashoff/Yang 2020, 4), but rather, it can be useful to point out both similarities and differences via a detailed analysis. Triple case studies are more complex, and multi-case studies tend to be more abstract and less detailed than paired and triple case studies, but often prove inspiring for future research (ibid.).

Stepping beyond the classification by way of numbers, typologies are a device to "systematize heterogeneity" (Grashoff/Yang 2020, 11) and often specific to an established context. One of the better-known typologies in Urban Studies is the typology of the so-called group of world cities, which form a global network of cities important in and to the capitalist system. Behind this typology "is the assumption that cities situated in any of the three world regions will tend to have significant features in common" (Friedmann/Wolff 1982, 311) if they have great importance for the world financial markets. But this is not just a matter of the markets: "Their roles were not simply functionally determined but emerged through political action and contestation" (Robinson 2015, 190).

Another way to systematize comparative approaches, generally, but also in Urban and Metropolitan Studies, is via the relationship between the researcher and the object of study. Here, the number of comparisons established in a study is not the decisive factor. This way to differentiate between different types of comparisons was established by Charles Tilly. According to his classification, there are four types of comparison: the individualizing comparison, universalizing comparison, variation finding comparison and encompassing comparison. In the first case, a small number of cases is investigated "in order to grasp the peculiarities of each case" (Tilly 1984, 82). The second type has a more generalizing function, assuming it is possible to find instances where "a phenomenon follows essentially the same rules" (ibid.) every time it manifests. The third aims to "establish a principle of variation in the character or intensity of a phenomenon" (ibid.). This kind of study tends to work with many examples of one phenomenon in order to understand how differences in reactions to this very phenomenon come to be. An encompassing comparison "places different instances at various locations within the same system, on the way to explaining their characteristics as a function of their varying relationships to the system as a whole" (Tilly 1984, 83).

Ward criticizes that comparative studies in relation to urban topics all too often lack attention to scale (2010, 478). Here, he refers not simply to the scaling of maps, but to the idea that studies which take into account two or more cities in different national contexts only focus on the city itself as their subject without taking into account, for example, national policies or other regional factors and their contributions to urban phenomena. Further, these studies do not tend to look at cities as parts of their particular networks but consider their subjects of study as a type of isolated phenomenon (Ward 2010, 479). This leads to instances where power dynamics are not taken into account sufficiently. Instead, the causation of a problem or phenomenon is addressed as the only focus (Ward 2010, 480).

Due to these challenges, a "relational comparative approach" (Ward 2010, 280) to urban subjects may be needed. This approach "recognizes both the territorial and the relational histories and geographies that are behind their production and (re)production" (Ward 2010, 480) and helps shift attention away from the attempt to find similarities between different closed entities. This often happens in comparative investigations of a subject and leads to "stressing interconnected trajectories" (ibid.). A relational comparative approach makes it possible to see cities as sites connected to each other over time, and to view cities as entities in constant interaction with their surroundings – to speak with Doreen Massey, to recognize how "places are both unique and interdependent" (quoted in Ward 2010, 48). Especially in the era of globalization, including global financial markets and the global flow of information, cities are not as independent from their context as it might seem to a narrowly focused researcher. Changes in the global dynamics will have an impact on the situation on the ground and thus no phenomena can be viewed in isolation from each other (Ward 2010, 482).

4. Comparing Urban Phenomena and their Representation

As an interdisciplinary field, Urban Studies is certainly not limited to quantitative comparisons that focus on objectively measurable similarities and differences. Since it is heavily shaped by the Social Sciences and the Humanities, qualitative research and qualitative projects are used in order to compare urban and metropolitan phenomena in a variety of contexts. Such comparisons range from questions of comparing youth cultures and spaces associated with nightlife in different cities and regions (e.g., Chatterton/Hollands 2003), to investigating phenomena such as urban violence and their triggers (e.g., Moran/Waddington 2015), or undertaking comparisons of the media representation of cities and regions, including ways of dealing with their pasts and ideas for their future (e.g., Sattler 2019). Here, methods can range from approaching questions of storytelling or narratives to analyzing imagery (e.g., symbols, metaphors; for a discussion, see Parr in this volume), looking at patterns of linguistic change in a particular area, or focusing on a close reading of select textual material (novels, newspaper reports, films, interviews etc.), e.g., with the help of one or several theoretical approaches.

The Social Sciences and the Humanities often define a "text" as any material that enables "reading" – an advertising poster can be a text just as much as a poem, a television documentary or a map. In literary studies, comparative studies are a field of their own and enable "making comparisons between literary works and architecture, music and paintings, and also comparisons between different literatures" (Cuddon 1999, 164), meaning that items submitted to a comparison can be very different from each other and once again pointing to the understanding that a building, a piece of music or a film can also be read as a "text" and can be analyzed with methods of textual analysis. This suggests that in Urban Studies, such types of comparison that might seem unlikely to the more quantitatively oriented researchers focusing on data are also possible, and that indeed, data and poetry or architecture and statistics may be used together.

Much like their quantitative counterparts, comparative approaches of the qualitative sort – which can mean comparing urban narratives in fiction, or comparing the media representation of one particular city across different time periods, but also include such approaches as conducting standardized interviews with residents of different cities to learn about their perception of their lives – help to highlight local specificities, but can also enable the recognition of shared characteristics of different cities.

Ward (2010) detects a particular emphasis on the idea of comparing cities in terms of their livelihood and ranking them accordingly. City rankings can be a motor of tourism, but also of investment, as companies may invest in such regions where their employees can expect to live a good life – meaning a place where they can find good housing conditions, superior educational opportunities, but also ways to spend their free time. City rankings thus have become part and parcel of city marketing strategies. This also shows that quantitative and qualitative approaches often go hand in hand – it is not measurable factors alone that qualify a city or region as 'livable'; rather, the representation of particular places and sites in marketing materials as well as in the media at large also contribute to such a perception.

In any comparative study one will have to pose the question of whether it actually looks at urbanity and urban phenomena, or whether the city or the metropolis is the context of a study (e.g., in studies focusing on diversity, it makes sense to work with cities, as the urban environment enables encounters with a variety of lifestyles). Generally, a comparative approach places emphasis on understanding "the general" vs. "the specific" (Ward 2010, 474). One of the central challenges remains adequately commenting on the specificities of cities or sites within cities while at the same time paying close attention to similarity and difference between them. Ideally, undertaking a comparison – especially one in which quantitative and qualitative data work together – will help recognize which characteristics of a phenomenon are singular and which of them are universal. When researching a subject from a comparative angle, the comparative agenda sets part of the goal and in that sense may limit the options of what can be found out (Tilly 1984, 82). At the same time, a comparative approach in its particular complexity may be especially useful when studying equally complex topics such as those relating to urban identity or urban development. Ideally, comparison enables transgressing boundaries of the nation, the region or other perceived separating factors, and may thus contribute to an entirely new understanding of a phenomenon that is not caught in preconceived notions of it.

5. Comparative Approaches in Practice

There are several examples of projects in the field of Urban and Metropolitan Research that productively integrate qualitative and quantitative approaches. These illustrate the potential of comparative studies beyond the immediately visible, meaning beyond tourism or marketing and ranking cities according to their supposed importance or quality of life. One example is the project Shrinking Cities, which took place from 2003 to 2008. Shrinking Cities investigated urban shrinkage as a cultural phenomenon.

This project can be considered especially significant in the context of comparative projects, as it focused on those cities that usually do not appear in such studies, that are not 'global' cities, and that do not loom large in city rankings: Detroit in the US Rust

Belt, Ivanovo in Russia, the Manchester/Liverpool region in the United Kingdom and Halle/Leipzig in Eastern Germany (former GDR). All four cities and city regions are confronted with shrinkage: due to suburbanization, post-socialism, de-industrialization or a mix of all or some of those. This means that they lend themselves to comparisons of shrinkage in terms of its spatial, economic and cultural dimensions. Shrinking Cities, which resulted in several print and digital publications and in the first *Atlas of Shrinking Cities*, which fills some of the gaps for research on shrinkage, started from the assumption that modern processes of shrinkage are different from earlier such processes of urban decline that often were due to accidents or natural disasters. In the project, human geographers, urban planners, economists, filmmakers and others worked together.

The sites chosen for studies, as well as the further places included in the context of local projects and exhibitions, are the kinds of places for which a discipline like Urban Planning, which traditionally focuses on development in terms of growth, has to still find approaches. So far, the discipline "has had little to say about what cities should become following decline – population and employment loss, property disinvestment, and property abandonment" (Dewar/Kelly/Morrison 2013, 289). But the processes that manifest in these shrinking cities and regions across the globe make evident that "[t]he planning profession needs to develop the language, data, tools, and pedagogical frameworks that deal with the reality of America's [and other] shrinking industrial cities" (Dewar/Kelly/Morrison 2013, 300). For this new field of discovery, comparisons may be particularly fruitful, for example to see which answers and which terminologies have already been found for such scenarios beyond the immediately obvious, and to build a community of learning from each other.

The "Shrinking Cities" project successfully intervened into ongoing discourses of urban decline and showed how shrinkage can enable new ways of looking at the city and at urbanity from a variety of disciplinary perspectives. While it certainly asked for possible scenarios of future development for Detroit, Ivanovo, Liverpool/Manchester and Halle/Leipzig using the mode of comparison, it also pointed out the significance of interdisciplinary cooperation in comparative studies. The cooperation between artists, social scientists, architects, planners and others enabled a renegotiation of shrinkage as an urban phenomenon of the present, as well as a discussion of the local and global characteristics of this phenomenon in a discussion that went beyond lament and opened a public debate about the challenges and possibilities ahead (*Projektbüro Schrumpfende Städte*).

6. Future Potential and Challenges of Comparative Approaches in Metropolitan Contexts

More recently, research in Comparative Urban Studies has taken to transgressing established boundaries of North and South to enable comparison and co-produced research between partners from supposedly very different backgrounds. One such project, the MISTRA Urban Futures project connecting sites across the world in relation to questions of urban sustainability, highlighted the potential for learning from each other in each and any direction – from the North to the South, but very definitely also the other way around (Simon et al. 2020b, 156). The project illustrates that comparative studies as an investigative strategy has moved beyond its 1970s normative stance and towards the understanding that justice in the city is also and crucially a matter of productively working with local specificities and taking into account the diversity of cities and their citizens (Simon et al. 2020b, 161f.).

At the same time, in city marketing and associated disciplines, but at times also in politics, the idea of ranking cities according to characteristics and prestige is still prevalent. This is especially true in a time shaped by shrinking budgets and fewer opportunities for funding. Such campaigns provide much material for comparative studies in those branches of Urban and Metropolitan Studies that are working with approaches from the Humanities and Social Sciences such as with methods of textual analysis.

Comparisons between cities such as the ones used in the media or in marketing materials or material relating to development projects can be used to inspire and to create goals worth aspiring to – such as when the post-industrial Ruhr Region in Germany is linked to New York, "the Big Apple" (Wilms 2008). But they can also point to a perceived superiority of one city or region over another. This is the case, for example, when the struggles and challenges of Detroit, Michigan, are used in order to create a threatening scenario for the city of Bochum, Germany, also located in the Ruhr Region, and other European cities in which General Motors produces or formerly produced cars. In the "Detroit-Projekt", one of the follow-up projects of the European Capital of Culture – RUHR.2010 –, citizens are not only made aware that "This is not Detroit" – one slogan of the project, which was publicly funded. They are also being informed that "[t]he people of Detroit have already faced what we do not want to experience: the closing of the automotive and steel industry, moving away and leaving behind a landscape of ruins" (*Urbane Künste Ruhr*). While this statement can potentially serve a motivating purpose and invite people to think about the future of their city, the comparison with Detroit also points to the perceived superiority of those who – supposedly in opposition to Detroiters – participate in a process of reinvention. The project does not ask, for example, how postindustrial cities may learn from each other when faced with the closing of factories (Sattler 2017).

Still, comparing, as McFarlane has emphasized, ideally becomes a practice building on "learning through difference" (quoted in Simon et al. 2020b, 162), a notion that was present in the Shrinking Cities project already. Comparative Studies have moved away from a rather static setting to developing more dynamic approaches, and toward an idea of mutual learning in local contexts that points to furthering justice, equality and diversity in research as well. At the same time, there is great need for innovation in theory in the light of new experiences and with urban scholars travelling and conducting investigations globally (Robinson 2015, 193): Comparative setups are an opportunity to speak for the need for greater openness and fewer formal limitations to cooperation around the globe, and further theorizing on the subject will have to take this factor into account – both as a challenge and an opportunity.

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Urban Modelling: Quantitative and Qualitative Approaches

Jochen Gönsch/Jens Martin Gurr

1. Research Context: Urban Complexity Research and the Role of Models in Understanding and Managing Urban Complexity

A large number of contributions have proposed complexity as *the* key characteristic of the city and have in various ways called for a transdisciplinary research programme organised around the integrating paradigm of 'complexity' (cf. especially Eckardt 2009; Albeverio *et al.* 2008; Batty 2009, 2013; Portugali 2011, 2012a, 2012b).

Portugali (2006) conveniently defines the complexity of the city thus: "a very large number of interacting parts, linked by a complex network of feedback and feedforward loops, within a system that is open to and, thus part of, its environment" (657; cf. also Portugali 2011, 232). Further characteristics of complexity frequently discussed include self-organisation, emergence, non-linearity, phase transitions, density, mobility (as one cause of change over time and as the occasion for increased interaction and mixing), ethnic and cultural multiplicity, heterogeneity and hybridity, violence, conflicts over the use of space, intersections of technology and virtual spaces with physical spaces, overlapping and intersecting spatial scales – from the local to the global – and their interdependencies, as well as complex interferences, interdependencies or intersections in the interaction between multiple players, intentions, or force fields. Together, these make urban systems prime examples of translocal networks of complex relationships, connections, and interdependencies subject to rapid change over time. Moreover, as already indicated in Portugali's working definition, the city is of course an open or dissipative rather than a closed system (in the technical sense): It exchanges goods, energy, information, people, money, etc. with its environment. All these characteristics, it seems, are more or less part and parcel also of urban simulation models in the more technically oriented disciplines concerned with urban modelling from a complex systems perspective. However, the 'softer', less easily quantified and modelled characteristics of urban complexity are no less central to the 'urban experience'. In this vein, in addition to the 'usual suspects' such as "hierarchy and emergence, non-linearity, asymmetry, number of relationships, number of parts", Mainzer (2007, 374) also lists the following features:

"values and beliefs, people, interests, notions and perceptions" (they appear in a visualisation, hence in no particular order). Additionally, while the notion of a system's 'history' – in the sense that previous developments have an impact on the present and future course of the system – is central to urban modelling (if only in the sense that past developments can be extrapolated for predictive purposes), one specific aspect of a city's history is of particular importance to an understanding of urban systems from the perspective of literary and cultural studies: This is the notion of the city as a palimpsest, a form of layered spatialized memory.

The Role of Models in Understanding and Managing Urban Complexity

Models can be regarded as a central tool in any attempt to understand and manage urban complexity. According to a general theory of models (cf. Stachowiak 1973, 131–133), all models share the characteristics of being (1) representational, (2) reductive and (3) pragmatic. Thus, a model may be defined as a simplified physical, digital or mental representation of a more complex outside entity to which it must be functionally or structurally similar in order to function as a model. Models are devised or chosen for a specific purpose and – depending on that purpose – will selectively focus on different characteristics, elements or connections of the system perceived as central to this purpose, while disregarding others. Thus, a map of a city with colour-coding in green, yellow or red to represent high, medium or low average incomes per district is a model of that city in that it (1) represents the city, (2) does so in a highly selective, simplified, abstracted and aggregate form, and (3) does so for specific purposes – possibly to support decisions about where to launch social cohesion programmes – while it would be largely useless for other objectives.

Compression and strategic 'reduction' of complexity are of course part and parcel of any modelling process, as Stachowiak's notion of "reduction" ["Verkürzung"] as central to any model already makes clear (132). The crucial task in the building and use of models, therefore, is to decide what can safely be left out or abstracted so as not to distort the overall picture. This will naturally depend on what the model is supposed to achieve – whether, for instance, to help understand all interdependencies within a system or whether to capture only those features of a system perceived as relevant to a specific investment decision. In both cases, the heuristic nature of the model is not to be ignored.

Moreover, mathematician and information theorist Bernd Mahr has argued that models should additionally be understood in their dual nature of always being both "models *of*" something and "models *for*" something:

> A model is always based on something *of* which it is a model, i.e. departing from which or referring to which it has been produced or chosen, its matrix. The purpose of building or choosing a model is its use. […] One of the typical uses of models is their use as a *means of designing* [*or creating*] something. [Here] models are samples, pre-formations or specifications. […] The notion of the model can therefore only be explained convincingly if it is acknowledged that a model is always both a *model of something* and a *model for something*. (2015, 331f.; italics original; our translation)

Adapting this notion, a model can be understood as being to varying degrees both the *descriptive* rendering of an entity *of* which it is a model and – at least implicitly – the *prescriptive* blueprint for the design or transformation of a future entity *for* which it is a model. Building on this understanding of models, the present chapter selectively discusses two fundamentally different types of models, quantitative models in Operations Research on the one hand, and verbal models in literary and in pragmatic texts as one specific type of qualitative model on the other hand.

2. Quantitative Models in Operations Research

2.1 Overview

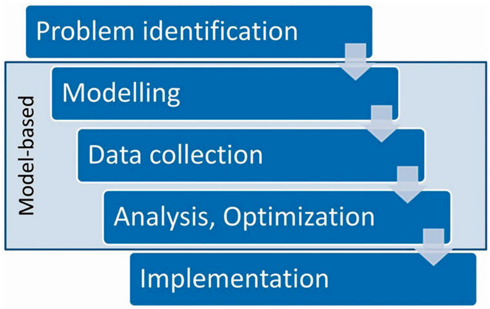
In operations research (OR), a model is a *task-driven, purposeful simplification and abstraction* of a perception of reality, shaped by physical, legal, and cognitive constraints. It is task-driven, because a model is built with a certain question or task in mind. Simplifications leave all the known and observed entities and their relations out that are not important for the task. Abstraction aggregates information that is important to become more general and, thus, gain relevance beyond a singular observation or use case. Both activities, simplification and abstraction, are done purposefully. However, they are done based on a perception of reality. This perception is already a model in itself, as it comes with a physical constraint. There are also constraints on what we are able to observe with our current tools and methods.

The *model type* is the language used to represent the outcome of the above-described process of model building. Its choice is clearly interrelated with the processes of simplification and abstraction, but choosing a model type is an important decision of its own that is largely driven by the model's purpose. The choice of the model type often precedes model building and actually determines already what can be easily captured in the model and what can not, usually because capturing a certain aspect would dramatically increase the model's size and complexity. For example, if we consider models of a car, a physical model made from Lego, a 2D drawing, and mathematical formulae clearly each have different advantages and disadvantages.

Models are central to Operations Research. In a way, they can be viewed as the interface between the discipline and the real world. The Analytics process depicted in Fig. 1 captures a standard approach to real-world problems. Starting with the identification of the problem, it is then formalized, i.e. a model is built. Scientists then work with this model, which often includes data collection to create instances, analysing the model and/or the instances (e.g., solving, simulating). Finally, the results are relayed back to the real world and implemented. Here, the need to change or refine the model may arise, starting a new cycle.

In the following, we discuss the three most important model families: *Forecasting models* seek to predict future states of the world. *Simulation models* are a subgroup of forecasting models that often capture stochastic influences and make predictions by playing through complex systems. Finally, *optimization models* provide decision support by determining the best alternative according to an objective function.

Fig. 1: Analytics Process

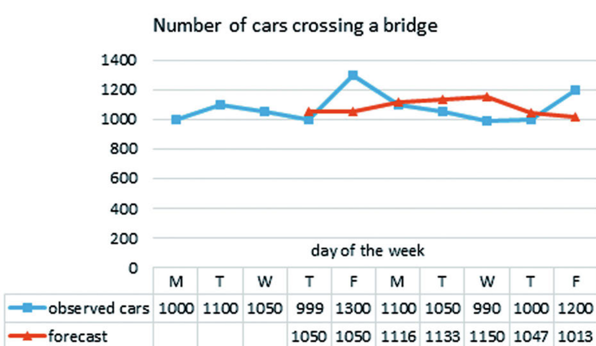


2.2 Forecasting Models

Forecasting models seek to *predict future events*. Usually, subjective (e.g., the Delphi method) and objective forecasts are distinguished. Operations research focuses on quantitative, objective forecasting models. A popular family of approaches uses past values from a *time series* to forecast future values.

As a simple example, we consider forecasting the number of cars crossing a bridge on a working day using the moving average method (see Fig. 2). In particular, the prediction for a day equals the average of the last three days (so-called MA[3]).

Fig. 2: Forecasting the number of cars crossing a bridge using the moving average method



Over the years, a plethora of forecasting models have been developed. In our example above, we may want to include the weekends, but account for the fact that traffic is usually reduced because no commuters are on the roads. Fitzsimmons et al. (2014) provide a tutorial on the most basic approaches, whereas more formal introductions include Henry et al. (2019) and Brockwell and Davis (2016).

2.3 Causal Models

Causal models focus on the relationships between exogenous and endogenous variables. They seek to *describe the causal mechanisms of a system* and often involve a strong simplification. Causal models allow some questions to be answered from existing observational data without the need for an interventional study such as a randomized controlled trial. They can also help with the question of external validity (whether results from one study apply to unstudied populations).

Causal models are falsifiable, in that if they do not match data, they must be rejected as invalid. They must also be credible to those close to the phenomena the model intends to explain.

If the resulting model is simple enough, it may be possible to use mathematical methods (such as algebra or calculus) to obtain exact information on the system of interest via an analytical solution. However, please note that 'exact' refers to the model, not to reality as there is usually a gap between both, for example because of simplification or abstraction.

As an example, take the distance travelled by a falling object: The distance s travelled by objects during the first t seconds of free fall is described by the well-known formula

$$\mathrm{s} = 1/2\mathrm{gt}^2,$$

where g is the gravity acceleration

$$(\mathrm{g} = 9.81\tfrac{\mathrm{m}}{\mathrm{s}^2} \text{ on earth}).$$

This model describes very well the movements of objects that are comparably heavy (like stones or apples). However, it becomes inaccurate for objects whose air resistance is quite big compared to their weight (such as feathers).

2.4 Simulation Models

Simulation models are a special kind of forecasting models for complex systems, where it is impossible to capture the system's behaviour as a whole analytically, often because of stochastic influences and complex relations between the system's elements. Instead, computers are used to *imitate*, or simulate, the system. To do so, the behaviour of each element is specified. When the simulation is run, the computer tracks each element and imitates its behaviour. Finally, quantitative performance indicators are collected and reported.

Simulation models often involve stochastics. In this case, the result of a single simulation run is more or less meaningless and the simulation is run multiple times to calculate valid averages (i.e. that come close to their expected values because of the law of large numbers) and determine confidence intervals etc. for the performance indicators of interest. While simulations implied a lot of manual coding in the past, modern software packages recently rendered this process much more user friendly.

A die, for example, is simulated by drawing a random number between 1 and 6. To obtain its expected value, this is repeated a hundred times and the following frequencies are recorded: 1: 15, 2: 17, 3: 14, 4: 18, 5: 20, 6: 16. Summing up leads to 359, that is, an average of 3.59.

Note that this example is so simple that we would usually not use simulations to approximate the die's expectation but rather use probability theory to exactly determine it:

$$\sum_{i=1}^{6} \frac{1}{6} \cdot i = 3.5.$$

This is also a nice example for the limitations of an exact, analytical solution: 3.5 is obviously the expectation of the die in our model. But clearly not of any real-world die: because of mechanical defects or deviations during the production process, the real-world die will not have exactly equal probabilities.

There are many features of simulations we cannot capture with the space available here. However, we would like to briefly describe two special types of simulations that enjoy an increasing popularity (see Law 2015 for an in-depth introduction to simulation).

Agent-based Simulation

Agent-based simulation (ABS) is comparably new and gained popularity through a tutorial and a dedicated track at the 2005 Winter Simulation Conference. However, there is no generally accepted definition of an agent or ABS. Lots of concepts are associated with ABS, but it is not clear what is at its heart.

An *agent* is an autonomous entity that can sense its environment, including other agents, and use this information in making decisions. In particular, agents have attributes and a set of *rules that determine their behaviours*. Some may have a memory and learn over time. Agents may include people, animals, vehicles, and organizations. Often, an ABS is defined as a simulation where agents interact with each other and their environment in a major way.

In ABS, a *bottom-up approach* to modelling is taken, where the emphasis is on describing the behaviour and interaction of the individual agents. In some ABS, the interactions of the agents over time result in emergent behaviour of the system as a whole, which is not deducible from the characteristics of the individual agents.

Introductions to ABS include Law (2015, Ch. 13.2) as well as Deckert and Klein (2010). They also briefly describe popular software packages like AnyLogic. (For details on ABS, see also Weyer et al. in this volume.)

System Dynamics

System Dynamics (SD) is a type of simulation that is often used for designing and improving policies or strategies in business, government and the military. In contrast to ABS, it is a *top-down* approach to modelling a system. SD models look at systems at a more *aggregate level* and are used for strategic decisions. The majority of models is deterministic, but random components are also possible. SD was created by Professor Jay Forrester at MIT in the 1950s.

Common components of an SD model are *stocks* (an accumulation of a resource), *flows* (streams of a resource into or out of a stock) and *information links* (brings information from a stock to the valve of a flow). For more details, the reader is referred to Law (2015 Ch. 13.3).

2.5 Optimization Models

An optimization model adds an *objective function* to one of the aforementioned model families to *rate* (predicted) outcomes or system states. Evaluating the model for different decision alternatives thus allows selecting the preferred one. Optimization models are a formal representation of optimization problems, where the *best alternative* is selected with regard to the defined goals.

Scientists usually formulate optimization models using mathematical formulae and seek so-called closed-form solutions. As an example, we may take a landscaper who designs a public park with a rectangular lawn surrounded by a row of roses. She wants in total 100m of roses, and she prefers the lawn as big as possible. How long should she choose both sides of the lawn? This optimization problem is represented by the following optimization model:

$$\max_a f(a) \text{ with } f(a) = a \cdot (50 - a),$$

where we use that the length of both sides of the lawn must sum up to 50m. The problem is solved with basic calculus as:

$$f'(a) = -2a + 50 = 0 \Longleftrightarrow a = 25 \text{ and } f''(a) = -20.$$

Thus, a square lawn with an edge length of 25m is optimal for her.

More complex optimization problems make the relations between causal models and optimization more obvious. Here, we may take the example of a farmer's crop choice: A farmer disposes of two fields of land. Field A is 20 ha in size, field B 10 ha. He can plant corn or wheat. Field A is slightly more fertile than B. He expects a profit of 11€/ha from corn and 9€/ha from wheat on field A and 10€/ha for corn and 9€/ha for wheat on field B. Because of long-term contracts, he must at least produce wheat equal to 5 ha. Let c_A denote the amount of corn (in ha) on field A and c_B on field B. Likewise, the wheat planted is denoted by w_A and w_B.

$$\max_{c_A, c_B, w_A, w_B} 11 \cdot c_A + 10 \cdot c_B + 9 \cdot (w_A + w_B) \quad (1)$$

$$c_A + w_A \leq 20 \quad (2)$$

$$c_B + w_B \leq 10 \quad (3)$$

$$w_A + w_B \geq 5 \quad (4)$$

$$c_A, c_B, w_A, w_B \geq 0 \quad (5)$$

Here, (1) is the objective function that allows to rate a state of the system. (2)-(5) is a causal model that describes restrictions a feasible solution must satisfy. We must admit that to save space, the problem is so simple we can find an optimal solution without any advanced technique:

$$c_A = 20, c_B = 5, w_A = 0, w_B = 5$$

with a total profit of 315 €.

In contrast to the previous example, more complex problems can usually not be solved with basic calculus from secondary school. To choose an appropriate solution technique, the model type is important. The crop choice example is a so-called linear model and thus comparably easy to solve exactly using, for example, the widespread simplex algorithm invented by the US mathematician George Dantzig in 1947. For other model types, other techniques may be necessary. Sometimes an exact solution (in the mathematical sense) cannot be found, but numerical approaches find arbitrarily good solutions. Optimization models are at the heart of operations research, see, for example, Taha (2016) for an introduction.

In other cases, it may be too complicated or even impossible to capture the system's mechanics in mathematical formulae as we did in (2)–(5) of the crop choice example. In this case, a simulation model may be used instead of formulae to represent the system.

Scenarios, Decision Support, and Simulation-based Optimization

Simulations predict the evolution or behaviour of the system modelled. Thus, at their heart, they do *not* provide decision support. However, simulations can be repeated with different initial parameter values to predict the system's behaviour for an alternative scenario. If the scenarios correspond to decision alternatives, simulation can be used to evaluate the alternatives and select the most preferred one according to an objective function (e.g., think of simulating traffic in a city centre with a new tunnel with one or two lanes).

Clearly, the evaluation of each scenario as described above is only possible if their number is low (often five to ten). For example, a traveling salesman who wants to visit 11 customers already has 19,958,400 sequences to choose from. For such problems with a large number of or even continuous alternatives (like global warming given yearly future CO_2 emissions), complete enumeration is impossible. Instead, simulation-based optimization (SBO) approaches are used. These iterative approaches usually simulate a few scenarios and derive approximate relations between the decision variables (the parameters that can be varied) and the objective function. Based on this, they make an 'educated guess' which variable values may lead to a better objective. This guess is then tested with new simulations, which starts a new cycle with improving the derived approximate relation, based on which a new guess is made. Over the years, countless mathematical approaches have been developed to realize this (see, e.g., Gosavi 2015 or Fu 2015). To be precise, simulation-based optimization is not a model, it is a solution approach that uses simulation to solve optimization problems.

3. Texts as Qualitative Models

3.1 Limitations of Quantitative Models from a Cultural Studies Perspective

Quantitative models are characterised by abstraction and aggregation and thus are generally not concerned with local or individual specificity. Despite their undisputed achievements in dealing with a range of aspects of urban complexity – demographic developments, material and energy flows, mobility planning and innumerable others – it is in understanding qualitative phenomena – such as urbanity, individuality, place-specificity, individual patterns of interpretation and sense-making – that quantitative models show their limitations. For although it is, of course, possible to include certain 'subjective' features into a model (for instance by including group-specific cultural preferences, as is common in agent-based modelling and other types of urban simulation models), what is individual, unique, historically and personally specific and not reducible to an underlying pattern, is what disappears in abstracting from the individual and in the aggregation of preferences, needs, desires, hopes, fears into an equation (for a brief discussion of these limitations, cf. also Gurr 2021, 15–19).

3.2 Analysing Urbanity, Individuality, Local Specificity: Texts as Qualitative Urban Models

This is where texts can play a role as a specific type of complementary qualitative model: It is precisely this individuality and specificity both of different urban environments in their "intrinsic logic" (*sensu* Berking/Löw 2008) and of human behaviour, of perceptions and patterns of sense-making that literary texts model in uniquely differentiated ways. It is in literary texts that the "non-sensual" city of sociologists (*sensu* Lindner 2006) and quantitative modellers becomes perceptibly individualised.

Here, the inquiry into the "knowledge *of* literature" (cf. Hörisch 2007; our italics) or into the strategies of producing knowledge *in* literature may be especially relevant: What are the specific achievements of literature and of literary texts as a unique form of generating, storing, transmitting and mediating knowledge (cf., for instance, Fluck 1997; Gymnich/Nünning 2005; Felski 2008; Gurr 2013)? It has been argued that literary texts represent knowledge – or create it in the first place – in ways fundamentally different from discursive, expository texts (cf., for instance, Glomb/Horlacher 2004; Hörisch 2007). Specific literary strategies thus become "devices for articulating truth" (Felski 84). This centrally concerns questions of genre and questions of literary modelling generally: In which ways do literary texts function differently from discursive texts on the same subject (for an example, cf. Gurr 2017) or what are the specific cognitive achievements of narrative as opposed to, say, quantitative models of complex matters?

With reference to the relation between the city and the text, a text can thus be understood as a qualitative urban model in that it is – again to varying degrees – *descriptive* in its representation of the city and – again at least implicitly – *prescriptive* in that it formulates directions or options for a different future city. This dual nature is also evident in the fact that texts not only represent an external urban reality but contribute to shaping perceptions of the urban and thus to highlighting that a different city is at least conceptually possible. Moreover, as the increasingly frequent collaboration between planning experts and science fiction writers shows, literary texts as models *of* and models *for* urban realities also have a crucial role to play in developing scenarios.[1] What literary and cultural studies can contribute here is an understanding of precisely those elements of urban complexity that cannot be measured, modelled, classified in quantitative terms.

When it comes to defining elusive notions such as 'urbanity' or 'metropolis', for example, purely quantitative models can be shown to be of limited use: 'Metropolis' and, to a lesser extent, 'city', it seems, are not merely designations that are tied to quantitative criteria; they are not solely descriptive terms, but more or less strongly imply normative elements, even a utopian promise – and this is largely a cultural promise that is difficult to categorise or quantify. However, the concept of the metropolis of course is not only normative. It does make sense to classify cities according to various criteria, and many historical as well as recent attempts to define the metropolitan character of cities are very enlightening.[2] Thus, the concept of 'metropolis' – just like 'urbanity' – curiously oscillates between descriptively designating a quantifiable status of centrality as a financial centre, a traffic node, a centre of research and education or of the media industry on the one hand, and a normative requirement of a far less tangible metropolitan 'feel' of cultural promise (cf. Gurr 2010, 2015): Frankfurt/M. may be a financial metropolis, because, second to London, it is the seat of the most important European stock exchange and of several important banks, but is it, on a global scale, a cultural metropolis? Berlin, although certainly not a financial centre, is a metropolis, because it is a capital with over three million residents, but it also appears to have the intangible cultural 'flair' a metropolis in the wider sense also seems to need. The urban novel, for instance, in the panoramic representation of social interactions as well as individual responses to specific cities or metropolitan regions, can here be shown to function as an alternative form of 'modelling' urban complexity.

3.3 Case Study: Modelling the Complexities of the Ruhr Region in a Novel

As a case in point, we might take Jürgen Link's 2008 novel *Bangemachen gilt nicht auf der Suche nach der Roten Ruhr-Armee: Eine Vorerinnerung*. The title translates into something like "Don't Be Intimidated in Search of the Red Ruhr Army: A Pre-Memory", the Red Ruhr Army being a reference to the left-wing worker's army which, since March 1920, defended the early Weimar Republic against reactionary and anti-republican forces after the right-wing Kapp-Putsch. In over 900 pages, the text on the one hand is a fictionalised (if sometimes thinly veiled) collective biography of a group of 'old leftists', "non-

1 Thus, the German Federal Institute for Building, Urban and Spatial Research (BBSR) in 2015 issued a study entitled *Learning from Science Fiction Cities: Scenarios for Urban Planning* (our translation; cf. BBSR).

2 Cf. especially Danielzyk and Blotevogel, who distinguish between the (1) innovation and competition function, (2) decision and control function, (3) gateway function, and (4) symbolic function. For an early influential study, cf. Hall 1966; for a widely debated recent contribution, cf. Sassen; for a survey, cf. Bronger. Cf. also Terfrüchte in this volume.

renegade members of the 68 generation"[3] (Link 2008, 881; translation JMG) in the Ruhr region from the 1960s to the early 2000s. On the other hand, it is an attempt at representing the complex topography of the Ruhr region and its multiple historical layers in a structurally and conceptually – and often stylistically – highly complex novel:

> The route changes in its combinations of bits of *autobahn* and alleged short-cuts, that is labyrinthically curving residential neighbourhood streets or transition roads from the last suburb of the previous Ruhr city to the 1st suburb of the next; traffic jams increase or intermittently decrease in parallel with construction noise and the economic situation; the airstream of the cars in front of you whirls up shreds of tabloid papers from the ditch and sometimes a completely empty car with flashing alarm lights stands on the right curb [the sentence continues for eight more lines] (Link 2008, 28; translation JMG).
>
> The Turkish colleague had to brake hard: right on this stretch of commercial street through which we then had to commute on our way to work, felt reminded of France every time: broad and splendid it went on for several 100 metres straight on and slightly uphill between glaring and pleasantly renovated façades in all sorts of Krupp styles: from Krupp Romanesque via Krupp Gothic all the way to Krupp Renaissance and Krupp Baroque, in which large shop windows flashed, facades, and nothing behind them [again, the sentence continues for several more lines]. In the evenings, as is typical of the Ruhr region, such brightly lit neighbourhoods with shop windows and shiny tube station entrances abruptly alternated with gloomy stretches, where, to the left and to the right, there were still fields, before it just as abruptly became bright again, but this time as if we had entered the inside of a production site, where bright lights were supposed to protect a mix of new plastic halls and old brick buildings against gangs of burglars. (Link 2008, 37f.; translation JMG)[4]

3 The novel professes to be "a realistic report on the experiences of a group of non-renegade members of the 68 generation" (Link 2008, 881; my translation); the German original reads: "realistische[r] Erfahrungsbericht einiger nichtkonvertierter 68er".

4 The German original reads: "Die Route wechselt in ihren Kombinationen von Autobahnstücken und angeblichen Schleichwegen will sagen sich labyrinthisch biegenden Wohnviertelstraßen oder Überbrückungspisten vom letzten Vorort der letzten Ruhrstadt zum 1. Vorort der nächsten, die Staus nehmen weiter zu oder zwischendurch wieder etwas ab parallel mit dem Baulärm und mit der Konjunktur, der Fahrtwind der Wagen vor Euch wirbelt Schlagzeitungsfetzen in der Gosse auf und manchmal steht ein vollständig leeres Auto mit blinkendem Alarmlicht am rechten Straßenrand [der Satz geht noch über acht Zeilen weiter]." (Link 2008, 28) "Der türkische Kollege musste voll auf die Bremse treten: mitten auf diesem Stück Geschäftsstraße, durch das wir damals pendeln mussten auf dem Weg zur Arbeit, uns jedesmal wieder erinnert an Frankreich: breit und prächtig ging es ein paar 100 Meter schnurgerade und leicht bergauf zwischen knallig und schön renovierten Fassaden in allen möglichen Kruppstilen: von Kruppromanik über Kruppgotik bis hin zu Krupprenaissance und Kruppbarock, worin überall große Schaufenster blitzten, Fassaden und nichts dahinter […]. Abends wechselten, wie es typisch im Ruhrgebiet ist, solche hell erleuchteten Viertel mit Schaufenstern und glitzernden U-Bahn-Eingängen abrupt mit finsteren Abschnitten, wo rechts und links noch Felder waren, bevor es ebenso abrupt wieder hell wurde, aber diesmal wie als ob wir ins Innere eines Werksgeländes geraten wären, wo helle Laternen ein Gemisch aus neuen Plastikhallen und alten Ziegelbauten gegen die Einbrecherbanden schützen sollten." (Link 2008, 37f.)

In an interview, but also in an essay on his own novel, Link comments on the function of these complex structures as follows: "The Ruhr region is one of the very few conurbations that are structured like a rhizome" (Heidemann n.p.).[5] Thus, in keeping with the original biological meaning of the term 'rhizome' as a multifariously interconnected network of roots, the concept as established by Deleuze and Guattari also designates a web of interconnections without a tree-like hierarchy. As an organisational structure in which, to put it simplistically, 'everything is connected to everything else', as a symbol of a non-hierarchical organisation of knowledge, such a decentralised structure also implies a moment of resistance against dominant, authoritarian and hierarchical forms of organising knowledge and of exercising power.

Thus, it is not least on the micro-level of its individual endlessly meandering sentences that the novel simulates the heterogeneous *spatial* structures, layers and interdependencies of and in the region. Yet, as the above passage with its reference to a succession of "Krupp styles" makes clear, the novel also subtly engages with *temporal* layers, both in such individual passages and in its overall structure, which frequently includes so-called "simulations", often highly political projections of the future from previous decades, which are then explicitly or implicitly checked against actual developments as they *did* take place. However, the palimpsestuous nature of the region, its spatialized layered memory, is arguably even more centrally represented through the individual and collective recollections of the protagonists and in the forms and locations in which these recollections physically manifest themselves and through which, in turn, they are kept alive and are invoked.

A recurring image that is in keeping with the frequent references to the region's mining past is that of consciousness and memory as functioning in layers that are explicitly referred to as the levels of a mine (cf. fig. 4.15), for instance in a reference to "all five levels of our pit of consciousness" (Link 2008, 398; translation JMG):

> though in that brief moment of saturation before falling asleep we may have felt an insight flit through our brains – during our walks through the colliery grounds, again and again, a further clarity of insight had temporarily come into our heads, accompanied by multivocal simultaneous awareness of the various levels in our heads, sometimes almost down to the lowest, the 5th level. (Link 2008, 398; my translation; cf. also 711, 721)[6]

Moreover, the novel frequently stages the layering of the region by referring to the temporal succession of dominant industries on specific sites, not least in numerous references to car manufacturing as the major industry that has taken over from mining.

5 The German original reads: "Das Ruhrgebiet ist eines der ganz wenigen Ballungsgebiete, die wie ein Rhizom strukturiert sind." (Heidemann n.p.)

6 The German original reads: "alle 5 Sohlen unseres Bewusstseinspütts" (Link 2008, 398): "mochten wir dann im kurzen Moment des Sattseins vor dem Einschlafen noch eine Einsicht durch die Gehirne huschen fühlen – so war bei den Spaziergängen im Zechengelände immer wieder zeitweise eine noch zusätzliche Durchblicksklarheit in unsere Köpfe gekommen, wozu ein mehrstimmiges simultanes Bewusstsein der verschiedenen 'Sohlen' in unseren Köpfen gehört hatte, manchmal fast bis auf die unterste, 5. Sohle herab." (Link 2008, 398).

Thus, in the course of the novel, there are some 40 references to "Ruhr-Motor", sometimes also referred to as "Inter-Ruhr-Motor", which is clearly recognisable as a reference to the Opel plants in Bochum. Occasionally, the text even directly refers to the succession of industries on the same site: "'He had been working in mine Gneisenau Two […] where now there is plant 3 of Ruhr Motor'" (Link 2008, 370; my translation).[7] This passage is also telling in its use of specific place names: "Zeche Gneisenau" was in fact a coal mine in Dortmund, but it seems to be typical of the novel to obscure, blur or amalgamate concrete place references in order all the more strongly to suggest an overarching 'Ruhr local colour' at the same time.

In sum, Link's novel thus lends itself to exemplifying both the importance of the unique spatial structures of the Ruhr region *and* its temporal layers.

3.4 Literary Texts as Qualitative Simulation Models

Somewhat speculatively, we might argue that literary texts as models of reality are *per se* combinations of order and disorder: In frequently highly structured and ordered ways, they represent complexity and multiplicity, even disorder, and overlay disorder with order – established plot structures, schemata, or typological patterns of interpretation (cf. Koschorke 29ff.) – and thus structurally replicate key patterns of urban complexity (for a detailed discussion of texts as structural and functional urban models, cf. Gurr 2021).

Moreover, if 'scenario building' and the testing of alternative parameter settings in their impact on a given system is regarded as a crucial function of urban systems modelling, then a parallel with an important type of quantitative model (see 2.5 above) emerges: One of the central functions of literature, according to one understanding, is that it serves as a form of symbolic action, as a social experiment free from the constraints of everyday life – literature as 'depragmatised behaviour in rehearsal' ['entpragmatisiertes Probehandeln'][8] which makes it possible symbolically to try out in fiction different scenarios or potential solutions for key societal issues. Here, too, given the descriptive, representational as well as the – at least implicitly – prescriptive, speculative, exploratory function of texts, this conceptualisation – developed in the wake of Mahr's understanding of the model – of texts as both descriptive "models *of*" and prescriptive "models *for*" urban structures, developments and functions, seems highly appropriate.

4. Conclusion: Intersections and Parallels between Quantitative and Textual Models

A key issue that needs to be addressed in comparative discussions of quantitative and verbal urban models is the fundamentally different status of the 'model' in both fields:

7 The German original reads: "'Der hatte da auf Zeche Gneisenau Zwo gearbeitet […] wo jetzt Werk 3 von Ruhr-Motor steht.'" (Link 2008, 370).

8 This is the view formulated, among others, by Kenneth Burke, Dieter Wellershoff, Wolfgang Iser or Glomb/Horlacher.

While in technical urban complexity research, the model is the *result* of scientific endeavour, in literary and cultural studies, the literary text functions as the 'model' and is thus the *object of study* rather than the *result* of the scholar's own work. Thus, Mahr's rather casually enumerative formulation of the two alternative ways in which models come into being – "no object is a model per se. Models are *built* or *chosen*" (331; italics original) – here constitutes a fundamental distinction between different research cultures and their dominant forms of engaging with models.

Despite the fundamentally different status of the 'model' in urban complexity modelling on the one hand and in literary and cultural studies on the other hand, there are a number of important parallels and points of intersection between the two types of 'model' and in the understanding of complexity: What most technical notions of complexity share is that they measure the complexity of a system in terms of the length or the complexity of the description or representation of that system. A number of complexity theorists have even argued that "complexity is not primarily a characteristic of the object that is being described, but of the description" (Richter/Rost 112; my translation).[9] This notion might lend itself as a bridge between technical or mathematical and cultural conceptualisations of complexity. Ultimately, what is relevant to literary studies, one might argue, is not so much the complexity of the city itself, but the representation of this complexity, i.e., its description in the 'model' of the literary text. Literary studies are thus concerned with the challenge of 'modelling' it, or, in the terminology of literary studies, of 'representing' it. Thus, where technical and mathematical complexity research is concerned with the mathematical description of complexity, literary and cultural studies of urban complexity are concerned with the challenges of verbal representation.

Gell-Mann's notion of "effective complexity" provides an important connection between a technical and a literary understanding of complexity:

> A measure that corresponds much better to what is usually meant by complexity in ordinary conversation, as well as in scientific discourse, refers not to the length of the most concise description of an entity (which is roughly what AIC [algorithmic information content] is), but to the length of a concise description of a set of the entity's regularities. Thus something almost entirely random, with practically no regularities, would have effective complexity near zero. So would something completely regular, such as a bit string consisting entirely of zeroes. Effective complexity can be high only in a region intermediate between total order and complete disorder. (1995, 16)

This seems precisely to be the case with cities and, even more so, metropolitan regions: In the sense of "effective complexity", they are systems in which there are multiple regularities as well as contingencies, and hence systems in which "a concise description of a set of the entity's regularities" would be extremely long. Thus characterised by an intricate combination of both order and disorder, cities have long been understood as systems of extremely high "effective complexity" (take Jane Jacobs's classic formulation that cities are "problems in organized complexity", 449).

9 The German original reads: "Komplexität ist nicht in erster Linie eine Eigenschaft des beschriebenen Objekts, sondern der Beschreibung selbst." (Richter/Rost 112).

The different procedures used in different fields and disciplines to represent, reduce (or: constitute in the first place) and seek to 'manage' complexity do justice to different facets of urban complexity in varying degrees: Mobility systems or energy flows lend themselves to quantitative models far better than do processes of sense-making or conflicting patterns in the perception and use of space, which find privileged expression in verbal models of literary texts. Even the selection criteria for facets to be included in (and, conversely, excluded from) the model are virtually diametrically opposed: that which is individual, specific or characteristic in literary texts as opposed to that which can be generalised, aggregated and quantified in quantitative models.

Moreover, the boundaries between numerical, visual and narrative models do not necessarily coincide with disciplinary boundaries, as the example of modelling urban complexity in social cartography shows (for a detailed discussion cf. Gurr/Schneider; for questions of statistics and cartography, cf. Schneider 2006, 2011a, 2011b, 2014; for mapping in literary studies, cf. Mattheis 2021, 83–133; Moretti 1998; Rosseto 2014): Here, visualisations are regularly preceded by quantitative models, which in turn may be informed by underlying – often unquestioned – narratives. Similar forms of overlay and transfer between quantitative and visual models are to be found in different methods of mathematical optimisation such as graph theory or in the geometrical tesselation of areas as they occur in the optimisation of infrastructures, logistics networks, scheduling problems or evacuation scenarios. What is more, qualitative and quantitative representations of complexity by no means have to correspond: some forms of complexity may be easy to describe qualitatively but may be extremely difficult to quantify (and vice versa).

Nonetheless, a number of strategies in dealing with complexity are rather similar, and there are a large number of overlaps, interactions and transfers between different basic types of models. There are, for instance, a number of remarkable parallels and analogies between algorithmic and aesthetic/literary strategies of representing and reducing complexity (sometimes only reduction may make representation possible in the first place). Thus, a number of literary strategies of reducing complexity – for instance, the metonymic strategy of telling one story and suggesting that innumerable others would also have been worth telling, or the breaking of linearity by means of partition and distribution (for a typology of such strategies, cf. Gurr 2021) – are paralleled in mathematics and information technology in the handling of complex calculations and large quantities of data by means of distributed computing, randomisation or decomposition (for an accessible discussion, cf. Schulz).[10]

Despite such parallels, analogies and processes of exchange, the different methods of modelling complexity cannot be seamlessly integrated or converted into one another: Rather, the different types of model might be seen to complement each other, for instance by mutually offsetting shortcomings and by filling in each other's blind spots.

10 Some of this part goes back to discussions with Alf Kimms, professor of Logistics and Operations Research at the University of Duisburg-Essen's Mercator School of Management, in a previous project.

This kind of integration of various approaches to modelling, we argue, is crucial to a more refined understanding of complex metropolitan structures and systems.[11]

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11 Sections 1, 3 and 4 partly reuse material developed in Gurr 2021.

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Delineating and Typifying Urban Neighbourhoods: A Mixed-Methods Approach

Thomas Terfrüchte/Susanne Frank

1. Introduction: Problems of Comparative Neighbourhood Analysis

For over a hundred years, neighbourhoods have been perceived as central elements of the urban society and community (Albers 1974). As spaces for diverse activities and encounters, they play an important role in the everyday lives of their inhabitants. They provide basic functions of life: housing, work, education, (local) supply, recreation and, last but not least, social life. Processes of social change can therefore be observed particularly well in these "dynamic micro-worlds" (Schnur 2014, 21). For more than two decades, neighbourhoods have also been gaining in importance as a level of urban development policy action, which can be seen in a multitude of small-scale funding programmes and instruments (Franke 2011; Schnur 2018, 1833).

Therefore, from a social, spatial and planning science perspective, neighbourhoods are increasingly relevant spaces for observation, research and action. At the same time, however, systematic and, above all, comparative neighbourhood analysis faces a number of practical, theoretical and methodological problems.

1.1 Spatial Monitoring at Neighbourhood Level

Since neighbourhoods are not standardised objects of spatial observation, there is often a lack of meaningful data at the small-scale level. In Germany, spatial monitoring as a legally prescribed task starts at the municipal or district level. It is thus possible to observe city-wide development trends, but not small-scale changes. Many cities and municipalities therefore set up their own small-scale monitoring, which is usually tailored to the administrative (sub)structures (usually city districts and/or subdivisions). This leads to at least three problems: firstly, the spatial outline hence follows an administrative logic, which often does not correspond to the everyday understanding of neighbourhoods. Secondly, the administrative divisions in the various cities often differ significantly from each other, from the depth of division to the average number of inhabitants. Thus, district A of municipality X can only be compared to district A of municipality Y to a limited extent. For this reason, the Metropole Ruhr, for instance, has attempted to set up a region-wide monitoring system (RuhrFIS), in which the 53 cities are mostly subdivided into 635 comparable districts on the basis of the local administrative division (RVR 2017, 11). Thirdly, all cities survey the number of inhabitants at the level of their small-scale subdivisions. But that is where the commonalities end: there are considerable differences between the cities in terms of the variables observed (e.g., age or nationality) as well as the possible characteristics of these variables (e.g., cohorts in the case of age, and regional groupings such as "Maghreb" or dichotomous scalings such as "national" and "foreigner" in the case of nationality). This means that comparative neighbourhood research – within a city, but also on a supra-local level – faces great methodical difficulties.

1.2 Understanding Space and Neighbourhoods

In addition, comparative neighbourhood research is complicated by the fact that there is no unified understanding of 'neighbourhood'. However, there is a clear dividing line between neighbourhood concepts based on an absolute or objective understanding of space and those based on a relational or constructivist conception. In the former perspective, neighbourhoods are conceived as clearly delimitable 'containers'; in the latter, they appear as 'social spaces' defined by the living world with open, fluid boundaries.

Absolute neighbourhood concepts usually entail quantitative research approaches. The aim is to make the social phenomena or processes taking place in the 'containers' measurable with standardized procedures or to describe them statistically, to analyse them and, possibly, to compare them.

But according to the constructivist perspective, spaces or neighbourhoods are precisely "not fixed units that precede social processes, but are themselves a result of these processes" (Kessl/Reutlinger 2010, 27). This research therefore aims to understand the individual and collective construction processes of neighbourhoods and to trace the position-dependent perceptions, interpretations and action orientations that constitute neighbourhoods from a subjective perspective. Qualitative methods are particularly suitable for this purpose. They stand for (at least semi-)open, interpretative approaches that are intended to identify overarching patterns within the diversity of subjective perspectives, for example, shared neighbourhood concepts or overlapping spaces of action. In this view, there can be no firmly defined neighbourhoods with objective, binding boundaries. Rather, neighbourhoods are characterised by fuzzy boundaries.

The social constructivist understanding of neighbourhoods is widely shared today. Nevertheless, empirical neighbourhood research and practical urban or neighbourhood planning are repeatedly faced with the task of meaningfully delimiting spaces of investigation, action or intervention for their respective purposes, i.e. ultimately defining 'containers' nonethless. After all, municipal planning must "determine places and areas in which employees are to carry out outreach work, kindergartens or roads are to be built, green spaces or playgrounds are to be created, emissions are to be limited or social division is to be countered" (Groos/Messer 2014, 10), and must justify this selection in a comprehensible way. Thus, the dilemma of "real complexity" and "necessary simplification" (Schnur 2014, 42) cannot be resolved. Schnur therefore calls for a reflected pragmatic approach (ibid.).

In what follows, we present such an approach. It is characterised by the integration of qualitative and quantitative methods. The aim of this paper is to present a transferable model of neighbourhood delineation and typification that enables comparative neighbourhood analyses within a city, but also between cities. The approach has already been successfully tested in the city of Remscheid in cooperation with the local administration.[1]

2. A Mixed Methods Approach

The delimitation and typification of observation areas is one of the classic tasks of spatial observation – from the European to the regional level. Numerous (standardised) methodological approaches have been tried and tested for this purpose (cf. Terfrüchte 2015). So far, there is no such established approach for spatial observation at the neighbourhood level.

2.1 Mixed Methods

Since our aim is to capture a multifaceted object of study, i.e. the neighbourhood, in the most complex way possible and from different perspectives, we choose a mixed methods approach (Burzan 2016, 9). We understand "mixed methods" as "the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the purpose of breadth and depth of understanding and corroboration" (Johnson et al. 2007, 123).

In doing so, we combine qualitative and quantitative instruments carefully tailored to the subject matter, i.e. along the research question of how to meaningfully delineate and typify neighbourhoods for research and planning purposes. For, as Johnson and Onwuegbuzie (2004, 17f) state: "What is most fundamental is the research question—research methods should follow research questions in a way that offers the best chance to obtain useful answers."

In this context, we assume that "all methods can only capture sections of the empirical reality of interest, have different strengths and weaknesses and can therefore complement each other" (Hense/Schork 2017, 360). For us, however, methodological plural research also means, as far as possible, always relating the data obtained from different

1 The model was developed within the framework of the joint project "MOSAIK – Model Strategies for Integrated and Culturally Sensitive Housing Stock Development" funded by the Federal Ministry of Education and Research in the "Kommunen Innovativ" programme. We would like to thank the city of Remscheid for the opportunity to use the municipal data stocks for our research. For his dedicated organisational and technical support of the MOSAIK project, we would especially like to thank Dennis Hardt very much.

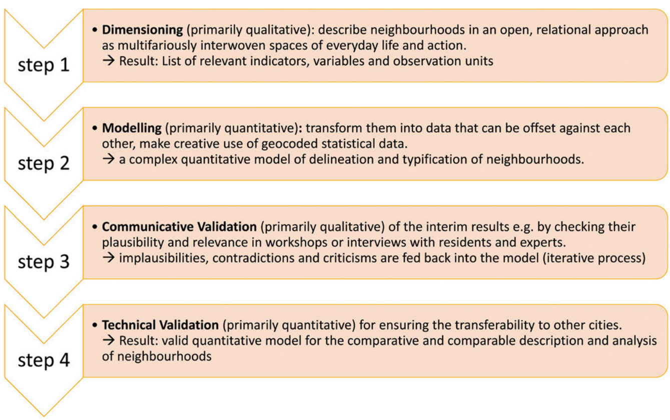
sources and with different means to each other in such a way that they not only complement each other, but can also, if possible, challenge or even contradict each other. So this is not only about combining methods, but also about integrating methods.

Thus, our research approach is "problem-centred", "pluralistic" and "oriented towards 'what works' and real-world practice". In this respect, it fully corresponds to the "pragmatist worldview" in mixed methods research, as characterised by Creswell and Plano-Clark (2018, 34ff.), among others.

2.2 Sequential Design ("Four Steps")

In model building, we proceed in qualitative and quantitative sub-steps that systematically build on each other, but should not be understood linearly (cf. Fig. 1).

Fig. 1: Sequential design in four steps



The starting point is, firstly, a qualitative, open, relational understanding of neighbourhoods as multifariously interwoven spaces of everyday life and action, which we, secondly, transform into a complex quantitative model of delineation and typification of neighbourhoods with the help of a creative use of geo-coded statistical data. Thirdly, interim results are repeatedly validated with qualitative methods, e.g., by checking their plausibility and relevance in workshops or interviews with residents and experts ("communicative validation", Flick 2014, 413ff.; Kvale 2007). It is crucial that the delimitations and typifications correspond to the everyday perception of neighbourhoods. If this is not the case, the model or its components are put to the test. Contradictions and criticisms are fed back into the model, which is corrected and improved until its results stand up to the critical scrutiny of residents and experts. At the end of this iterative, sequential procedure, there is, fourthly, a valid quantitative model that can be transferred to other cities for the comparative and comparable description and analysis of neighbourhoods, which, as its application in the city of Remscheid shows, can also provide a valuable basis for evidence-based urban and neighbourhood development.

3. Challenges of Modelling

In our project, the delineation of neighbourhoods therefore stands at the end and not at the beginning of the research process. The attempt not to define neighbourhoods in advance, but to discover them in the statistical data from a lifeworld perspective, is associated with great challenges. For one thing, suitable material, i.e. material that is available or can be translated into data, must first be identified or collected and processed (sections 3.1 and 0). On the other hand, it is necessary to find ways of including defining neighbourhood characteristics in statistical modeling, such as everyday interactions, principle openness, and the social and functional interdependence of neighbourhoods (section 3.3). This is anything but trivial.

Therefore, the first step is to take a look at the variables and observation units that are relevant for neighbourhood delineation and typification. In the following, we will examine the question of which data are available to us at all, what significance they have and how they can be modelled.

Fig. 2 classifies the usual indicators of neighbourhood research according to whether the variables or observation units are manifest or latent.

Fig. 2: Latent and manifest variables and observation units

	observation unit: **manifest**	observation unit: **latent**
variable: **manifest**	people • age • citizenship area • morphology (e.g. size) • located infrastructures	household • size (number of people) • mean age neigbourhood • mean age • located infrastructures
variable: **latent**	people • educational background • migration background building • primarily usage • property value	household • type • Income neigbourhood • local identity • household-types

3.1 Manifest Variables and Observation Units

People

Since we consider neighbourhoods as spaces of activity and interaction for their inhabitants, we first look at the people living there and the ways they live (together), i.e. in private households. (Private households – apart from one-person households – are already aggregates of the persons belonging to the household). Persons as observation units are in principle directly observable. However, not all variables attributed to them can be observed beyond doubt. The most prominent example is probably gender, whose dichotomous recording as "male" and "female" has been prohibited in German civil status law since the end of 2018 (Federal Constitutional Court, 2017). The validity of the observed or observable characteristics in the context of the concept of migration background is also complex (see below).

Irrespective of this, a great deal of information about people is available, of comparatively good quality, through compulsory registration (in Germany and many other European countries), and this information can be geo-referenced via the registration address. The registration laws in each case regulate which characteristics are recorded. In Germany, these variables include the date of birth, gender, place and country of birth, nationality, and, in the case of minors, the same information on the parents, and many more (§ 3 Bundesmeldegesetz [BMG]). For individuals, monitoring (in accordance with data protection) is therefore possible at any small-scale level.

Infrastructure Facilities

Infrastructural facilities are not only important with regard to the perception of the basic functions of existence in the neighbourhood. In our approach, they play a central role as potential places for everyday encounters and interactions. Therefore, we focus on mobility infrastructure (especially public transport stops and routes, roads, footpaths and cycle paths), education and care infrastructure (especially day-care centres and schools), supply infrastructure (especially retail facilities) and health infrastructure (e.g., general practitioners and paediatricians). Basically, a distinction must be made between point infrastructures, which can be geo-referenced via addresses, and network infrastructures. While point infrastructures are destinations of everyday interconnections, network infrastructures influence the accessibility of these destinations. Just as large as the variety of relevant infrastructures is the number of institutions that hold the relevant data. Although many cities are trying to systematically compile such points of interest and make them available to third parties, there are only uniform state or national data sets for those infrastructures that are the responsibility or sovereignty of the states or the federal government. However, this does not prevent small-scale monitoring.

Buildings and Areas

In addition to population and infrastructure facilities, structural characteristics are particularly relevant for neighbourhood perception (Schnur 2018, 1832). Observation units are then essentially buildings and, if applicable, associated cadastral areas. These data are processed uniformly throughout Europe on the basis of the INSPIRE Directive (*INfrastructure for SPatial InfoRmation in Europe*). In this way, comparable statements can be made on the (dominant) land use or on the use of buildings. In addition, the official house coordinates assigned to the buildings form an excellent data basis for the georeferencing of people and infrastructure facilities.

3.2 Latent Variables and Observation Units

In addition to the three directly observable observation units of persons, infrastructures and buildings, there are – as mentioned – also interesting variables and observation units that are latent and must first be constructed.

Private Households

In comparative neighbourhood research, private households are often considered as *the* relevant characteristic carriers. The focus then is on characteristics such as income, receipt of transfer payments, number of children and many more. However, since the municipal registration system does not recognise household membership as an obligatory survey characteristic of a person, households are not statistically observable.

Therefore, households must be modelled based on statistical information, as is done for the census, among other things. On the basis of a series of premises, married or paired persons who are registered at the same address are successively aggregated into households with biological children who are also registered there. What is easily possible with single-family and multi-family houses with traditional forms of living is more difficult with multi-generation houses and shared flats. Here it has to be determined whether it is the same household or separate ones. Insofar as households are already latent as observation units and their determination is subject to a multitude of premises, the variables aggregated at the household level always have a certain susceptibility to error.

Relocation

In social science, migration describes the (outward or inward) movement of people from a source to a destination. This includes both intra- and inter-communal migration within a nation state (internal migration) and migration across national borders (international migration) (Han 2016, 7f.).

From the perspective of municipal statistics, this means that by definition there is only internal migration within the municipality – without further differentiation. However, the (address-specific) raw data, which can be retrieved from the population registers of the municipalities, also allow intra-municipal migration to be modelled. This means that further differentiations can be made, e.g., migration within a neighbourhood, migration between neighbourhoods (within the city) or migration between the city and the surrounding area.

Migration Background

International migration is relevant for the concept of 'migration background' as defined by the Federal Statistical Office. While the destinations (i.e. the new places of residence) of migrants can usually be recorded without any problems via the registration system, this is by no means the case for origins and places of birth. There are many possible causes for incomplete and erroneous data records, ranging from incorrect recording at the registration office to unclear cases or the non-existent obligation to record the country of birth before 2015 (cf. Terfrüchte et al. 2021). The source of migration and the country of birth of migrants must be distinguished from their nationalities. In principle, migrants (like natives) can have any number of nationalities. They do not all have to be entered in the residents' register as long as no (new) identity card is requested. Since in Germany it is obligatory to do so only every ten years, it might be the case that, for example, non-German citizenships acquired in the meantime remain unknown to the registration system. In this respect, only the concept of "foreign national" is valid for persons who do not have German citizenship.

In addition to the fact that only those nationalities can be included in analyses that are known to the registration system, it must also be clarified whether and how the various combinations of nationalities are dealt with analytically. For example, do we ask in a survey whether a person has a Turkish or Russian passport (among others), or are German-Turks and Russian-Germans understood as a separate group precisely because of their combination of citizenships?

Official information on persons (as observation units) thus has its weaknesses, but from a pragmatic point of view it is still the most suitable, since the latent variables of interest in the research context (such as migration background) can be constructed in a reasonably plausible and transparent manner, so that there is no need to draw on already constructed variables from secondary data sources.

Small-scale Monitoring Units

The aforementioned data is often subject to restrictive data protection. If data is passed on to research institutions for scientific purposes, then there is the obligation to aggregate it in such a way that it is not possible to draw conclusions on individual persons, registration addresses, companies, etc. The data must not be passed on to third parties.

At the same time, the municipalities do not have all data that are of interest from a research perspective, such as data on purchasing power, the labour market or health care. Requesting these data from the relevant agencies is only possible for spatially delimited sub-areas. However, to define such sub-areas for the data query conflicts with our claim not to define neighbourhoods in advance, but to develop them from the available (data) material.

Due to both requirements (data protection and spatial data retrieval), we therefore form spatial units, in such a way that we can assume that the buildings and persons belonging to these units will under no circumstances belong to different neighbourhoods, and can therefore be considered 'inseparable' in the sense of belonging to a neighbourhood. We call them the 'smallest units'. They are building blocks of the neighbourhoods to be delimited and should not be confused with the neighbourhoods themselves!

Box 1: Sequential mixed methods procedure for determining the smallest units Based on observation (Step 1), it was initially building blocks that seemed suitable as the smallest units. However, we have found that there are building blocks with a heterogeneous building and settlement structure – a criterion that can itself have a neighbourhood-defining effect and can therefore also be relevant for the delimitation. Our model for the formation of smallest observation units (Step 2) therefore combines building blocks with settlement types. In the further course of the neighbourhood delimitation, it has become apparent that there are large units with only one or a few buildings. This can sometimes result in smallest units which are adjacent in the sense of the delineation algorithm, but the buildings within them are far away from each other (Step 3). After reviewing a few individual cases, we introduced a plausibility check which, based on the population density and the density of residential buildings, identifies such smallest units that may have an 'unsuitable' cut (Step 4); if this was the case, the smallest units were separated manually. The example shows that a method-integrated approach with qualitative validation leads to more plausible findings in the sense of the aforementioned subject adequacy.

3.3 Modelling (Dis)similarity

In this project, neighbourhoods are understood as spatially coherent settlement bodies, composed of smallest units, with usually similar building structures, which are characterized by an above-average degree of interconnectedness in everyday life (cf. Section 0). From this we deduce that, methodologically, neighbourhoods are multifunctional similarity spaces: They are similar with regard to the building structure and with regard to the (many) everyday interconnections. We therefore test the smallest units for such similarity structures.

Building and Settlement Structure Similarity

The physical-structural coherence of a settlement body can – unlike spatial-functional interrelations – be perceived directly through the senses. If one looks at a traditional block perimeter development, one will hardly assign the respective buildings and people to different neighbourhoods. If this type of housing development were to be adjoined by a dispersed single-family housing development, many people would, simply based on the clear change in the development structure, probably assume that this is where one neighbourhood ends and the next neighbourhood begins – it remains unquestioned that there may well be substantial interrelationships between these settlements. Since building structures often correspond to social structures, many cities also work with settlement types when it comes to different requirements for action in (social) urban development.[2]

Spatial-Functional Linkages (Source-Destination Linkages)

Spatial-functional interdependencies can assume very different intensities. To ensure comparability between the different spatial dimensions for neighbourhood delineation, 'pairs' of smallest units assume the value 0 if there are no linkages and the value 1 is assumed as the maximum of the linkage intensity, which is reached if all (external) linkages of a smallest unit (as an observation unit) are accounted for by the 'pair'. This is also referred to as the so-called linkage coefficient (Terfrüchte 2015, 131ff.). In contrast to

2 We also explicitly do not include data on social structure in the construction of neighbourhoods. We use such data to describe, but not to delineate the neighbourhoods.

Fig. 3: Transforming nominal scaled variables into an interconnection-matrix

City	Type
a	A
b	A
c	A
d	B
e	B
f	B
g	C

	a	b	c	d	e	f	g
a	-	1	1	0	0	0	0
b	1	-	1	0	0	0	0
c	1	1	-	0	0	0	0
d	0	0	0	-	1	1	0
e	0	0	0	1	-	1	0
f	0	0	0	1	1	-	0
g	0	0	0	0	0	0	-

1 = max. similarity

the building and settlement structure with usually one or – when considered separately – two variable(s), there is a multitude of relevant spatial-functional linkages that are expressed via routes: to the day-care centre, to school, to the playground, to the shops, to friends, to the doctor, to an office or a public authority, etc. In the model, these routes are understood and processed as source-destination connections.

However, the modelling of source-destination linkages is only valid if the sources (i.e., the residential locations of the users) are entirely available for the respective destinations (i.e., the infrastructure facilities). In this respect, the municipalities are in possession of a multitude of valuable, but so far – if at all – insufficiently used data resources (Terfrüchte/Hardt 2021). For example, they know which children use which day-care centre or open-all-day school (through the parental contributions) and they know which children attend which school (at least for those in municipal responsibility).

In the area of outpatient medical care, it is the Association of Statutory Health Insurance Physicians (Kassenärztliche Vereinigung) that has nationwide and address-specific knowledge about source-destination relationships for the provision of general and specialist care by statutory health insurance physicians. Through the billing data, the practice locations of the treating physicians as well as the residential locations of the patients are available. The associations of SHI-accredited physicians therefore know which patients have billed which doctors, when and how often.

Methodologically, it is now a matter of offsetting the diverse interdependencies against each other as multifunctional interdependencies. In any case, the result is again an n:n matrix in which 'pairs' without spatial-functional interdependencies are given the value 0 and those with the maximum possible interdependencies are given the value 1. In our example, we have offset the various interdependencies equally and normalised them on a scale from 0 to 1.

Neighbourhoods as Places of Encounter

If a large number of different linkage data are available, multifunctional linkage areas can be identified in the same way as central-location interdependency areas (Terfrüchte 2015, 214). The starting point is then the individual destinations with their specific catchment areas. Moreover – and this seems to be 'new territory' in spatial sciences so far – the sources (i.e. the residential locations of the users) can also be the starting point for modelling, namely for the aforementioned modelling of similarities. Based on the assumption that the destinations (schools, day-care centres, supermarkets, waiting rooms of doctors or public authorities, churches, etc.) are also potential places of encounter), it is determined which spaces show similar patterns of interconnectedness from the perspective of patients, pupils, parents of children in care, etc. The results are then used to model similarity. In practice, a link between the sources (i.e. the households/locations) is created via the respective target. An enormous advantage of this approach is that it opens up the possibility of discovering and delineating neighbourhoods in the material that do not themselves have any of the above-mentioned targets (such as social or medical infrastructure facilities).

Political-administrative Responsibility

The example of primary schools is also suitable for introducing a further perspective on spatial interdependencies. Before the abolition of primary school districts in North Rhine-Westphalia in 2006, there were clear responsibilities, i.e. depending on the place of residence (address), children were assigned to a specific primary school. The linkage was practically predetermined. The situation is analogous to other administrative or "responsibility" areas (Terfrüchte 2015, 42ff.), such as city districts or parishes. Even if offices or places of worship are not regularly visited destinations for many, from a methodological point of view they lead to a commonality, since the same church parish or district council is responsible for the inhabitants of these smallest units. These examples always boil down to the question of whether a smallest unit X has something in common with a smallest unit Y, which indicates whether they should, ceteris paribus, belong to the same neighbourhood – or not.

In the model with the n:n matrix, 'pairs' of smallest units thus take the value 1 if they belong to the same jurisdiction space; otherwise the value is 0.

4. Delineating Neighbourhoods

If neighbourhoods are thus methodically understood as similarity spaces and, in particular, the interrelationships are also included in the modelling of similarity and dissimilarity, classical cluster analytical approaches can be used not only for the typification of neighbourhoods, but also for their delimitation. In Section 3, the central challenges of modelling were presented with corresponding approaches to solving them. Now the task is to statistically delineate the neighbourhoods for comparative neighbourhood research on the basis of this data. For this purpose, tools from the GIS software ArcGIS and the statistical software SPSS are used.

4.1 Spatially Constrained Multivariate Clustering

The ArcGIS tool "Spatially constrained multivariate cluster analysis" combines spatially neighbouring polygons (with a common boundary) into similarity spaces on the basis of any number of content-related characteristics, provided that so-called spatial constraints do not prevent this (see below). In addition, further premises can be set, for example, for the number of clusters or target values for certain characteristics (such as a minimum number of inhabitants).

In our case, the smallest units are aggregated into neighbourhoods on the basis of the existing interdependencies and the similarity in terms of building and settlement structure. The mode of operation corresponds to a cluster centre analysis (cf. Section 0), i.e. a distance model is first created on the basis of the characteristics and those smallest units (if they are spatially neighbouring) are aggregated into neighbourhoods that have the smallest distance – i.e. the greatest similarity. However, the spatial-functional linkages are available as a source-destination matrix and therefore cannot be straightforwardly used in the tool.

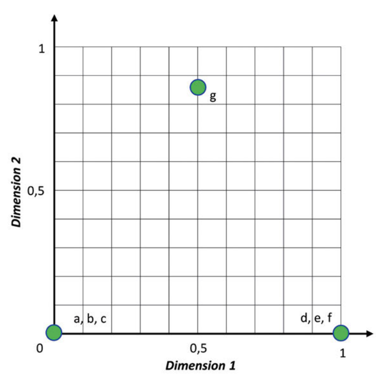
4.2 Multidimensional Scaling

The relevant interdependencies must therefore first be converted into latent characteristics (with the above-mentioned smallest units as characteristic carriers) via the interdependency intensity. The following applies: the stronger the interdependence intensity, the smaller the distance and the smaller the differences in the characteristic values of the latent characteristics. Fig. 4shows this transformation schematically. Technically, the SPSS tool "Multidimensional Scaling" is used for this.

Fig. 4: Transforming interconnection-matrices into latent variables

	a	b	c	d	e	f	g
a	0	0	0	1	1	1	1
b	0	0	0	1	1	1	1
c	0	0	0	1	1	1	1
d	1	1	1	0	0	0	1
e	1	1	1	0	0	0	1
f	1	1	1	0	0	0	1
g	1	1	1	1	1	1	0

1 = max. dissimilarity



City	dim1	dim2
a	0,00	0,00
b	0,00	0,00
c	0,00	0,00
d	1,00	0,00
e	1,00	0,00
f	1,00	0,00
g	0,50	0,87

The SPSS tool "Multidimensional Scaling" allows users to transform statistical distance measures of all observation units to each other (e.g. Euclidean, Manhattan etc.) into a multidimensional coordinate system. The individual coordinate values are then the characteristic expression of the latent dimensions.

While classical cluster analytical methods first have to generate a distance measure based on the included characteristics and characteristic values, multidimensional scaling takes the opposite approach. The advantage for spatial delimitation based on similarity or dissimilarity is obvious: in the first step, all relevant (interdependence) characteristics can be converted into a suitable distance measure, in the second step, the individual distances are statistically linked, and in the third step, the multifunctional distance is converted into a multidimensional coordinate system for the 'spatially restricted multivariate cluster analysis'.

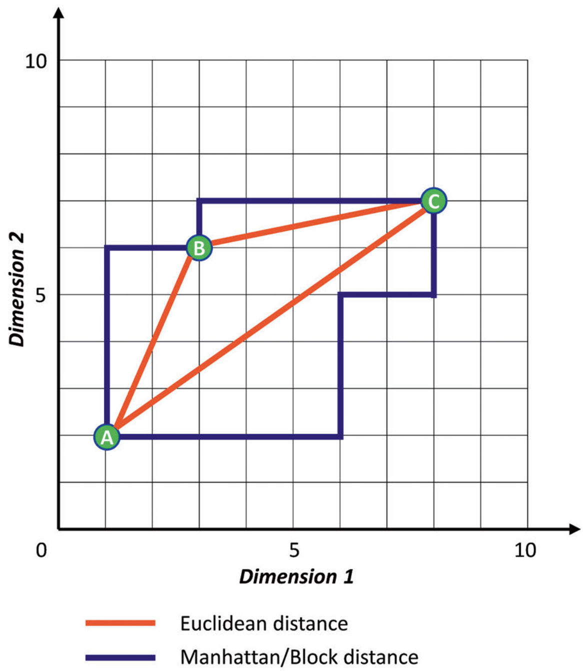
If we construct neighbourhoods via multifunctional similarity and model similarity as distance, the question of the appropriate distance measure inevitably arises. Widely used is the (possibly squared) Euclidean distance, which can also be interpreted as the air line between two points. The Manhattan or block distance, on the other hand, sums up the distances of the two points on the two axes. Compared to the block distance, the (squared) Euclidean distance decreases disproportionately the more similar the characteristic values of the two variables are. A scatter diagram with two variables (axes) illustrates the differences between the two distance measures (Fig. 5)

We are now dealing with different 'similarities', which are either available as a classical table with characteristics per characteristic carrier (e.g., the affiliation of smallest units to settlement types, cf. Section 0) or as interrelation matrices (cf. Section 0). Due to these different formats with their different logics, the data cannot therefore be directly 'offset' against each other. For the modelling of a multifunctional similarity, separate distance models must first be determined for all 'similarities', which are then offset to a multidimensional or multifunctional similarity. Here, the block distance offers the advantage that as much of the original information (of the respective 'similarities') as possible is retained. The multifunctional similarity can then also be represented in the Euclidean distance model.

4.3 Spatial Constraints

The modelling of similarity and dissimilarity is necessary to delineate neighbourhoods as overlapping spaces of everyday life and action for their residents and users – but it is not sufficient. At least three further rules (in the sense of premises) are necessary. Firstly, in our understanding of neighbourhoods there can be no enclaves or exclaves. As a rule, only such smallest units that have a common boundary, i.e. are spatially directly adjacent, can be combined into a neighbourhood. The cluster tool already meets this requirement (see above). Secondly, there are spatial barriers that separate even neighbouring smallest units from each other to such an extent that they cannot belong to one neighbourhood. These are in particular rivers, motorways and railway embankments. Less restrictive barriers (e.g., accessible federal roads) are taken into account in the model as ceteris paribus rules, i.e. if there are several assignment possibilities with the same similarity, those smallest units between which there is the smallest possible barrier should be aggregated. And thirdly, we assume – again ceteris paribus – that the better the pedestrian accessibility between the smallest units is, the more likely they are to belong to a neighbourhood if there are several allocation options.

Fig. 5: Manhattan distance vs. Euclidean distance.



distance	block	euclidean	difference
$\overline{AB}$	6	$\sqrt{4^2+2^2}$ = 4,47	1,53
$\overline{BC}$	6	$\sqrt{5^2+1^2}$ = 5,10	0,90
$\overline{AC}$	12	$\sqrt{7^2+5^2}$ = 8,60	3,40
sum	**24**	**18,17**	**5,83**

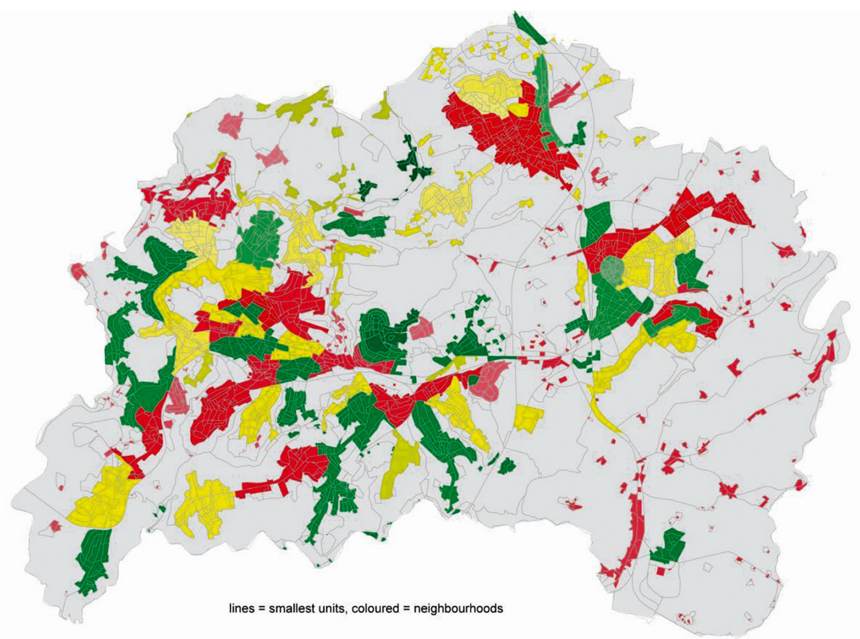
These restrictions are modelled using the ArcGIS tool "Spatial Weighting Matrix". This defines which polygons may not be combined despite a common boundary and which polygons are aggregated into clusters prioritised ceteris paribus. The spatial weighting matrix thus practically forms the corrective or the correcting counterpart to the multifunctional similarity matrix.

Box 2: Sequential methodological plural approach to neighbourhood delineation The application of these rules can occasionally lead to errors, for example when the barrier effect of traffic roads is mitigated or eliminated by structures such as tunnels or bridges and is therefore not perceived as such. However, such individual cases cannot be discovered and solved via the aggregation algorithms, but only through the specific local knowledge of the residents or users of neighbourhoods. The results of the primarily quantitative delimitation methodology are therefore subjected to a qualitative plausibility check through informal conversations, surveys or expert workshops. The result of this check can be individual 'manual' corrections, but also an adjustment of the model when it comes to individual cases that can be modelled quantitatively, which are placed after the rule as an exceptional case. In our practical examples, we have found, for example, that there are smallest units that are predominantly characterised by special forms of housing such as closed inpatient care facilities or also the penal institution. In such cases, we have excluded the smallest units from the neighbourhood delimitation.

4.4 The Example of Remscheid

On the basis of 1740 building blocks and 22 settlement types, a total of 2060 'smallest units' were identified as the foundation for the investigations in Remscheid, to which a total of 23,552 addresses and 48,253 buildings can be assigned. The aggregation of the smallest units resulted in 92 neighbourhoods (Fig. 6). A list of the data sources included can be found in Terfrüchte et al. (2021, 53).

Fig. 6: Neighbourhoods and smallest units in Remscheid



5. Multidimensional Typification of Neighbourhoods

The data monitoring at the small-scale level and the delineation of neighbourhoods based on this data already have their own value from the perspective of the planning administration, but in this article, as in our research project, they serve primarily as a basis for the typification of neighbourhoods. Only in this way is a type-related strategy development possible and the strengths of qualitative and quantitative methods intertwine in the best possible way.

5.1 About Similarity and Dissimilarity

The aim of any typification is to group observation units (here: neighbourhoods) on the basis of selected variables in such a way that the differences in variable characteristics within the groups are as small as possible, and between the groups they are as high as possible. Or, to put it more simply: the observation units are grouped according to similarity. If only one metrically scaled characteristic was considered, typification would be nothing more than class formation, i.e. the transformation of the metric scale to an ordinal scale, not on the basis of predefined class widths or a desired equal distribution, but on the basis of 'natural breaks' between different point frequencies. Within a point cloud, the characteristic carriers then do not have the same, but a similar characteristic expression (Fig. 7, left). Here we continue to speak of age or income classes and not of age or income types. Types are usually formed by at least two characteristics, which inevitably means that they can no longer be measured and ordered on a scale: by definition, they are nominally scaled.

Sometimes the characteristics included correlate very strongly with each other, which would be visible in a classic scatter plot by a clearly recognisable regression line (fig 7, right). Point clouds in the sense of observation units with similar variable characteristics are then primarily found on or near the regression line and are not arbitrarily distributed 'in space'. In such cases, it is reasonable to do a principal component analysis prior to typing. This allows one to extract a constructed (latent) variable from a large number of highly correlated (observable) variables. These latent variables can then be used for the typing.

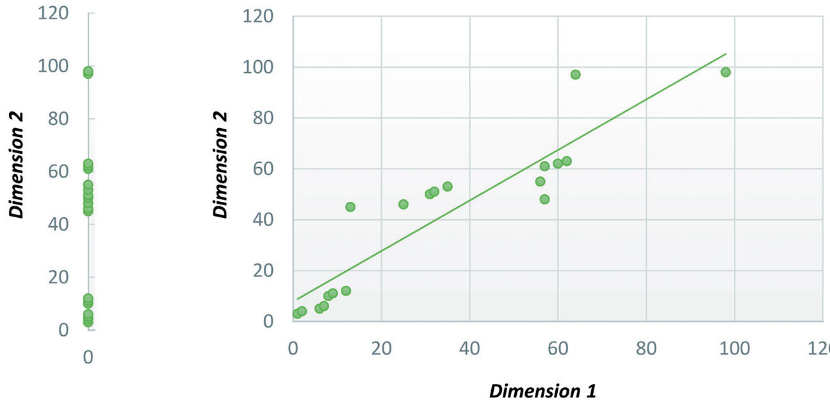
In principle, it can be assumed that, with an increasing number of characteristics to be used for typing, the probability increases that groups of variables have a high common variance and are thus highly correlated with each other. At the same time, however, the greater the number of variables, the greater the uncertainty as to whether the variables will be appropriately aggregated into types. For this reason, typing is often carried out as cluster analysis preceded by principal component analysis.

In the Remscheid case study, we combined a total of 111 manifest characteristics into 12 latent characteristics using principal component analysis (see fig. 10).

5.2 Dimensioning and Dimension Reduction

Within the framework of dimensioning, all those characteristics that can be type-forming are operationalised – based on theory. In contrast, dimension reduction serves to

Fig. 7: Scatterplot with two dimensions and regression line



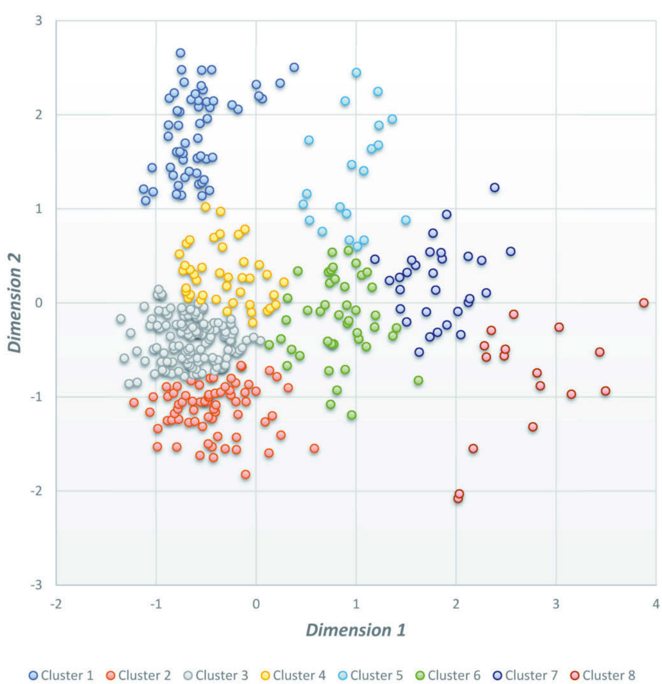
construct a few meaningful dimensions from the multitude of relevant characteristics. The essential difference between the two steps is that (quantitative) dimension reduction is based on the observed characteristics and those characteristics are combined into dimensions that show a similar spatial pattern, i.e. they are highly correlated with each other, whereas (qualitative) dimensioning is carried out independently of space, and the operationalised characteristics can, but do not have to, correlate with each other.

Basically, the point is that the characteristics of interest in terms of neighbourhood similarity are latent, i.e. not observable (e.g., socio-economic status). Only the operationalised characteristics are observable (here, e.g., unemployment, qualification level, etc.). Whether a latent characteristic "socio-economic status" can be meaningfully extracted using principal component analysis (cf. Terfrüchte, in this volume) depends on whether the characteristics correlate strongly with each other and also 'fit together' in terms of content. To stay with the example, this would be the case, for example, if neighbourhoods with high unemployment actually also have a low qualification level of the employed and a low household income. Another constellation, on the other hand, would prove problematic: for example, wage differentials between women and men lead to an increase in gross domestic product per person in employment if fewer women are in employment (cf. Terfrüchte 2019, 26), and a low female employment rate correlates with low youth unemployment. In such a case then, socio-economic status cannot be mapped on one dimension – at least not if one assumes both a high female employment rate and low youth unemployment as desirable. The statement 'The lower the female employment rate, the higher the socio-economic status' is then statistically quite expectable, but in terms of content it is not intended with regard to the dimensioning. These examples illustrate that the ability to assess the significance and thus the importance of content-related and statistical correlations is indispensable, especially in the case of constructed characteristics, in order to be able to interpret them at all and to use them for typification.

5.3 Hierarchical Cluster Analysis with the Ward Algorithm

The goal of every cluster analysis is to group characteristic carriers (here: neighbourhoods) into clusters in such a way that the neighbourhoods within a cluster are as similar as possible and the differences between the clusters are as great as possible (Bortz/Schuster 2010, 453). Depending on the cluster algorithm used, priority is then given to clusters of equal size, homogeneously populated clusters or clusters with the greatest possible differences between them. The possibilities of classifying neighbourhoods increase exponentially with the number of neighbourhoods: with five neighbourhoods there are 52 assignment possibilities, with 10 neighbourhoods 115,975 (Bortz/Schuster 2010, 458), with 15 neighbourhoods 1.4 trillion, and for the 92 quarters in the Remscheid case study (see below), the number of possibilities would have 105 digits; to find the best solution with conventional computers would be too time-consuming for any research process. Bortz and Schuster expect a duration "of several centuries" even "for samples of medium size" (ibid., 459). In this respect, it is important to reduce the number of potential solutions through certain premises.

Fig. 8: Visualised clusters in a scatterplot



Hierarchical cluster analysis is one of the agglomerative approaches (Bortz/Schuster 2010, 459). Based on the distance model (see above), all those neighbourhoods that have the smallest distance to each other are grouped into clusters. This is illustrated in fig. 8. Now the clusters of the first stage determined in this way are successively further combined on the basis of the distances existing between them (second to n-th fusion stage) until all neighbourhoods belong to one cluster. Our goal is to form clusters that are as homogeneous as possible, which is why we use the Ward algorithm. This minimises the increase in variance in the fusion steps, so that the respective neighbourhoods will be more likely to belong to the 'right' cluster. This can sometimes lead to clusters with very few or even only one neighbourhood (cf. case study Remscheid, see below), but also to clusters with a very large number of neighbourhoods. For spatial typifications, the Ward algorithm is therefore frequently used. Which of the fusion levels is the 'best' or the 'right' one can be plausibly assumed by looking at the so-called dendogram, a special form of a tree diagram (Bortz/Schuster 2010, 464), but the final decision can only be made qualitatively. For this purpose, we examine which neighbourhoods belong to which clusters, which neighbourhoods will be added in the case of further fusion, and with regard to which included characteristics the variance will grow (with increasing merger level) or will fall (with decreasing merger level). Finally, another significant issue is how many clusters – understood as neighbourhood types – are appropriate at all.

5.4 K-means Cluster Analysis

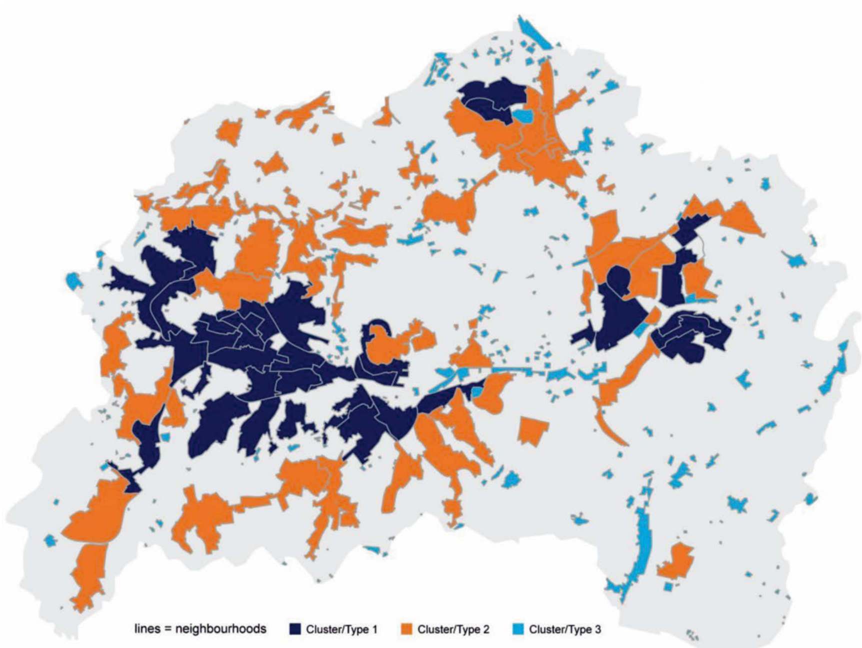
Agglomerative clustering methods have the disadvantage that once neighbourhoods have been grouped together, they are no longer separated from each other when they pass through the further merger stages. This can lead to the similarity of individual neighbourhoods to the neighbourhoods in their own cluster being lower than the similarity to neighbourhoods in other clusters. Cluster centre analysis as a non-agglomerative procedure (Bortz/Schuster 2010, 465) offers the possibility of correcting such 'misclassifications' owed to the agglomerative procedure. For this purpose, the cluster centres (as a result of the hierarchical cluster analysis) are first determined. The cluster centre shows the arithmetic mean for each included characteristic. Thus, a typical representative is formed for each cluster. Now, starting from all neighbourhoods, it is determined to which cluster centre the smallest distance exists. As a rule, some neighbourhoods are then rearranged. The cluster centres are then determined anew and the check for correct allocation is carried out again. This iterative procedure is repeated until each neighbourhood is also assigned to the cluster to whose cluster centre it has the smallest distance, i.e. the greatest similarity.

5.5 The Example of Remscheid

Using the methodological steps presented here, four neighbourhood types could be identified for the city of Remscheid (Fig. 9).

Dynamic arrival spaces form the most populous type comprising 53 percent of the total population. The 35 neighbourhoods, most of which are located in the inner city, are characterised by a mixture of residential and commercial areas and a high residential

Fig. 9: Neighbourhood types in Remscheid



density compared to other cities. The neighbourhoods have a heterogeneous age structure and a marked diversity of origin. Other characteristics are high rates of people moving in and out and, in some cases, precarious living conditions.

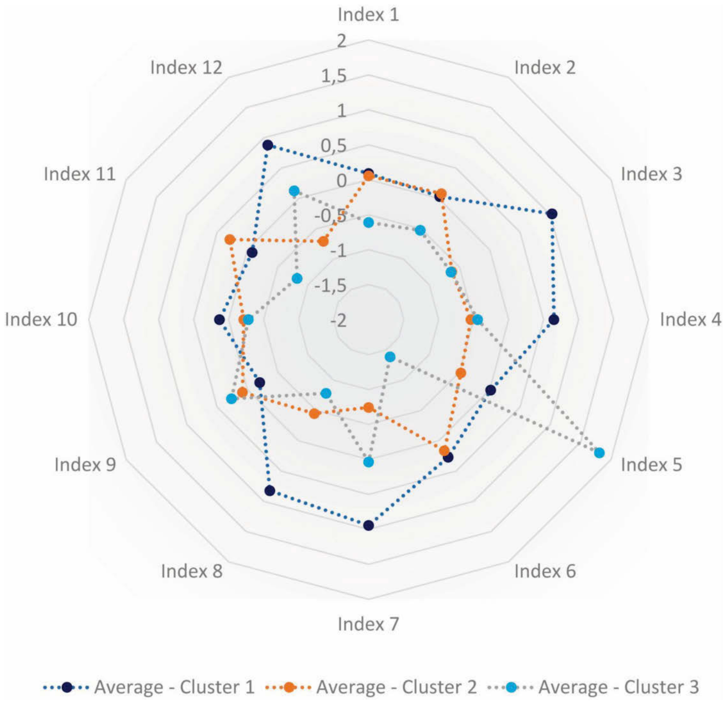
Stable spaces to stay areas comprise 44 neighbourhoods with 42 per cent of the total urban population, which are mainly located in peri-urban areas. The lower density results from the relatively high proportion of detached and semi-detached houses. Sociodemographically, this type is characterised by a rather affluent population. The average age of the population is relatively high, which results, among other things, from a long period of residence in the new housing developments of the 1970s, 1980s and 1990s.

Four per cent of the total population live in *hybrid intermediate spaces*, distributed over twelve neighbourhoods. This neighbourhood type is characterised by a high functional mix due to a high proportion of businesses or scattered settlements characterised by agricultural use. The distances to facilities of general interest are long, and fluctuation is high in the mostly shrinking neighbourhoods.

The fourth identified type comprises only one neighbourhood in Remscheid, which is why a general description of the characteristics (typification) can only be made to a limited extent here. In terms of urban development, the neighbourhood is characterised by *high-rise residential buildings*.

Fig. 10 shows the indices used in the result of the principal component analysis with their mean value per neighbourhood type.

Fig. 10: 12 Indices for typification



6. Conclusion: More Evidence for Urban and Neighbourhood Development

The question of how neighbourhoods can be adequately defined and typified is a matter of concern for both comparative neighbourhood research and the practice of urban and neighbourhood development. In this context, as Groos and Messer note, "numerous well-differentiated theoretical discussions […] have so far been contrasted by only a few good practical examples" (2014, 15). In view of this need, our contribution aims to present an approach to neighbourhood delineation and typification that, on the one hand, takes into account the complexity of neighbourhoods and, on the other hand, can well be applied in practice. Most of the required data is available to the municipalities.

This approach is innovative in several respects: As a mixed methods approach, it combines qualitative and quantitative methodological and methodological considerations and steps. By developing neighbourhoods in a theory-led manner based on the data material, it reflects the current state of theoretical discussions, which conceptualises neighbourhoods as relational social constructs or from a lifeworld, subject-centred perspective, as spaces of everyday actions, encounters and interactions emanating from the residential location. We have shown how we have translated these determinations step by step into a statistical model. As demonstrated above all by the example of functional interdependencies, we found new and original ways to give appropriate weight to the everyday interactions of the residents. The (interim) results were repeatedly validated through communication.

Neither the lack of administratively defined neighbourhood units nor the wholly legitimate interests of data protection fundamentally obstruct the goal of subjecting neighbourhoods, which are difficult to grasp, to well-founded quantitative analyses, and thus to meet the need, above all of the planning administration, for plausibly defined and statistically well-described small-scale intervention spaces. A small-scale division of the urban space, the creation of which is justified by comprehensible statistical operations and is also accepted and supported by the local population because it corresponds to their everyday actions, perceptions and experiences, offers all those involved in urban development a good basis for making decisions.

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Mixed-Methods Monitoring of Large-Scale Urban Development Projects: The Case of Lake Phoenix in Dortmund-Hörde

Susanne Frank/Verena Gerwinat/Ulla Greiwe/Jörg Peter Schmitt

1. Introduction: Monitoring Approaches in Urban (Development) Research

Although the observation and evaluation of socio-spatial developments have long been part of (urban) policy and (urban) planning, and thus also of metropolitan research, the focus and methods of systematic monitoring of programs and projects have only gained increased attention over the last two decades. Hanusch (2018, 1563) describes spatial monitoring as "the collection, evaluation, interpretation, and provision of relevant data/indicators as a basis for decision-making" that is "intended to provide information on the actual development of predicted effects".[1] In urban and regional development, monitoring exists, for example, in the areas of general spatial monitoring, urban development, the environment, sustainability, and climate change. Most recently, the implementation of the United Nations' "New Urban Agenda", which requires cross-level monitoring systems, has led to discussions on content and methodology in urban and spatial monitoring (BBSR 2021). For all of these areas, monitoring is based on solely quantitative approaches that work with statistical data and indicator sets.

Large-scale urban development projects have also been on the agenda of urban (development) policy (e.g., BMVBS 2011; 2012) for about as long. These often involve the construction of "new kinds of neighborhoods" (BMVBS 2011, 6) on industrial sites that have become fallow land in the course of structural change. In the worldwide competition between locations unleashed by globalization, these projects are intended to attract attention and provide an image boost; they (re)present the city to the outside world (Adam 2012, I). Therefore, it is hardly surprising that studies on the effects of large-scale urban development projects often focus on the change in the cityscape or on the image effect (Chilla et al. 2019/2020, 63). In contrast, very few studies also observe the long-term and inward impact of such projects, that is, on the local or regional environment.

1 All translations from German sources are ours unless stated otherwise.

Moreover, impact studies of urban development programs and large-scale projects usually have an evaluative character (see, e.g., BMI 2021). Typically, the aim is to compare expected and actual effects or to examine means–ends relationships. Evaluations thus frequently serve to assess implementation and success. They are necessarily retrospective. In addition, they are usually "sectoral" and "selective", that is, focused on specific (technical) questions (Chilla et al. 2019/2020, 64).

Monitoring, by contrast, is "conceived more openly" (Chilla et al. 2019/2020, 64). It aims to "keep a whole range of possible developments 'in mind'" and takes "more of an accompanying 'real-time perspective'" (ibid.). There is, with good reason, no established blueprint for monitoring large-scale urban development projects. The approaches, forms, and methods always depend on the case under consideration: the function of the monitoring, the respective knowledge objectives, and the specific local and regional context in which the "new neighborhoods" are embedded (Chilla et al. 2019/2020, 64f.).

A "fundamental problem" of open, ongoing impact analyses that accompany large-scale urban development projects is that at the start of monitoring, "it is not predictable which topics will turn out to be particularly relevant in the long term" (Chilla et al. 2019/2020, 66) and which ones will not. At the same time, (many) impacts must not be considered too early, "because a well-founded assessment depends on the maturity of the project" (BMVBS 2011, 16). However, all contributions on this topic agree that a longer, thematically open, comprehensive, and meaningful accompanying observation is extremely costly and resource-intensive. To limit the effort, Chilla et al. (2019/2020, 65f.) therefore suggest formulating plausible "spatial postulates" and then testing them empirically. By this, they mean formulating (hypo)theses about probable or possible developments in different areas (e.g., media discourse, traffic, the real-estate market) that may emanate from the large-scale urban development project. These postulates are then to be used to pragmatically derive a "'medium breadth' of perspectives and indicators" that are to be continuously collected in order to (partially) confirm or refute the "spatial postulates" at some point (Chilla et al. 2019/2020, 65f.). Thus, this multisectoral approach also follows a quantitative and deductive (i.e., hypothesis-testing) research logic.

We chose a different path. In this paper, we present a multidimensional monitoring approach that aims to observe and interpret the effects of a large-scale urban development project by using a qualitatively grounded mixed-methods research concept. It was successfully tested on the Phoenix project in Dortmund-Hörde.

2. Methodological Considerations

A monitoring system that is intended to record the effects of a major urban development project in as many dimensions as possible, but which are not fully known in advance, must be designed to be long-term and open. It must allow the collection and analysis of different data using different methods.

Long-term study. Desired or feared changes as a result of large-scale urban development projects do not occur overnight but rather develop slowly, over years or decades.

Thus, observing and interpreting change in a neighborhood and its significance requires planning an unusually long study over many years. “Longitudinal research serves two primary purposes: to describe patterns of change and to establish the direction [...] and magnitude [...] of causal relationships” (Menard 2004, 597).

Creation of data repositories. In order to be able to determine and describe changes over time, data are needed that allow comparative before/after-analyses. This can be data collected at intervals (i.e., at two or more different points in time) or continuously collected ongoing data for which comparison points in time can be selected depending on the question. In addition, it should be possible to establish and document connections between processes or events in one area and subsequent reactions in other areas (e.g., an artistic project triggers developments that ultimately lead to the amendment of a development plan). This requires the compilation of source materials of various kinds. It is therefore necessary to create diverse data pools, although it is not always known in advance whether and when the respective data will be needed for which analyses.

General qualitative design. The overall design of the monitoring approach presented here follows a qualitative logic. In this, it differs from most monitoring projects with which we are familiar. The open-ended questions (see section 4) require an open, explorative, nonlinear research process in which phases of (re)conceptualization, data collection and analysis, and in-depth interpretation are repeatedly intertwined in a flexible manner to be able to consider new content-related findings or new events or developments in the field. In addition, the research is conducted without any systematic prior knowledge or theoretical assumptions to be verified; generalizable theoretical and empirical statements are to be obtained gradually, that is, during the research process as the diverse source material is analyzed and referenced.

Mixed-methods research. A mixed-methods approach is suitable when the aim is to capture a multifaceted object of study, one that is also subject to change during the research, in the most complex way possible and from different perspectives (Burzan 2016, 9). We understand “mixed methods” to be

> the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the purpose of breadth and depth of understanding and corroboration. (Johnson et al. 2007, 123)

Within the monitoring approach, qualitative and quantitative instruments are combined in a manner appropriate to the subject matter, that is, along the respective research question of interest. In doing so, we assume that “all methods can only capture sections of the empirical reality of interest, have different strengths and weaknesses, and can therefore complement each other” (Hense/Schork 2017, 360). For us, however, mixed-methods research also means, to the extent possible, always relating the data obtained from different sources and by different means to one another in such a way that they not only complement one another but can also challenge or even contradict one another. For example, if we observe that lively discussions about gentrification around Lake Phoenix flare up periodically, but at the same time the statistical data do not provide any reliable indications of significant rent increases in or even displacement from the district, there is obviously a discrepancy between subjectively perceived and objectively verifiable changes. Such observations are particularly stimulating and challenge common interpretations (e.g., Frank 2018; 2021).

3. Setting the Context: Dortmund's Phoenix Project

In 2000, the Dortmund City Council unanimously set the course for a spectacular development project that was to symbolize the city's radical break with its coal and steel industrial past: in the Hörde district, only about five kilometers from the city center, a completely new urban area was to be created on the huge, approximately 200-hectare site of the former Hoesch and ThyssenKrupp blast furnace and steel mill: on one side would be the Phoenix West technology park, on the other the – according to its own promotional materials – "future residential, service, and leisure paradise" of Phoenix East with around 2,000 residential units around the artificially created Lake Phoenix (quoted in Frank/Greiwe 2012, 575). The overall project also included Phoenix Park, a green corridor with industrial vegetation structures and some abandoned industrial facilities.

The highly symbolic Phoenix project was the flagship of the *dortmund-project*, a ten-year plan aimed at repositioning the city as a competitive location in the global economy for the leading growth sectors of information and telecommunications technology, nanotechnology, microsystems technology, and logistics. The prerequisite for this was a significant improvement in the quality of life in the city to become an attractive (residential) location for the companies and their qualified employees.

The Phoenix project and its two subareas embodied these ambitions like no other project before it. At Lake Phoenix, Dortmund's "setting off toward the shores of a new era" (Stadt Dortmund 2015) was to be made visible and tangible – both literally and figuratively. The material and symbolic significance of the project is also explained by the fact that the Hörde district is both the cradle and grave of Dortmund's heavy industry: the first steel mill was built here in 1841, and the last one was shut down in 2001. As a result, the working-class district, which for a long time was one of the most ecologically devastated places in Germany, was particularly shaped by unemployment and poverty. The Phoenix project was therefore also intended to help halt or reverse the district's decline. The lake and its surroundings were to create urgently needed green spaces and open spaces; the upscale residential complexes were to attract "stable" groups of residents; the local economy was to profit from their purchasing power; the newly attracted companies were to create jobs; and Hörde as a whole was to "become a 'strong part' of Dortmund again" (Stadt Dortmund/Stadtplanungs- und Bauordnungsamt 2012, 3). Ultimately, the spectacular conversion project was intended to make Dortmund's transformation into an innovative service metropolis "characterized by high quality in working, living, leisure, and environment" (Ellwein/Mai 2016, 152), one that was widely visible and would in this way contribute significantly to the much-desired change in image. In retrospect, Dortmund's lord mayor summed up the outstanding importance of the project in terms of urban development policy as follows: "We were faced with the strategic question: how do we provide Dortmund with a new narrative? Phoenix, the 'model project of structural change', is the answer" (quoted in Nellen/Zibell 2016, 56).

Just as Phoenix was to become the beacon of the “new” Dortmund, the working-class district of Hörde, home to the “Hoeschians”, embodied the “old” Dortmund – the industrial past that city leaders were so keen to leave behind. Even before the groundbreaking ceremony, it was foreseeable that Hörde would become a place of sharp contrasts and pronounced social differences. We assume that it was specifically the immediate proximity of rich and poor, past and future, depreciation and appreciation, all induced by planning, that sparked the immense (supra-regional, even international) interest in this project (Frank/Greiwe 2012).

In 2011, the lake flooding and public infrastructure measures were completed; the commercialization of the land was successful; and the first residential occupancies and the start of recreational use around the lake were announced for 2012. Soon followed the first voices to express concern about gentrification processes in old Hörde (Schneider 2008; Evert 2011).

4. Radiation Monitoring

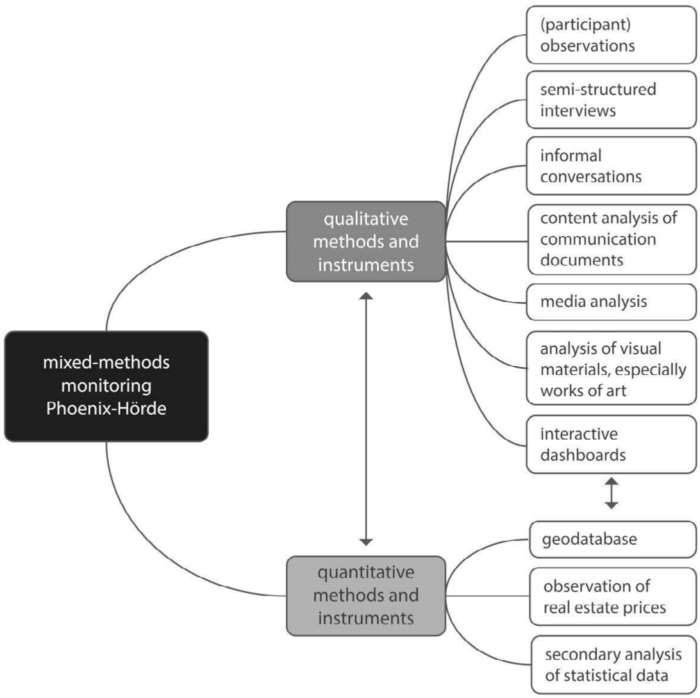
Among the questions that we asked ourselves were, *how will the Phoenix project radiate outward to old Hörde?* (This explains the title of our impact research.) Will it fulfill the city’s many hopes? In which areas will it succeed or fail? What unintended or undesired effects will it have? How do the various social groups and committed actors in the district perceive its transformation? How is it seen and evaluated from the outside? Which social groups can profit from the developments and which cannot? Which developments might ignite conflicts and how will they be resolved? How will established residents and newcomers live together? Will the gentrification processes predicted by many actually take place? And in general, how will this particular empirical case fit into the current state of social science urban research on topics such as structural change through lighthouse projects, middle-class-oriented urban development, social polarization and segregation, new-build gentrification, and so on?

These questions of ours were soon supplemented by a normative concern. Early on, our observations showed the following: in their absolute determination to tell a flawless success story of having mastered structural change with the Phoenix project, Dortmund’s city leadership was rarely willing to deal with critical questions, concerned voices, ambivalent feelings, or the stories of those who might benefit less or not at all from the Phoenix project. At the time, it was mainly artists and journalists who voiced such perspectives. Against the backdrop of these observations, our research has paid special attention to the plurality of perceptions, positions, and experiences in this far-reaching transformation process.

5. Methods Applied

Quantitative data are particularly suitable for describing (objective) changes over time. For this purpose, we have used small-scale statistical data on socio-demographics of the population of Hörde, on their voting behavior, and so forth, which are provided by

Fig. 1: Overview of the methods used in our "radiation monitoring"



the Statistical Office of the City of Dortmund. Especially important for our topic is the change in local rents and purchase prices. We have surveyed these at regular intervals in cooperation with the *InWIS – Institute for Housing, Real Estate Management, Urban and Regional Development* in Bochum on the basis of specially prepared data from the real-estate brokerage platform *ImmoScout24*.

Possible upvaluation processes in "old" Hörde would be reliably indicated by changes in retail, commercial, and service structures as well as by changes in the condition of buildings (renovation, modernization, [luxury] refurbishment). Since such data are not available on a small scale, we collected them ourselves. For this purpose, we defined an area adapted to the research question. The selected area includes the streets bordering the lake to the north and south, the nearby town center of Hörde, and some residential areas south of the railroad line that crosses the district.

In 2012, we recorded the structural conditions and the kinds of use (differentiated by floor) of all buildings located in the area for the first time in an elaborate standardized process. In addition, the exterior of each building was documented photographically. In 2018, we repeated this survey. The survey results were digitized and transferred to a specially created *geodatabase* using official address records, in which the photographs were firmly assigned to the individual building records (fig. 2). The results were checked and adjusted (including individual follow-up surveys).

The geodatabase was prepared by means of interactive dashboards with the *Tableau* visual analytics software and thus made usable for further analyses. The georeferenced building datasets can be filtered according to various attributes (e.g., use or building age) and spatial criteria (e.g., streets).

Fig. 2: Excerpt from the interactive dashboard of the database (for data protection reasons the photo has been blurred and the address blacked out)

Drawing on these data, we are able to make detailed statements about the structural-physical changes as well as the change in use for each individual building within the study area. The systematic and clear preparation of the information also allows for quick and structured in-depth qualitative (e.g., by comparing building photographs from different survey dates) and quantitative (e.g., on the extent of appreciation measures) analyses. Thanks to this kind of visualization, the results can be displayed in the form of maps and are easy to interpret and understand.

Using *qualitative survey methods*, we looked to access the subjective perceptions and interpretations of social and spatial change or the (collective) emotions that accompany these processes. Here, we focused primarily on the people who live, work, or are civically engaged in the neighborhood. With reference to the social contrasts in the neighborhood, we were particularly interested in the respective lifeworlds of the different social groups and their interactions.

In this context, conducting *semi-structured interviews* was a core component of our study. "The purpose of most qualitative interviewing is to derive interpretations, not facts or laws, from respondent talk" (Warren 2001, 83). In accordance with our qualitative approach, we understood the interview guidelines as a means to structure and focus the interviews, but we also remained open and flexibly adapted to further content that developed in the conversation (Rubin/Rubin 1995, 145f.).

When selecting interview partners, the aim was to gather as many different perspectives as possible. Our focus was on the perspectives of the wealthy lakeside residents who have since moved in and the long-established former working-class residents. (We do not consider these two groups to be homogeneous!) Therefore, we took care to recruit people from the group of lakeside residents living in different types of housing (single-family homes in the 'front' rows of the lake, condominiums in apartment buildings) and in different living situations (families with children in the household, couples without children, employees and retirees) as interview partners.

Recruiting interview partners among the long-established residents proved more difficult than among the newcomers. To get in contact and increase the chances of an interview, we approached people who had made statements to the local media about change in the district. As a result, the long-established residents whom we interviewed were usually particularly committed residents or civic actors who have lived or have been involved in Hörde for a long time.

However, this meant we were unable to reach many other groups living in the district. The well-known difficulties in accessing population groups with migrant roots and from educationally disadvantaged backgrounds due to a lack of language skills and socio-cultural distance also affected our project. For example, despite repeated efforts, we could not persuade further members from the comparatively large Turkish community in Hörde to take part in an interview.

Informal conversations proved to be a much more suitable way of reaching such long-established residents. These "conversations with purpose" (Burgess 1988, 153) usually arose unplanned and spontaneously during chance encounters but proved to be immensely productive. In our experience, this was especially true for hairdresser visits and cab rides. Two visits to different salons, for example, revealed that the hairdressers in each case were longtime residents of Hörde. In both cases, we gained vivid and detailed insight into the ambivalent feelings that the socio-spatial transformation in Hörde has evoked among many long-established working-class families of Turkish and German origin. In several conversations with former steelworkers who now drive cabs, we also encountered a sense of alienation (Frank 2021).

Unlike formal interviews, informal conversations take place spontaneously, in an unprepared fashion and an everyday context, and therefore often yield "more authentic data, where less performativity is involved" (Swain/Spire 2020). There is also no distraction and distancing through formalities such as recording the conversation with a recording device. These informal conversations were documented afterwards from memory. However, since the interviewees did not normally give their consent to participate in the research project, the information obtained must be handled with special care.

We also gathered important field information through *participant and occasionally passive observations*. Over the years, we attended a variety of urban development events such as panels and other discussions, "neighborhood labs" or "citizen dialogues", and many more. In this way, we were able to gain various insights into the neighborhood-related concerns and interests of long-established and new citizens as well as into interactions between these groups and with representatives of the city. We also used such occasions to recruit interlocutors for formal interviews and for many informal conversations at the margins of the events. In addition, our participation in official lake tours offered by the city of Dortmund repeatedly provided us with information about how the city leadership would like to see its prestigious project presented to the outside world.

A final and at the same time particularly revealing object of systematic participant observation was the series of "citizen dialogues" that have been held regularly since December 2018, moderated externally, and conducted with great effort, to which all new lakeside residents were regularly invited by the city at intervals of three months. Complaints about noise, litter, safety, order, and traffic problems in the new lakeside neighborhood were personally received by the mayor and demonstratively passed on in the form of specific work assignments to the numerously present heads of the relevant municipal departments. At the subsequent events, the latter had to give a public account of the completion status of their assignments. The citizen dialogues show with almost unparalleled clarity the undivided attention and preferential treatment given by the city leadership to the new citizens at Lake Phoenix and their interests and sensitivities.

Survey and analysis of a wide variety of communication materials. As explained at the outset, the Phoenix project has played a key role in the city's policy of structural and image change. For this reason, we were interested in all "official" word, image, and sound materials with which the city's leadership has disseminated its narrative of the "New Dortmund": official documents, maps, homepages, marketing brochures, books and videos, published interviews on the topic, and much more.

In addition, we collected and analyzed the diverse – approving, differentiating, critical, or adverse – reactions to the Phoenix project and its actual or anticipated consequences, which could be observed in a wide variety of analog and digital forms and formats. Three groups of actors have been particularly relevant here.

Since its beginnings, the project has been intensely followed by journalists. Considering the high influence of media coverage on the formation of public opinion, we systematically recorded the former from the very start. The local newspapers and radio stations play a special role here, as they dedicate a great deal of space to developments in Dortmund and endeavor to give different voices in the population and also many experts a chance to have their say. They are also the recipients of readers' letters. In terms of external perception, national media (newspapers, television stations) are also relevant as information carriers.

In addition, the lake project has inspired an astonishing number of artists to create artworks on the topic. These include photo series, documentary, fictional and biographical (audio) films, paintings, installations, interventions, cartoons, and much more. As creative visual commentaries, individual graffiti or rogue posters by nameless authors were also the subject of our consideration. We classified these artworks in a contextual perspective; that is, we asked about the respective conditions and motives that led to the production and the respective contents or messages of the work as well as about the reactions they triggered in different groups and from different perspectives.

The third group actively accompanying the Phoenix project from a professional perspective consists of natural and social scientists. The former are primarily interested in the water-management and water-ecology challenges posed by the construction and operation of an artificial lake.[2] The latter are mainly urban researchers of different disciplinary provenance, who often come to Hörde from outside to conduct empirical research on the social and spatial, material, and symbolic effects of the lake project, including many students. These usually present their findings in unpublished written works that are, however, accessible to us.

With their works, journalists, artists, and scientists also contribute significantly to the production and reproduction of meaning and significance around the Phoenix project. In doing so, the authors of these genres very often let the citizens of Hörde or committed local actors have their say. Hence, their works were also important sources for tracing the positions or moods of the local population (especially over time).

The different forms and formats of communication materials offered excellent databases for content-analytical or rather discourse-analytical evaluations, both individually and especially in combination.

6. The Power of Images

Our analyses have made us aware of the enormous significance of still and moving images as instances of the construction of social reality, which we would like to emphasize again separately in this section. In line with Mitchell (1994, 41) and Bohnsack (2014, 869), we assume that such constructions are not only represented but also constituted by images. The central importance of maps and promotional materials, photographs, and films for the (contested) construction, perception, and interpretation of the Phoenix project supports the observation of an increasing relevance of visual and audiovisual formats for the production of social meaning (Traue et al. 2014, 570). We can give many examples to show interactions between (audio)visual representations and (real) social events and discourses (Akremi 2014, 887). For example, we can determine that the photo exhibition of the former urban planner and photographer Jürgen Evert titled "Press – Clear – Wait – Change: GENTRIFICATION at Lake Phoenix?" in 2011 catalyzed a chain of events and processes that have been followed closely by the media, namely, public discussion events in the context of further exhibitions in Dortmund, which finally led to the amendment of a part of the development plan that now also integrates social housing. Evert's pictures thus comment on social developments and trigger new ones themselves. The same holds true for the multiple-award-winning longitudinal documentary GÖTTLICHE LAGE [DIVINE LOCATION] by filmmakers Ulrike Franke and Michael Loeken (2014) and the twelve-part mini-soap PHOENIXSEE [LAKE PHOENIX] by Michael Gantenberg and Bettina Woernle broadcast during prime time on public TV (2016 and 2019). Both films focus – with a great deal of humor – on the class antagonisms and the radically different lifestyles of old and new citizens in Hörde and use different creative means (such as camera angles, color scheme, lighting, and equipment) to express their sympathy with the first group without denouncing the second. The broad national response, especially to the documentary and the feature film, also shows the extent to

2 We did not pursue this line of discussion systematically due to our insufficient professional expertise in these matters.

which films are part of everyday social life and can therefore reach many people (Akremi 2014, 887).

7. Reflecting on our own Role as Researchers in the Monitoring Process

Regularly reflecting on one's own role in the field is an important principle of qualitative research. This is especially true for this long-term study, which is dedicated to an object of investigation charged with strong political and symbolic meaning. The longer the research project lasted, the more we became part of the dynamic events we were observing. After the publication of our first article on the significance of the Phoenix project for Dortmund's urban development (Frank/Greiwe 2012), we were already perceived as experts by interested sub-publics and regularly asked to comment. We were interviewed and quoted by journalists and scientists, invited to public lectures and discussion events, and asked by various groups of visitors for guided tours of the city and the lake. In this way, we ourselves became a voice in the discourse, intervening in the field of investigation in many ways. As explained above, this does not contradict our intentions. However, as interest in our research grew, we found ourselves in a situation that was complicated in several ways: on the one hand, we had to constantly rebalance our respective positions on the object of study as observers (distance, external perspective) and participants (proximity, inside insights). On the other hand, and this situation is more serious, we were and still are very often assumed or assigned a certain politically and ideologically motivated stance. Journalists in particular expect us to provide evidence and criticism of the subjectively perceived gentrification processes in old Hörde. However, our data do not support the latter. We did find numerous indications of symbolic but not actual displacement from the neighborhood (as of 2020). Similarly, although we criticize the way in which the city authorities communicatively "frame" or "sell" the lake project to the outside world, we do not have any fundamental criticism of the project itself. These are just two examples of differentiations that we apparently have difficulty communicating, so that we repeatedly see ourselves counterfactually portrayed in the local media and in the field of local city politics as sweeping "lake critics" or even "lake opponents" and occasionally defamed by the city leadership. That this classification of ours has solidified in the public perception over time, we can clearly discern from the various empirical materials. Thus, the role attributed to us on the level of discourse takes on an "objective" character, *nolens volens*. The real problem with these attributions, however, is not our sensitivities in this regard but rather the fact that they make it difficult or even impossible for us to access certain social groups, institutions, and individuals.

8. Selected Results

Although we are still far from having analyzed all of the collected data, we have already been able to gain important insights into various questions by using and combining different methods over a long period of time. With the help of the "hard facts", insights into the subjective perceptions and evaluations of the change by the old and new residents of the district and by outsiders, as well as insights into the structures and psychologies of community life in the district, we have succeeded in drawing a picture of the change in Hörde that is as broad as it is rich in detail.

The data on rental and purchase price trends show that although housing prices are rising in Hörde, they are in line with the citywide trend. However, the change in rent levels in Hörde is more dynamic than the citywide average (as of 2018). In addition, one can observe a decline in vacancies and the increased implementation of modernization measures. In the commercial sector, by contrast, changes toward higher-quality uses can be observed only very sporadically, as can conversions from commercial to residential uses. Building renovations and new construction are on the rise, especially in the streets bordering the new development area to the north. Numerous homeowners and landowners are directly affected by the increase in land values; they report being regularly contacted by brokers and real-estate companies interested in buying. Although the Phoenix project has partially triggered upvaluation and price increases, on the whole, it is not possible to speak of gentrification in the sense of appreciation processes that lead to the displacement of the long-established population. Understanding why discussions about gentrification nevertheless continue to flare up here requires interpretive methods (Frank 2018; 2021; see also Brown et al. 2019).

How the Phoenix project and its impact on the district are perceived and evaluated depends very much on the respective perspective. From the city's point of view, Lake Phoenix is considered a great success in every way. The "showcase project for industrial structural change" (Wilde 2016, 84) is considered groundbreaking for the transformation of the entire Ruhr region. Critical voices, even if they relate only to parts or individual aspects of the project, are often brusquely dismissed as inappropriate or groundless, or simply ignored. Nevertheless, many of the long-established residents of Hörde look at the lake and the transformation of their district with ambivalence. On the one hand, the lake is welcomed as the "best alternative" for the subsequent use of the steelwork wasteland, the positive effects on the environmental quality are highly appreciated, and the influx of citizens from the upper-middle class is accepted as a necessary development of the district. On the other hand, the project and the city's preferential treatment of the wealthy population make the former workers aware of their own marginalization in the "New Dortmund", which evokes melancholic feelings among many of the longtime residents (Frank 2021). Such emotional states of pain, loss, and discrimination, which find no place in the official city's narrative of the Phoenix project, are in turn discussed and thus represented by journalists and artists, especially in the form of articles, photographs, documentaries, and feature films.

The coexistence of the different milieus is characterized by the newly emerging social hierarchy in the district. Many informal conversations, most of our interviews, and also our observations have shown that there is hardly any social contact between long-established residents and newcomers. Since many newcomers rarely spend time in old Hörde and remain primarily in their immediate living environment by the lake, there is a lack of opportunities for and points of contact. Even at potential meeting places such as daycare centers or the town center of Hörde, the social groups usually keep to themselves. Old and new residents do not live together but rather next to each other. This once again confirms the findings of international urban research, according to which the spatial proximity of different social classes or milieus does not necessarily lead to social proximity. As opposed to sociological assumptions to the contrary, there are no open social or other conflicts between the two groups (Gerwinat 2020). The decisive factor here seems to be the described ambivalence of the longtime residents toward the project: most residents basically agree with the neighborhood transformation, even if it is not always to their personal advantage.

9. Conclusion: A Proven Transferable Approach

The "Radiation Monitoring Phoenix-Hörde" research project has been designed as a long-term observation of the material and symbolic or structural-spatial, political, social, economic, demographic, and emotional as well as the perceived and actual effects of the Phoenix project on the Hörde district. For ten years now, we have been systematically collecting and collating data on the question of how the "new" Hörde "radiates" onto the "old" Hörde, onto the city of Dortmund, and also beyond. The complex research design – with its basic qualitative orientation and its cornerstones of a) long-term orientation, b) creation of data stores that make it possible to trace developments over time and establish cross-references between different fields of observation, c) a flexible, open-ended concept, and d) a methodologically pluralistic approach – has proven itself in all respects. Today, we have a unique treasure trove of diverse data at our disposal, which we have not yet been able to fully exploit in terms of its potential for analyses and special features. Nevertheless, these data already enable us to draw an empirically well-founded picture of different facets of change in the district as well as the different perceptions and perspectives related to it. Moreover, we can offer explanations and interpretations for existing discrepancies between subjectively perceived and objectively verifiable changes and our own concepts for interpreting neighborhood change and the resulting conflicts. Thus, we provide theoretical and empirical contributions to national and international expert discussions in urban sociology, geography, and spatial planning, which deal with the manifold consequences of large-scale urban transformation projects. At the same time, it is our concern to offer interested local and supra-regional publics as well as the various groups of actors in politics, society, and culture a resilient basis for informed discussions and neighborhood-related action with our data.

Although the monitoring approach described is exceptionally time- and resource-intensive, it has repeatedly rewarded the substantial effort with exciting theoretical and empirical findings and returns. To exploit its full potential, it is highly recommended to start the monitoring of (large-scale) urban development projects early. Furthermore, the immensely important insights that can be gained through (participant) observation and informal conversations are tied to personal presence at the moment of action and can rarely be obtained through retrospective procedures. It is also advisable to carry out an initial survey of the functions and uses of buildings in the spatial environment of a (large-scale) urban development project as soon as it has been announced, because the mere announcement of an ambitious planning project can already trigger effects in the surrounding area.

With this in mind, we will now turn our attention very quickly to the project that is to replace Phoenix as the first flagship of Dortmund's urban development: Smart Rhino. On the centrally located, 52-hectare site of the former *Hoesch Spundwand und Profil GmbH* (HSP), the city of Dortmund is working with the Essen-based Thelen Group to develop a "future campus": an innovative "living, education, knowledge and technology park" that will act as an "incubator and accelerator for solutions in the digital society" (Mertins 2019). With our approach, a field-proven concept for studying its development and the effects on its social and spatial environment already exists.

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