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REGIONAL MORPHOLOGY
The Emergence of Spatial Scales in Urban Regions

KIMON KRENZ
Space Syntax Laboratory
The Bartlett School of Architecture, UCL
kimon-vincent.krenz.12@ucl.ac.uk

ABSTRACT

In space syntax, cities are thought of as emerging from a dual process of a global network shaped by micro-economic factors and a local network of residential space shaped by culture. This theory is based on an understanding of cities as independent entities. Cities, however, cannot be understood in isolation and often stay in complex relation to their surrounding and other cities. Departing from the notion of spatial configuration, this paper challenges the paradigm of what is considered as 'the city'. It goes beyond the fuzzy boundaries of cities and sets the economic functioning of urban form into regional context. I will argue that space syntax concepts of 'global' and 'local' scales in regional configurations are not applicable anymore and a better understanding of spatial scales in the context of space syntax as well as their emergence is needed. Revisiting Christaller's (1933) central place theory of the economic distribution of urban space, this study makes an attempt of theorising the relationship between geographic economy and spatial configuration of regions. This theory is tested on a large set of different centrality structures in two polycentric urban regions. Taking a method proposed by Serra and Pinho (2013) as a point of departure this study employs an exploratory factor analysis to investigate hidden centralities. The term latent centrality structure (LCS) is introduced to describe the phenomenon of emergent spatial scales that can be seen as influencing centrality patterns within polycentric urban regions. The findings underpin the need for a revision of the theorisation of the concept of 'global' and 'local' scales in light of space syntax analysis towards multilayered LCS'. This paper also exhibits that space syntax can be applied in regional contexts and gives further guidance on a methodology to understand regions through space. However, additional research is needed still to confirm whether found LCS' have any implications to empirical flow data as well as if they have relevance in a socio-economic context and hence be of use to inform regional policy making.

KEYWORDS

Morphology, Region, Space Syntax, Scale, Exploratory Factor Analysis

1. INTRODUCTION

Cities and regions are increasingly converging. This is not only materialising in the real world but can also be observed in newly arising theoretical debates. It has been argued that globalisation has led to a new type of urban morphology, the polycentric urban region (PUR) (Hall and Pain, 2006). Knowledge of configurational properties of regions in general and PUR's in particular is still in its developmental stage. Yet, with growing computational power and access to large data sets configurational studies of regions are increasingly becoming more feasible. This study seeks to shed light on regional spatial configurations. On a practical level, analytical ventures in regional spheres pose a series of challenges and questions, starting with the generation of computable models, to how to define model boundaries, or the level of detail and resolution, to which radii to choose in the analysis. I will argue that these questions are not technical in nature, as has been claimed so far, but instead are instead require a theoretical solution that relates to what 'scale' is in space syntax. Builidng on this, this study aims to understand spatial scales in regions and how they emerge.

This paper proceeds in three parts of which the first forms a theoretical contextualisation. Here, I will review preceding space syntax studies dealing with metropolitan and regional cases. Through a comparison of the methodology of these studies and a revision of the meaning of 'global' and 'local' radii in space syntax analysis and literature, I will argue that there is a need for a conceptualisation of scale in space syntax. Such a concept of scale is particularly needed when investigating regions. The initial attempt to conceptualise scale in space syntax builds on Christaller's (1933) central place theory (CPT) of the economic distribution of urban space.

The second part will introduce a methodology to investigate the emergence of previously outlined scales in regional spatial configurations. I present two case studies, as well as a randomly generated planar regional model. I will elaborate on the process of how to produce a randomly generated planar model and the reasoning behind a comparison of real world cases with this model. Finally, I will justify the selection of different centrality measures as well as the method of exploratory factor analysis.

The third part presents the analytical results and contextualises the findings in with the concept of scale in space syntax.

2. REGIONAL ANALYSIS AND THE MEANING OF SCALE IN SPACE SYNTAX

Only very few space syntax studies have set the region at the focus of analysis. Turner (2009) pioneers in this field by linking the local to the regional continuum and proposing two novelties. In terms of methodology, he makes use of road-centre line data for his analysis, and also focuses on a collection of cities in the regional context. This application of network analysis in the field of regional studies opens up the possibility of new understandings of spatial relations. As space syntax has been developed in a fundamentally local context, referring to the human body in space, it has not been explored in a regional context so far and, therefore, entails some challenges.

1 Space syntax studies in regional or metropolitan context

Author	Year	Studie Area	Model type	Level of Detail	Model Size	Model form	Analysed Scales (in km)	Measures*
van Nes	2007	Leiden metropolitan are, Netherlands	Axial line	all spaces	20km	irregular	topological n	CC
Turner	2007	Manchester and Leeds-Bradford metropolitan area, United Kingdom	ITN road-centre line	vehicular network	120km	administrative border	metric 0.5, 1, 1.5, 10, 20, 30, 40	ASA BC SLW
van Nes	2009	Randstad region, Netherlands	Axial line	motorway, main roads & local streets	90km	irregular	topological 1, 2, 3, n	BC & CC
Serra and Pinho	2013	Oporto metropolitan area, Portugal	Axial line	all spaces	60km	circular	metric 0.4, 1.2, 2.1, 3, 3.8, 6, 8.2, 10.4, 12.6, 14.7, 16.9, 21.3, 23.5, 25.6, 30	ASA BC & CC SLW
Cemasi and Psarra.	2013	Emilia Romagna region, Italy	OSM road-centre line	vehicular network	120km	irregular	metric 10, 20, 30	ASA BC & CC
Gil	2013	Randstad region, Netherlands	OSM road-centre line	vehicular network and rail	130km	administrative border	n	ASA BC & CC
Hanna et al.	2013	Europe	NIMA Road-centre line	highways and rail	2000km	geographic border	metric 1, 50, 100, 500, 1000	ASA CC
Mohamed et al.	2013	Greater Cairo metropolitan area	Road-centre line	vehicular network	40km	irregular	metric 2, 5, 10, n	ASA BC & CC
Psarra et al.	2013	Detroit metropolitan area	Road-centre line	vehicular network	450km	administrative border	metric 1, 10, n	BC & CC
Karimi et al.	2015	Jeddah sub-region, Saudi Arabia	Axial	all spaces	60km	Irregular	n	CC
Krenz et al.	2015	Rio de Janeiro, Brazil	OSM road-centre line	all spaces	60km	administrative border	metric 0.4, 0.8, 1.2, 2.1, 3, 3.8, 6, 8.2, 10.4, 12.6, 14.7, 12.9, 19.1, 21.3, 23.5, 25.6, 27.8, 30, n	ASA NBC & NCC
Krenz	2015	Ruhr Valley and Halle-Leipzig region, Germany	OSM road-centre line	all spaces	120km	administrative border	metric 2, 10, 30, n	ASA BC & NCC
Serra et al.	2015	Great Britain, United Kingdom	Meridian 2 road-centre line	motorway, main roads (A-level)	930km	geographic border	metric, 1.2, 2, 2.4, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 150, 200, 250, 350, 400, 500, 600, 700, 800, 1000, n	ASA BC & CC SLW
Serra et al.	2015	Great South Eastern region, United Kingdom	ITN Road-centre line	vehicular network	250km	administrative border	metric 0.8, 1.2, 2.4, 5, 10, 50, 100	ASA BC & CC SLW
Ugalde et al.	2015	Rio Grande do Sul, Brazil	Axial line	urban spaces & regional roads	40km	irregular	topological n	BC & CC
Law and Versluis	2015	Great Britain, United Kingdom	Meridian 2 road-centre line	motorway, A- roads, B-roads and minor roads	950km	geographic border	metric 0.8, 2, 5, 10, 20, 50, 100, 250, 500	CC

CC Closeness Centrality
BC Betweenness Centrality
NCC Normalised Closeness Centrality
NBC Normalised Betweenness Centrality
ASA Angular Segment Analysis
SLW Segment Length Weighting

Table 1: List of space syntax studies dealing with the regional and metropolitan scale, from 2007 – 2015.

With a view on recent space syntax studies dealing with the 'regional' continuum a number of commonalities and differences can be found (Table 1). The most striking observation is the non-defined usage of the term 'region'. This is rooted in difficulties with the very definition of the term itself and becomes most obvious in the difference of model sizes that range from 20 to 950km. Particularly the term 'metropolitan area' is often used synonymously for 'region', which complicates the comparative application of findings. Additional to differences in model sizes, studies use a variety of different model types. These types vary from manually drawn axial lines by researchers, over models based on governmental data to models based on voluntarily supplied geographic information. Also, the level of detail and resolution within each model differs from an inclusion of all open spaces to analysis based only on upper tier highway systems. Adding to this variation in each approach, the use of space syntax measures and their respective scales of analysis are not consistent. This is due to the constant development of analytical procedures and technologies in the field on the one hand and due to the developmental stage of regional studies in the field of space syntax on the other hand. The overall inconsistency in the field poses difficulties in the comparability of findings.

In this study the term 'region' and PUR refers to concepts used in geography. In geography, the term region is broadly applied to three fundamental territories, trans-, supra- and sub-national (Trippl, Maier and Tödtling, 2012, p. 13). While supra-national territories are regions that can be consolidated of several nations across the globe (Latin-America, Southeast Asia), trans-national territories are regions that spread across two or more adjacent states (EUREGIO, ARGE). Here, I refer to the third use the third kind of the term region that denotes a sub-national territory (ibid., p.14). Sub-national regions lie within one independent state and share the same political and socio-economic systems, contrary to trans- and supra-national territories. The object of this research is a particular type of region within the category of sub-national territories, namely the PUR. The concept of polycentrism in general is often used to describe a hierarchical organisation and refers to 'the spatial clustering of almost any human activity' (Kloosterman and Musterd, 2001, p. 623). Polycentric entities are, thus, characterised by a clustering of human activity leading to a complex spatial organisations. Polycentric urban regions are such polycentric entities. They consist of a number of historically distinct, political and administratively independent cities in close proximity to another (Kloosterman and Lambregts, 2001, p. 718). The defining feature is the lack of a dominant central city and a more even distribution of a smaller number of similarly sized cities with equal economic importance next to a greater number of smaller cities (ibid., p.719). Regions that feature a dominant central city, in contrast to polycentric regions, are usually characterised by a stronger hierarchical relationship between urban spaces towards the centre. There are other terms used to describe such polycentric urban regions, such as 'city-region' (Scott, 2002), 'city networks' (Camagni and Salone, 1993), or 'network cities' (Batten, 1995). The reason why PURs are of special interest and should be researched closer, is due to their inherent complexity of their spatial organisation.

The majority of Space syntax studies apply network analytical approaches to the scale of the 'city', whereas only few studies expand this focus to the scale of metropolitan and regional regions. In most space syntax studies, the 'city' is defined by natural or administrative boundaries. Each model consists of one independent city. These investigations have lead to a series of cross-country comparisons of cities and their morphological structures and give valuable insights into their socio-economic functioning (Figueiredo and Amorim, 2007; Peponis et al., 2007; Hanna, 2009). Hillier et al. (2012) study 50 different cities and present evidence that there is a globally occurring dual relation between a global and local structure of cities. This dual relation has been theorised by Hillier as the generic city (Hillier, 2014). The 50 different cities Hillier et al. compare vary significantly in size. The three smallest networks in their list of cities, Mytiline, Nicosia and Venice, are approximately 1km, 1,5km and 5km wide, whereas the largest networks include Istanbul, Bejing and London with approximately 26km, 34km and 64km. Thus, the largest system scrutinised is 64 times larger than the smallest system. Hillier et al. (2012, p. 164), deem this comparison appropriate, as they draw on a previously developed method to normalise betweenness centrality leading to a range of comparable values, which they argue 'permit[s] direct comparison of radii within and across cases' from 'local to global'.

They argue that their analytical approach allows comparisons across different sizes as the systems under investigation feature the same unit, namely streets and hence 'share the same scale and mean the same thing' (ibid., p.167). What is referred to as 'scale' here, could be better described as 'resolution' and does not sufficiently account on scale as a whole.

Leaving the term 'local' unspecified, Hillier et al. investigate the 'global pattern' of each city comparing radius n, i.e. each segments with each other segment for each case. The reasosn for why this is problematic are the following: a) the boundary selection has a strong impact on the observed structure. This impact has been termed 'edge effect'. The model of the city of Tokyo and Bejing, for instance, are cut-outs of larger continuous metropolitan agglomerations and areas at the border of the model are hence representing only a fragmented network of the real world situation. Gil (2015, p. 2) demonstrates that 'centrality measures are affected differently by the "edge effect"' and that 'the same centrality measure is affected differently depending on the type of distance used'. This effect is stronger the larger the applied radius is and consequently effects radius n the most; b) radius n is not a distance-free measure. Rather, it is the radius distance necessary to capture the two segments in the graph that are the furthest away from each other. In other words radius n has a precise distance, it is the longest shortest path (or the network geodesic) of the system. We can assume that for the model of Mytiline radius n is slightly larger than the geographic distance of the model boundary ≥ 1km, whereas for the model of London radius n similarly must be something approximating ≥ 64km. When comparing these two betweenness centrality structures, the comparison is hence based on one structure that exhibits movement on a very small radius (some might refer to as 'local') and another structure of a very large radius (some might refer to as 'global').

Both difficulties are rooted in the lack of theorising scale in space syntax and the fact that the radius of what is considered 'local' and 'global' changes dramatically throughout the body of space syntax literature depending on the object under investigation. The general use of the term is initially derived from cellular spaces and graph theory terminology, but departed at later stages to the context of society above and beyond network relationships. First referred to by Hillier et al. (1976, p. 153), 'local' and 'global' was used in a descriptive context of cellular agglomeration patterns derived from a simple rule set. Here, 'local' refers to an individual cell and its rule, whereas 'global' describes the agglomerated object as a whole, that is all individual cells together, and their subsequently derived global structure. For Hillier et al. (1976) it is not of particular importance at which scale 'global structure' emerges or if there are other structures in-between, rather their focus is on the theoretical positioning that it emerges at all and its subsequent implication for the observed entity. While it is clear in the context of cellular spaces what is meant when the term 'local' and 'global' is used, it becomes vague when the authors convey their concept to real world examples, where it will be argued scale becomes an intrinsic aspect of any analytical endeavour. Cellular agglomerations are theoretical constructs, ultimately non-spatial and, hence, do not feature spatial scales; what differentiates them is their topological relationship. When network principles are applied to real world spaces, scale becomes an important factor. This is because, when leaving the theoretical sphere of non-spatiality, geometrical characteristics, such as metric distance become an important factor of differentiation (Salheen and Forsyth, 2001). If 'global' relates to the agglomeration of all human journeys in space, and as a product generates a spatial configuration subsequently shaping movement, then all journeys can only refer to those taking place within the model and, therefore, exclude any inter city relationships. A large body of work in the field of mathematical methods of spatial analysis dealing with the spatial organisation of society on inter city and regional relationships was already established at the time when Hillier et al. (1976) first sketched their notion of space syntax, but the authors decided to not engage with these strands due to fundamental differences in their conception of distance and space. The outcome of this decision becomes particularly apparent when Hillier et al. (ibid.) transfer their theoretical models on real world examples. When the scaleless model becomes spatialised – and, thus, starts to incorporate scales – in forms of buildings, neighbourhoods and settlements of a range of sizes, the term 'local' and 'global' starts to refer to entities of entirely different size. The authors bridge these differences with the terminology of 'small' or 'large' scales, or synonymously 'levels' (ibid., p.183) while simultaneously describing 'local' and 'global' characteristics of the respective system. What is considered here as 'global', however, needs to be seen in the context of each respective spatial scale.

The reasoning behind this can be found in 'The Social Logic of Space', where Hillier and Hanson state that they deliberately excluded notions of distance and location in their theory, arguing that space syntax is ultimately distance free and that the notion of location can be replaced by the notion of morphology, enabling the incorporation of an entire set of simultaneous relationships (1984, p. xii). They further argue, it is the analysis of these simultaneous relationships and 'the global properties of such complexes of relations' that allow revealing hidden structures, which prior approaches building on distance notions have failed to provide (ibid., p.xii). Indeed, such global properties reveal hidden structures, but as argued earlier the comparability of these properties across systems seems unclear and becomes difficult in regional applications. Hiller and Hanson's decision to exclude the notions of distance and location from their theory prevented a possible convergence of developments of mathematical methods of spatial analysis in quantitative geography. Particularly the work of Peter Haggett (1965) and his colleague Richard Chorley (1967, 1969), Richard Morrill (1970) as well as Abler et al. (1971) focuses on finding patterns of spatial relations and their geometric network properties, as well as stressing the importance of distance in human spatial organisation. This is why it comes rather surprising that this strand of thought was not incorporated or converged, which might be an explanation of the vague concept of scale in the space syntax literature. However, Hillier and Hanson have express their appreciation for the theories of von Thünen (1826), Christaller (1933) and Lösch (1940), but do not incorporate their notions into the broader theory. All of the named authors played an important role in the development of the field of quantitative geography and deal specifically with the notions of distance and location. A quote by Peter Haggett from 1965 exemplifies the very proximity between his and Hillier and Hanson's thinking.

> *'One of the difficulties we face in trying to analyse integrated regional systems is that there is no obvious or single point of entry. Indeed the more integrated the system, the harder it is to crack. Thus in the case of nodal regions, it is just as logical to begin with the study of settlement as with the study of routes. As Isard comments: "the maze of interdependencies in reality is indeed formidable, its tale unending, its circularity unquestionable. Yet, its dissection is imperative. … At some point we must cut into its circumference." We chose to make that cut with movement.' (Haggett, 1965, p. 31)*

Both, Hillier and Hanson as well as Haggett, see the entry point of analytical ventures inunderstanding human spatial organisation in the study of streets with the focus on movement at its core, opening up points of contact. With the developments in the field of space syntax of the last decade, particularly the development of angular segment analysis and the introduction of metric distance radii (Turner, 2001; Hillier and Iida, 2005) the possibility of a point of connection was established. While the majority of space syntax studies put the focus of their research on the city, quantitative geography departed towards an understand of regions as integrated systems of different settlements from early on. This is particularly the case for the geographic strand of economic theories, which started with a one-city theory (von Thünen, 1826) and moved to a system of different hierarchically ordered cities (Christaller, 1933) into what is now coined as a more complex network-based relationship of cities and their hinterland (Sassen, 1991; Taylor, 2004).

Type	Urban Population	Market Population	Market Radius (m)
Marktort (M)	1,000	3,500	4,000
Amtsort (A)	2,000	11,000	6,900
Kreisstadt (K)	4,000	35,000	12,000
Bezirkstadt (B)	10,000	100,000	20,700
Gaustadt (G)	30,000	350,000	36,000
Provinzstadt (P)	100,000	1,000,000	62,100
Landstadt (L)	500,000	3,500,000	108,000

Table 2 - Christaller's central place hierarchy (1933, p. 72).

I believe that particularly Walter Christaller's Central Place Theory (CPT) (1933) of hierarchical order can bring valuable insights into the emergence of scales. Albeit, the fact that several investigations and practical applications on real world examples have shown that regional distribution of urban areas must follow a more complex relationship, there has hitherto not been a better self-consistent theory of economically driven human spatial organisation. Christaller analyses and categorises urban areas of different size and their relationship to their surrounding rural area based on retail services (ibid.). The notion is based on the idea that cities are points of economic exchange. This economic exchange follows a hierarchical order in such a way that specific economic trades occupy particular areas of potential distribution and spatially compete with trades of the same kind. This leads to an economic even spatial distribution with efficient accessibility for each of the trades (Figure 1:1a) and to a hierarchical spatial network. Settlements that are centrally located offer more goods and services and have larger populations. Relative locational centrality is the fundamental determent for this notion. Although Christaller investigates fundamentally spatial phenomena, i.e. the hierarchical spatial distribution and size of cities, his conceptualisation of the city is one of abstract nodes within a networked economy. Still, Christaller's central place system does not come without any spatiality. According to Christaller, one can think of spatiality as a distance and market area (Figure 1:1b). Ultimately, regions are networks of nodes with edges of a given radius. His central place system is, thus, divided into seven hierarchical levels of urban form (Table 2), ranging from a small town Marktort with a population of a 1,000 up to large-scale cities Landstadt with populations over 500,000 inhabitants. Each hierarchy features a potential market population as well as a given market radius.

Figure 1 shows how his theory manifests if tested on the case of southern Germany. Here, L centralities form the upper network of interconnected centres. In the order of P, G, B and K centres are then cluster around the respective next upper level. What is particular for his model is that the relationships are inherently one-directional, this means that each lower class depends on the level above. Since each level is characterised by a cluster of particular economies that is relevant to the hierarchy, horizontal interdependencies are considered as redundant and, thus, non-existent. This idea implies that interregional relationships do only exist on the level of large metropolitan cities. Many authors such as Berry (1961), Bourne et al (1978) and Haggett (1969) have extended the theory (See Coffey, 1998, for an extensive reviews).

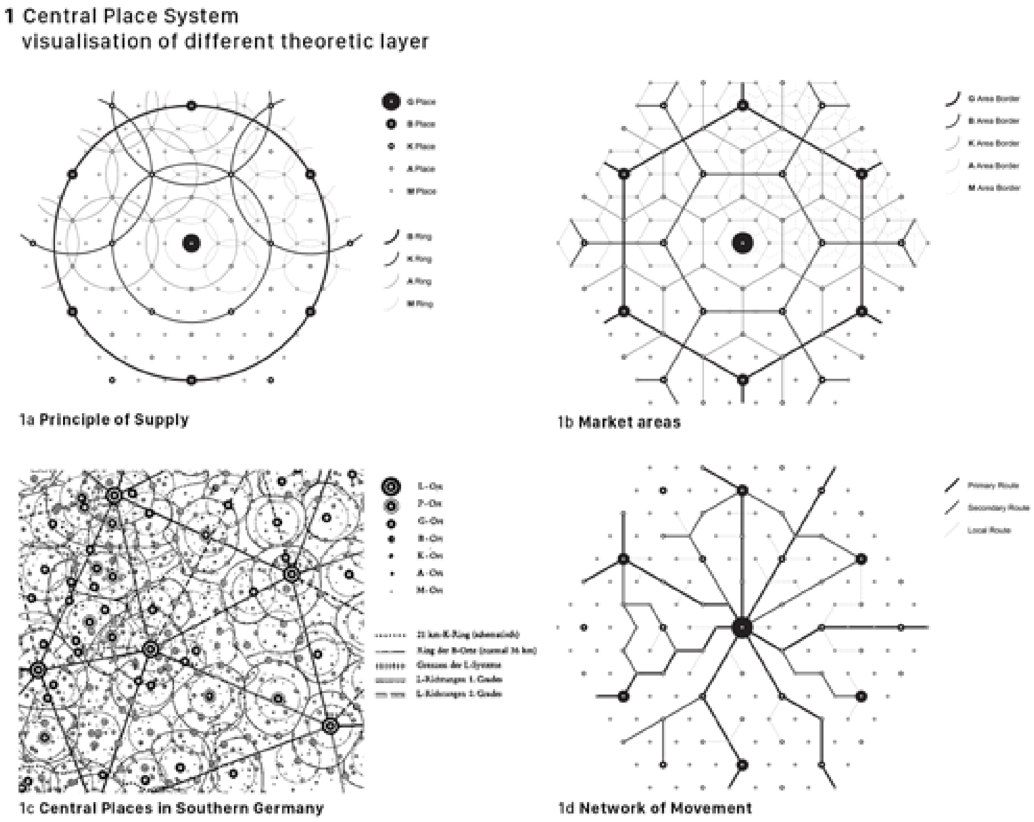

Figure 1 - Central Place Systems featuring the principle of supply (1a), market areas (1b) and resulting networks of movement (1d). Also, mapping of the theoretic central place system in a real world example of Southern Germany (1c: Christaller, 1933, p. 338).

What differentiates Christaller's CPT theory from a space syntax approach is that he theorises distance, although metric in nature, as a directly connected line between nodes, rather than considering distance through the human shaped configuration. Christaller's theory is a strong simplification that takes place in an ideal plane space. His aim is to understand the distribution of cities, rather than the immediate morphology that produces such a process. Space syntax, on the other hand provides methods and tools to explore the morphology of spatial configurations. If Christaller's theory proves to be valid this entails that there is more human activity on scales of market spaces than on other scales. This lead not only to the pattern of city distribution that Christaller described but to a particular polycentric spatial configuration reflecting these scales.

The notion of scale has long been a mayor concern for the geography discipline in general. Over the last decades several authors have stressed the importance of scale (Harvey, 1969; Watson, 1978; Meentemeyer, 1989), particularly so for physical geography and remote sensing in GIS (Quattrochi and Goodchild, 1997). When dealing with geographic data, it is inevitable to specify the respective scale of investigation. Lam and Quattrochi (1992) summarise the core notions on spatial scale and related difficulties when dealing with spatial processes in a triad of *cartographic*, *geographic* and *operational scale*. Here, *cartographic scale* refers to the ratio between the mapped representation and the real world. While, *geographic scale* relates to the spatial extent or the scope of the analysis, *operational scale* gives an account of the level at which the respective process operates. In addition to this, scale can also be interpreted as the level of detail or resolution (ibid., p.89). For the authors one of the core reasons for the importance of dealing with precise definitions when they refer of a scale is that spatial patterns are usually related to a precise scale and different processes might lead to similar spatial patterns (ibid., p.89). This relationship between specific scales and observed patterns makes it necessary to define the spatial extent and the spatial resolution of any data and its analysis in order to investigate at which scale processes operate. This is particularly the case since the advancement of GIS allows conducting cross comparisons of different scales despite their potentially meaningless outcome.

Apart from these data related aspects of scale in physical geography, a large body of work in human geography deals with scale on a theoretic level. In human geography, the focus lies in understanding how 'the production of scale is implicated in the production of space' (Marston, 2000)[1]. Erik Swyngedouw argues, that the social and physical transformation of the world is taking place in an 'interlocked and nested geographic scale' (2004, p. 129). For Swyngedouw social life is process-based, constantly iterates, transforms and reconfigures itself. This process stays in a reciprocal relation to nature and produces in its appropriation and transformation 'historically specific and physical natures that are infused by a myriad of social power relationships' (ibid., p.130). These '[s]ocio-spatial relations operate over a certain distance and produce scalar configurations' (ibid., p.131). Swyngedouw brings with his notion of environmental transformations as integral parts of social and material production of scale, the opportunity to perceive such scalar relationships through space. What Swyngedouw describes are scales that manifest themselves in space. Since these scales are in their generation dynamic and process-based, Swyngedouw argues that '[s]tarting [an] analysis from a given geographic scale seems [...] to be deeply antagonistic' (ibid., p.132). In contrast to Christaller's CPT, according to Swyngedouw, scales are not primarily shaped by economic but by human activity and the nature of social life. Swyngedouw further emphasizes that scales incorporate complex power structures that govern social relations (ibid., p.131). These structures emerge because scales generate geometries of power that produce advantaged and disadvantages in their very existence. In space syntax terminology one can speak of integrated and segregated locations, or, as Stephen Read has put it in his typology of urban levels, as 'being in or out of the network' (2013, p. 10).

Based on these two notions, one can conceptualise scale, in the context of space syntax. Scale, is, thus, the structure shaped and constantly reshaped by socio-spatial and economic processes, operating over a certain distance and time. While the process shaping the scale structure can stay in a quick and constant transformation, the spatial scale is believed to be changing in a rather inert way. Spatial scales are nevertheless in Swyngedouw's words 'never fixed, but perpetually redefined, contested and restructured in terms of their extent, content, relative importance and interrelations' (2004, p. 133). When analysing spatial networks on different centrality radii the patterns that one can observe are constantly influenced by this underlying scale structure that is manifested in the very configuration of the network. It is believed that in order to understand the fundamental morphology of a region, one needs to unveil this hidden or latent scale structure, or, in other words, this multi-levelled interrelated system of spatial scales that cause certain centrality patterns to emerge. I argue, that instead of starting from the dichotomy of the 'local' and 'global' radii in the analysis, the spatial configuration needs to be understood through an extensive collection of different metric radii.

3. DATASETS AND METHODOLOGY

In their seminal study on the structure of the metropolitan city of Oporto, Serra and Pinho (2013) deal with a similar problem. They investigate closeness centrality structures on 15 different radii and propose a principle component analysis (PCA) to arrive at a reduced dimensionality of these radii (ibid., p.186). Their findings consist out of three components, theorised as: neighbourhood, city and regional scale, highlighted to be seen as 'natural centrality scales' and 'intrinsic hierarchical organisation of metropolitan centres' (ibid., p.190). The reason behind using a PCA analysis in their study is to arrive at 'variables that are contained, albeit not explicitly, in the original one' (ibid., p.189). The aim of this study is to uncover the latent structure causing centrality patterns to emerge. For this purpose, an exploratory factor analysis (EFA) will be applied to a series of radii. PCA and EFA are often

1 See Marston et al. (2005)–albeit their contested criticism on the existence of scales in human geography–for a comprehensive review on scale related literature of the past 20 years.

confused as similar, or in the case of PCA, as a simpler form of EFA. Yet, this assumption is incorrect as PCA builds on a different mathematical model than EFA, that differentiates it form EFA (Widaman, 2007; Fabrigar and Wegener, 2011). The PCA 'was not originally designed to account for the structure of correlations among measured variables, but rather to reduce scores on a battery of measured variables to a smaller set of scores (i.e., principle components)' (ibid., p.31). The main purpose of components derived via PCA is to explain as much variance as possible from the measured original variables, rather than to explain the correlations among them (ibid., p.31). In this sense, PCA is an efficient method to represent crucial information of measured variables. EFA on the other hand produces common factors of measured variables. These factors are unobservable latent constructs that conjecturally cause the measured variables (Costello and Osborne, 2005; Fabrigar and Wegener, 2011, p. 31). Contrary to PCA, which constructs components directly from the measured variables, the EFA common factor model partitions the variance of measured variables into common variance and unique variance (Figure 2).

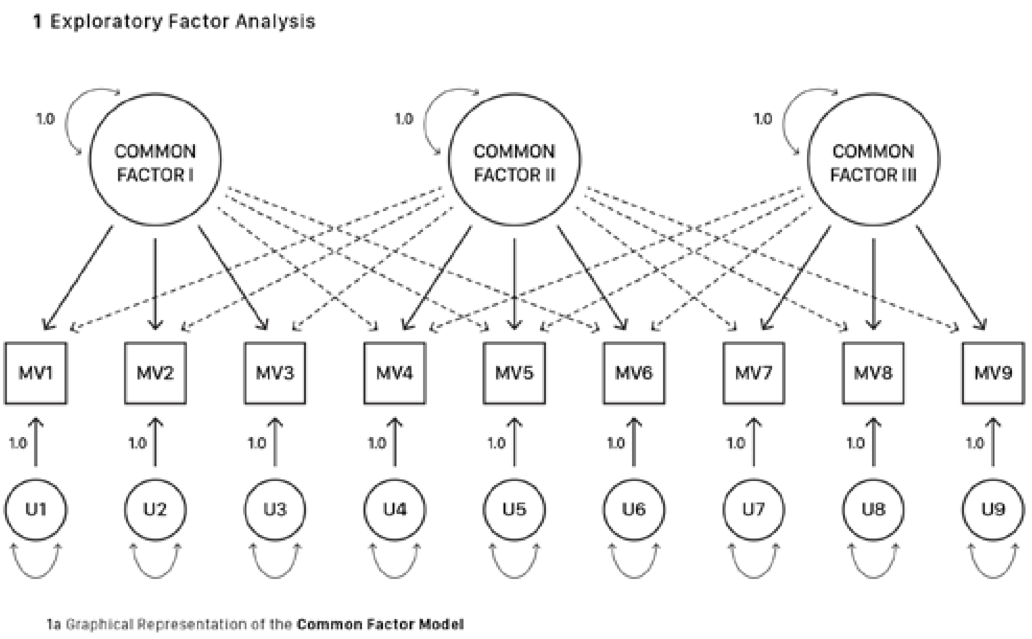

Figure 2 - Illustration of the Common Factor Model for an example involving three common factors and nine measured variables.

The reasons why I choose EFA over PCA are, because a) I aim to identify latent constructs (spatial scales) that are assumed to cause the measured variables (centrality pattern), to inform a broader theory building and it has been argued that EFA is the appropriate method for this (ibid., p.32), b) EFA is designed for cases, 'in which the researcher has no clear expectations or relatively incomplete expectations about the underlying structure of correlations' (ibid., p.4) as it is the case in this paper, and c) in contrast to PCA, EFA generates parameter estimates that allow a generalisation beyond the measured variable collection on which they are based (Widaman, 2007). This means that the components gained via PCA and component loadings change with every addition or removal of other variables. In the case of EFA, however, adding more measured variables (or radii) does not alter the parameter estimates such as respective factor loadings for original measured variables, unless they rely on a new common factor that was not present in the original selection of measured variables (Fabrigar and Wegener, 2011, p. 33). If one includes enough radii in the analysis to make sure the differences between each radius are small enough one can presume that all existing factors are captured. These advantages make EFA more robust in the context of radii selection and investigations of scale structures. This study will employ an EFA to extract latent centrality structures, conceptualised as spatial scales that I presume to cause centrality patterns of different radii.

The models used in this study are based on two European polycentric urban regions, the German region of the Ruhr Valley (hereafter called GE) and the British region of Nottinghamshire, Derbyshire and Yorkshire (hereafter called UK). Both regions are strongly influenced by processes of industrialisation and comparable in their historical development. The real world street network models for both regions are based on OpenStreetMap road-centre line data. The models' boundaries are of a circular shape with a diameter of 230km centred on the approximated geographic midpoint of each region. This is done to avoid edge effects for the regions under investigation. The GE model contains 1,203,173 segments with a total segment length of 122,707.61km, whereas the UK model contains 1,019,915 segments with a total segment length of 107,542.92km. This leads to an area coverage of 41.547km2 including a population of more than 14,000,000 inhabitants in both cases. The networks are manually checked for consistent network coverage and then simplified using a semi-automated ArcGIS simplification workflow (Krenz, Forthcoming 2017). The model coverage is defined by all components of the public rights of way network. The simplification is based on an average width of each street level and defines the models' resolution. The models form the first of their kind on the scale of sub-national territory with a resolution and comprehensive network information from the smallest urban path to large motorways.

In addition to this, this study makes use of a randomly generated street network on a regional size as a means of testing whether spatial scales are an intrinsic part of spatial networks. Automated street network generation is not a trivial task. While there are several approaches dealing with street network generation in general, approaches that produce entirely random networks remain scarce. This study builds on the algorithmic approach of an Erdös-Rényi random planar graph (ERPG), proposed by Masucci et al. (2009). Different to the ERPG, most of the available procedures to generate street networks are parametric in nature. Such parametric approaches use either a set of generative rules in order to arrive at street networks (Parish and Müller, 2001; Marshall and Sutton, 2013), employ pattern-based approaches to generate networks (Sun et al., 2002), or a combinatory approach of both (Chen et al., 2008). Parish and Müller (2001) introduce CityEngine, a procedural method that considers global goals and local constraints. Sun et al. (2002, p. 42) identify a series of existing frequent patterns in real world networks and create a matching pattern template for each. Through the application of different pattern templates they are able to generate new street networks that are combinatorial. Chen et al. (2008), on the other hand, combine Parish and Müller's (2001) procedural method with a tensor field to generate pattern. Marshall and Sutton (2013) present the simulation tool NetStoat to model the growth of street network. Their tool explores the potential of generative street layouts. This brief review should not be seen as a complete account on generative network tools, but as a rough guide towards the general approach taken in this field.

All of these parametric approaches emulate networks based on cities, yet, it remains debatable if these network structures are comparable to structures of regions. Moreover, none of the parametric approaches can be considered as being random by nature but this is a necessity for the model we want to employ. If the model does not feature a strong degree of randomness then the results of the analysis will exhibit centrality patterns of emulated human-shaped, configurational environments. In contrast, the aim of the planned test is to gain insights into fundamental network characteristics of regional sized models that are not shaped by human interaction and are instead random by nature. This is why an ERPG is selected for the generation of the model. An Erdös-Rényi random graph is a graph with a given number of vertices n, and the probability of an edge p between two randomly selected vertices with equal likeliness. Erdös-Rényi random graphs are O(n2) problems (Gerke et al., 2008), and, therefore, take a long time to process if n is significantly large ($n \geq 1{,}000{,}000$). An ERPG is a variation of the Erdös-Rényi random graph. Differently to the original Erdös-Rényi random graph, the ERPG proposed by Masucci et al. (2009, p. 261) introduces a selection process that tests each edge for planarity, that means, on a possible intersection with already existing edges in the graph. An edge will only be added to the graph during the process if no intersection with an already added edge has been found. Moreover, I introduce an additional restriction to the Masucci et al. ERPG that is a segment length frequency selection, which is derived from the two real world regional models. This selection process will increase the probability of segments of certain lengths in order to arrive at a higher comparability.

The final ERPG features equal numbers of nodes, equal number of edges, a comparable frequency of segment length, and the same model boundary diameter as the two real world regional models. The difference between the models lies in their spatial distribution of each segment or, in other words, the ERPG is a graph that does not inherit the effect of human action in its emergence. This will enable a comparison with the morphology that is shaped by human interaction and the morphology that is random in nature in order to identify centrality patterns that are inherent to any spatial network.

Bins	I	II	III	IV	V
Number of Segments	1000	4000	25000	70000	900000
Maximum distance	5200	1300	800	400	200
Minimum distance	1300	800	400	200	0.1

Table 3 - Segment frequency binning based on top 95 percentile.

To arrive at the outlined ERPG, this study develops an algorithm using R (2016), which is a programming language for statistical computing. Building on the strategy proposed by Masucci et al. (2009, p. 261), the ERPG process builds on a Poisson point process of n points in an Euclidean space of circular shape and a diameter of 230km. In contrast to Masucci et al. (ibid., p.261), an initial k nearest neighbour algorithm is employed to find a set of point pairs in a given maximum distance for every point of the Poisson distribution dataset to overcome the long time needed to compute a model of more than 1 million edges. The given maximum distance between two edge pairs is based on the longest segment found in the two real world models. The result is a matrix of edge pairs with a distance from 0.1 to 5000 metres. Based on this nearest neighbour dataset a random selection of point pairs is chosen, then a line segment is added to the graph. The point pair selection is limited by an average segment length frequency found in the existing two regional models, derived through the average of five frequency bins of both real world models (Table 3). Any following line segment is then evaluated against possible line intersections and dismissed if true, in order to arrive at a planar graph. The algorithm proceeds until a previously defined maximum number of segments is generated. Figure 3 shows a detailed section of each of the models on a scale of 1:10,000. Here, the different network morphologies of the automated ERPG are visible (1c).

Figure 3 - Regional street networks, detailed sections (1:10,000) of the three different models, GE (1a), UK (1b) and ERPG (1c).

These three models are analysed with the centrality measures of angular segment analysis (ASA) segment length weighted (SLW) betweenness centrality (Turner, 2001, 2005). ASA SLW betweenness centrality is similar to mathematical betweenness (Freeman, 1977), which calculates how often a segments has been chosen as part of a shortest path between every pair of segments on a specific cut-off radius. Hillier (2009) has theorised this as a measure of accessibility or through-movement and linked it to the economic function of urban form. It should be noted that ASA closeness centrality might provide additional interesting insights into regional morphologies, as the seminal study by Serra and Pinho (2013) has already demonstrated. However, two reasons lead to the focus on betweenness centrality only, a) betweenness centrality has been associated with the economic functioning of urban space (Hillier, 2009) and Christaller's CPT focus on the spatial organisation of economic activities. It, therefore seems plausible to investigate those centrality patterns that can be related to the theoretical positioning of spatial organisation of economic activities. The other reason is that, b) initial tests have shown that closeness centralities generates unexpected outliers where the network structure forms linear clusters (see appendix I). Although this issue can be resolved using the method provided in appendix I, where I demonstrate how to detect such outlier segments, further tests are need on the effect of such outliers on centrality patterns across different radii.

As there is, hitherto, no established method to select radii, this research bases its analysis on 49 different radii that have a smaller metric difference on small radii and grow in difference with larger radii, accounting for the growing computational time and fewer differences on larger radii. The smallest radius is selected based on the mean segment length found in the two regions (GE: 101.99m, UK: 105.44m), while the distance differences between each radius is smaller than the longest segment in each system (GE: 5777.72m, UK: 4732.79m). The reason behind this is to analyse a large collection of radii with only small differences between them to be able to capture any existing scale. If each of the scales correlates strongly with the next one, one can assume that there exists no hidden scale between the two radii chosen that is not covered by the analysis. The radii selected are: *100, 150, 200, 300, 500, 800, 1300, 1800, 2500, 3200, 4100, 5000, 6100, 7200, 8500, 9800, 11300, 12800, 14500, 16200, 18100, 20000, 22100, 24200, 26500, 28800, 31300, 33800, 36500, 39200, 42100, 45000, 48100, 51200, 54500, 57800, 61300, 64800, 68500, 72200, 76100, 80000, 84100, 88200, 92500, 96800, 101300, 105800 and 110500*[2]. The resulting data for each of the centrality measures ranges above 49,000,000 values, which is an uncommonly large number of observations for analyses in space syntax and, therefore, promises unusually robust results.

4. ANALYSIS AND DISCUSSION

I will start with the results of our random graph model, ERPG, for ASA SLW betweenness centrality to evaluate what kind of patterns might one could expect in human shaped models of regional scale and polycentric urban morphology (Figure 4:1a & 1b). The EFA is derived using four different factors for the ERPG model. The premise is that these four factors are causing the centrality patterns to emerge. The diagram in Figure 4:1a and 1b shows the regression coefficient of each radius for the extracted respective factor (I-IV). Each line graph represents one factor and the factor loading of the radius it is influencing. Based on the factor loading one can observe associations of different radii and each factor. This allows interpretations for each of the factors and a collection of measured variables. In the case of betweenness centrality for the ERPG we can observe that almost half of all radii (33,800 – 110,500m) are influenced by factor I. Larger radii show the strongest regression coefficient, this means that factor I can estimate parameters more precisely than the remaining factors II-IV. Radii between 6,100 and 33,800m are associated with factor II, radii between 500 and 6,100m to factor III, and radii between 100 and 500m are influenced by factor IV. The fact that EFA produces these factors and that they form a clear pattern in their rotated factor loadings provides insights into the general behaviour of centrality patterns in planar graphs. Independent of how the spatial

2 The radii selection can be further extended by the following equation: y = 50x2 while the resulting value should be rounded to the nearest hundredths.

configuration is structured, there are always shortest paths and locations in the system that have an advantaged or disadvantaged accessibility. Yet, these shortest paths presumably do not exhibit a large variation throughout different radii of comparable distance between radii of significantly different distance. This leads the hierarchical order to switch form one scale to the other, meaning that if a journey takes place between two points on a radius of 1,300 metres and another one on a radius of 1,800 metres these two journeys are more likely to select the same path within the network than a journey taking place between two points on a distance of 41,800m. Such switching in hierarchy between two spatial scales is not sudden, but constitute a smooth transition. This is visible in the gradual difference of rotated factor loadings leading to the assumption that spatial graphs inherently feature best-fit structures or scales for certain distance modes. If this is the case one should find similar structures in human-shaped configurations and these structures might exhibit a level of optimisation to each of these scales. This is because human beings as well as other natural processes have evolved through mechanism of optimisation. Accordingly, Barthélemy (2011, p. 59) points to the existence of such spatial network characteristics as indicators of 'evolutionary processes'.

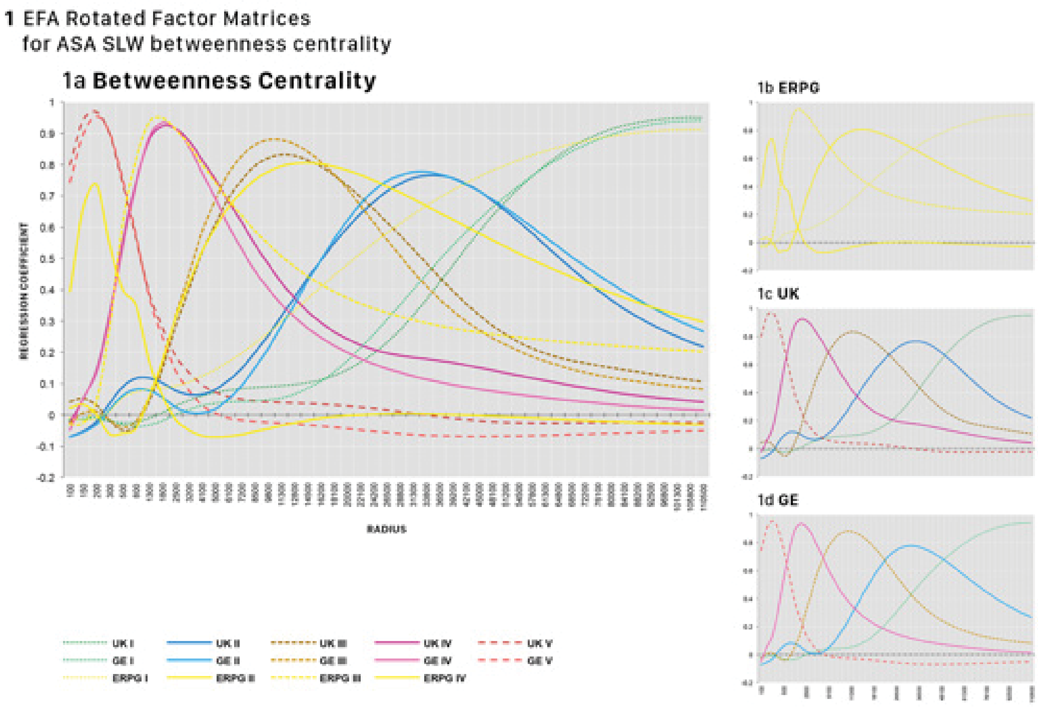

Figure 4: 1a: Explorative Factor Analysis rotated factor loadings for 49 metric distances of ASA SLW between centrality for three case studies: United Kingdom (UK), Germany (GE) and ERPG. Extraction method: Principle Axis Factoring. Rotation method: Equamax with Kaiser Normalisation. Rotation converged by 22 UK, 19 GE and 35 ERPG respectively.

Both, the UK and GE model, show strikingly similar patterns in their factor loadings (Figure 4:1c & 1d). The EFA is produced with 5 factors for both regions with the same radii association for each of the factors, namely: factor I (48,100 – 110,500m), factor II (22,100 – 48,100m), factor III (5,000 – 22,100m), factor IV (800 – 5,000,m) and factor V (100 – 800m). Compared to the results of the EPRG model, the real world regions feature an additional factor and exhibit a clearer manifestation of each factor. This could be an indicator for a hierarchical organisation in human activity patterns that are underlying the shaping process of the spatial configuration and define spatial scales. Hillier argues that betweenness centrality gives insights into the location of economic activities (2009), providing his conjecture on the emergence of theses spatial scales. Walter Christaller's CPT (1933) point to a hierarchical relationship between differently sized urban areas and their respective market spaces. In relation to human activity and movement this means individuals are more likely to engage with everyday goods in local markets and rare goods in higher hierarchies. In reality this implies that grocery shopping is more likely to take place in a local neighbourhood, while specialised services such as the services of a lawyer would benefit from being situated at centres of higher hierarchy as they need to extend their market area in order to suffice the need of frequent customers. Assuming that certain activities take place more often than others, such as the daily commute to a workplace for the majority of the population, other activities will occur less often, such as buying electric goods. If these repeated everyday patterns of human activity have an impact on the spatial organisation of societies in a way that an optimisation process shapes the spatial configuration so that these repetitive everyday activities are more effectively distributed in the system, then they should manifest in the form of spatial scales. Moreover, the spatial product of this process will have an impact on the possibility of future activities and, subsequently, influence the former. Thus, one can make assumptions of the nature of these extracted spatial scales.

Comparing those radii that the derived factors (spatial scales) predict the best, with those radii predicted by Christaller's CPT for different market areas (Table 4), a relationship between the two, empiric and theoretic radii becomes apparent. The factors extracted are similar to the radii defined by Christaller's CPT. Three of these five extracted factors exhibit estimate parameters on exactly those radii that Christaller estimated for each of his central place hierarchies. The exceptions of this are very local centrality patterns (factor IV and V), which might be caused by the fact that smaller centrality patterns are influenced more strongly by cultural process then by economic activity. Whereas three of Christaller's seven central place types can be explained by the factors extracted, the remaining four seem are not captured by the EFA. However, with regards to the randomised graph ERPG model, we have already gained insights into the inherent scales embedded in planar graphs and only four of such scales emerged. This might indicate that the remaining centres are not pronounced enough to constitute independent spatial scales. Based on this assumption, it is worth considering the intersectional area of each of the latent centralities as points of interest; these intersections are points that can load on either of the two factors. Table 4 include additional sub-categories of potential spatial scales between the factors found. Again, one can observe rather similarities with the distances in Christaller's CPT and the factors extracted.

Latent centralities	UK Region	GE Region	Market Radius (m)	Christaller Type
Neighbourhood	200	200	-	-
City	1,800	1,800	-	-
-	-	-	4,000	Marktort (M)
Between City/Metro	6,100	6,100	6,900	Amtsort (A)
Metropolitan	11,300	11,300	12,000	Kreisstadt (K)
Between Metro/ Inter-Regio	22,100	22,100	20,700	Bezirkstadt (B)
Inter-Regional	33,800	33,800	36,000	Gaustadt (G)
Between Inter/Intra-Regio	45,000	45,000	62,100	Provinzstadt (P)
Intra-Regional	105,800	105,800	108,000	Landstadt (L)

Table 4 - Comparison of the betweenness latent centrality structure with Christaller's central place system and their respective scales.

These findings indicate that regional morphologies might, indeed, be able to provide insights into economic processes and human activity patterns causing this formation. The findings also suggest that Christaller's theory can only be used to a certain extent to explain the spatialisation of the two European regions under scrutiny. Very little has been said so far about the actual spatial configurations that the different factors produce. Following the strategy proposed by Serra and Pinho (2013), I visualise each factor based on its respective loadings. Figure 5 provides a loading plot for each factor for each of the three models, UK, GE and EPRG. The factors include loadings at different intensities for each segment and, therefore, provide a rich pattern. Here, only loadings above a standard deviation of 2.0 are highlighted in red (Figure 5). This way of visualisation increases the distinctive difference between each factor visually and facilitates the interpretation of their morphologic nature. In Figure 5, the pattern observed in the rotated factor loadings is now mapped on the respective spatial network. Again, both regions UK and GE are exhibiting very comparable patterns on all five factors. The ERPG model seems to be comparable with the factors II – V of the UK and GE models, however, it lacks a spatial pattern that is comparable with the first factor of the real world models. While the radii, which are associated with both first factors are similar (ERPG: 33,800 – 110,500m and UK & GE: 48,100 – 110,500m), the actual morphology seems much more comparable to the second factor of the real world cases. With regard to each spatial scale (factor I – V) of both real world regions, one can observe how each scale features larger distances between intersecting nodes. This might be an indicator of scaling effects of optimisation processes embedded in human activity. A view on a zoomed-in section will highlight how human shaped networks differ compared to a randomised graph (Figure 6).

Figure 5 - Latent centrality structures for angular segment analysis segment length weighted betweenness centrality. EFA loadings for each factor and case with values above a standard deviation of 2.0 highlighted in red.

Figure 6, enables a direct comparison of the differences between the real world networks and the ERPG. Real world networks exhibit spatial scales that are characterised by long linear clusters of lines. The fact that each scale exhibits such linear networks is a strong indicator for inherent optimisation processes. The ERPG shows comparable line clusters whereas the line clusters morphology differs significantly. Here, the spatial scale pattern is more zigzagged in nature (Figure 6:1c & 1f). This is simply because the network does not feature straight linear networks, which seems to be a much more efficient distribution of flows through the network. The economic spatial distribution of market centres and a potential optimisation process seems to manifest in the emergent spatial scales. This points to a much more complex relationship between economic activity and spatial configuration than the space syntax concepts of 'global' and 'local' scales suggest. Furthermore, the findings point to the constraints and problems a 'one city' theorisation produces. Without considering surrounding cities and their hinterland of any urban area in an analysis, an accurate picture of the spatial morphology remains impossible. The third factor (Figure 6:1a & 1b) exemplifies this strong intercity relationship. Each of the clusters in factor III consists of several cities. This pattern could not be observed with a focus on one independent city only.

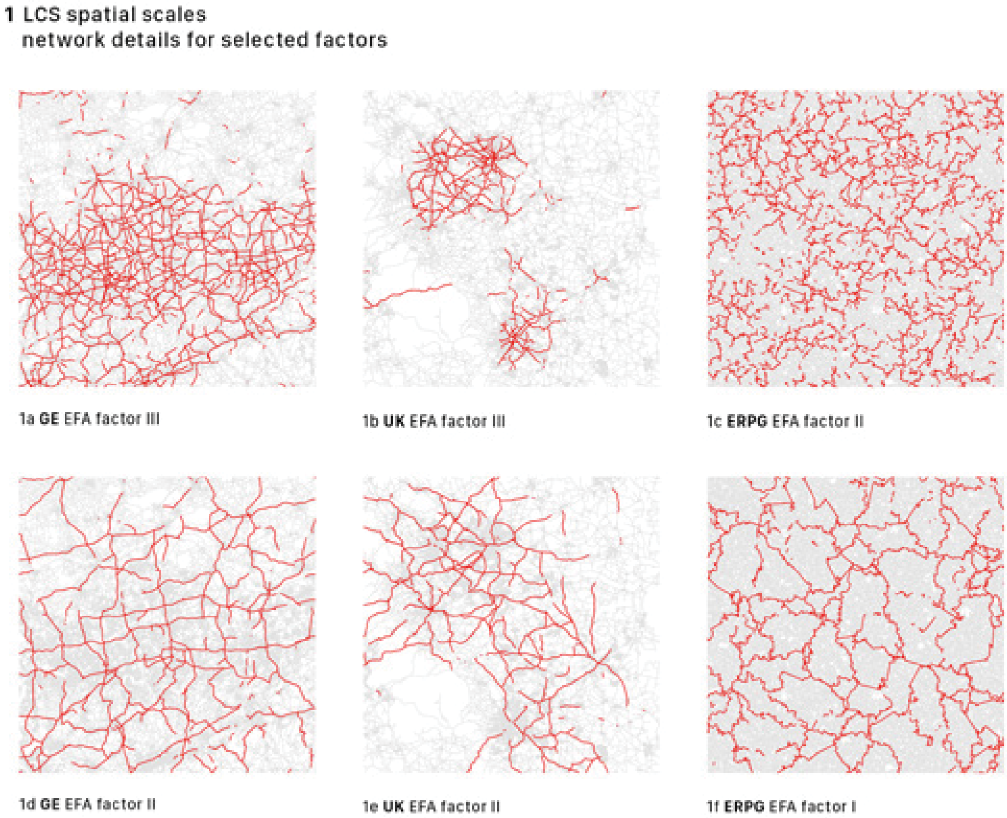

Figure 6 - Details of latent centrality structures, EFA factor loadings for two selected factors of the three models GE, UK and ERPG. Values above a standard deviation of 2.0 are highlighted in red.

The aim in each study of urban morphology should be to uncover the inherent spatial scales underlying each network by investigating a large array of different radii and extracting latent centrality structures, instead of merely employing the dichotomy of 'local' and 'global'. The findings of this study cannot confirm the hierarchical configuration conceptualised in Christaller's CPT. While Christaller's core notion of the distribution of centres remains reasonable, the actual network this hierarchical distribution generates, is of more complex nature than he suggests (Figure 1:1d). The morphology of the observed spatial scales point to a much more complex pattern and relationship between cities and their hinterland, which is what more recent theories have argued (Sassen, 1991; Taylor, 2004). Polycentric urban regions are particularly characterised by these complex spatial relationships. This constitutes challenges for urban policies trying to address change on local levels because the outcomes might have a very different effect than they were set out to have, if these strategies commonly used do not comprehensively understand the spatial reality of cities as intrinsically linked to different spatial scales and their surrounding urban areas. Although in this research we have started from the point of view of the region, it is believed that the findings have a strong informing character for any analytical investigation interested in understanding the city. Still, further research is needed to compare the spatial scales uncovered to large-scale data of human and economic activity. If such investigations can support the relevance of these spatial scales they can be appropriated to effective planning tools.

5. CONCLUSIONS

Regional analysis in the field of space syntax is still in a developing stage. Only very few studies have dealt with the scope of a region in a systematic manner. This is not only due to the difficulties researchers are facing in the construction of high-resolution models but also due to a lack of theorisation of the very entity. More difficulties arise when researchers apply space syntax concepts that have been developed for the context of independent cities. Instead this study tried to link concepts of quantitative geography and provided an initial sketch of the concept of spatial scales to overcome this difficulty. The findings support the need for a revision of the theorisation of the concept of 'global' and 'local' in light of space syntax analysis towards a multi-layered latent centrality structure of spatial scales.

This study shed light on centrality patterns in polycentric urban regions and random planar graph networks. The analysis compared 49 different betweenness centralities patterns using an exploratory factor analysis and arrived with five different factors. The morphology of real world and random networks share similarities in latent centrality structures but are very different in their morphology. These five latent centrality structures are theorised as emergent spatial scales by employing Walter Christaller's central place theory and Erik Swyngedouw's theory of scales. Such spatial scales are presumed to be inherent to human shaped spatial networks as they are the product of repetitive human activities and primarily informed by economic processes.

The comparison of human shaped networks to a random planar graph pointed to an optimisation process that might underlie the formation of human networks in general and spatial scales in particular. The findings in both real world regions pointed to a much richer pattern than the one-sided hierarchy described in Christaller's central place theory and uncovered a complex inter-city and interregional network that is shaped and reshaped over time. Further research is needed to investigate whether the spatial scales discovered are relevant in a socio-economic context and can be of use to inform regional policymaking.

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6. APPEDNDIX

1 ASA Closeness Centrality Outlier Detection

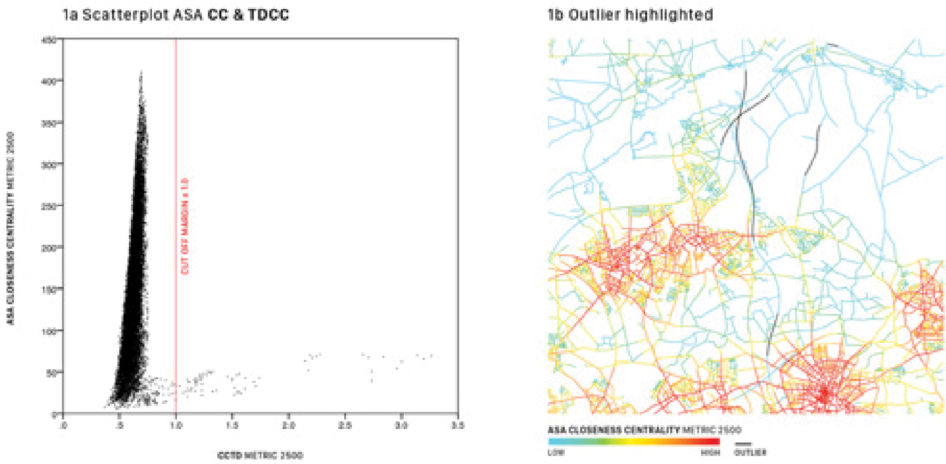

Figure 1: 1a Scatterplot of ASA Closeness Centrality and CCTD radius metric 2500, highlighted in red the cut off margin ≥ 1.0. 1b Detail section of a ASA Closeness Centrality metric 2500 with outliers highlighted in black.

In this paper, I have applied angular segment analysis closeness centrality in a regional context. An arising problem from such an application is that there are few cases of clusters of high- values in areas of low urbanisation, where lower values are expected. This is particularly the case at small radii (100 – 2500m), but measurable at a radius of up to 5km for the investigated cases. One can compare this effect to a similar problem that Hillier et al. (2012, p. 191) faced when they introduced normalised least angle choice. The problem seems to be related to long linear segment structures or cul-de-sacs (Figure 1: 1b). Such linear structures or dead-ends are very common for rural or less-urbanised areas; but also features of highway systems. As partially urbanised areas and rural structures are very common in large metropolitan cities and an intrinsic part of regions, it is necessary to detect such outliers. While the majority of outlier cases can be identified via visual comparison, some cases of lower value ranges are difficult to identify visually. These exceptional cases can only be identified by a comparison with values of their immediate surrounding segments, which makes it difficult to clean the data manually. However, all segments with an unexpectedly high value share a common characteristic, namely a significantly lower total depth (TD) value compared to the respective closeness centrality (CC) value. This allows for an objective reproducible strategy to identify outliers, even in cases where a visual comparison of the data does not allow detection. The following equation detects outliers in ASA closeness centrality results. By adding the constant of 3 to CC and TD and dividing the logarithm of CC by the logarithm of TD of the respective radius, the resulting variable can be used for outlier detection:

$$CCTD\_r = Log(CC\_r+3)/Log(TD\_r+3)$$

In the event that the obtained value is equal or above 1 the respective segment can be considered as an outlier. Figure 1: 1a shows a scatterplot that visualises this effect. All values on the right side of the red cut-off line can be considered to be outliers, whereas the distance to the left indicates the amplitude of the outlier effect.