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REGIONAL MORPHOLOGY
The Emergence of Spatial Scales in Urban Regions

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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. It will be argued that space syntax concepts of 'global' and 'local' scales are in regional configurations 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 is done by investigating 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 suggest a need for a revision of the theorisation of the concept of 'global' and 'local' scales in light of space syntax analysis towards multi layered LCS'. This study shows that space syntax can be applied in regional contexts and gives further guidance on a methodology to explore regions through space. However, additional research is needed to confirm whether the found LCS' have implication to empirical flow data as well as if they have relevance in a socio-economic context and hence be of use to inform regional policymaking.

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 stages. However, with growing computational power and access to large data sets configurational studies of regions are increasingly becoming feasible. This study tries to shed light on regional spatial configurations. On practical level, analytical ventures in regional spheres pose a series of challenges and questions, starting with the generation of computable models, over how to define model boundaries, or the level of detail and resolution, towards which radii to choose in the analysis. These questions, however, are not technical but theoretical in nature and, it will be argued, relate all to the question of what 'scale' is in space syntax. The aim of this study is hence to understand spatial scales in regions and how they emerge.

The paper is structured into three parts; the first part forms a theoretical contextualisation. We 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 the analysis and space syntax literature, it will be argued 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 the chosen methodology to investigate the emergence of previously outlined scales in regional spatial configurations. Two selected case studies are presented, as well as a randomly generated planar regional model. We will elaborate on the process behind the generation of this randomly generated planar model and the reasoning behind a comparison of real world cases with such model. Finally, the selection of different centrality measures as well as the method of exploratory factor analysis will be justified.

The third and final part presents the analytical results and sets the findings in the theoretical context of 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. Turners (2009) study into the linkage of the local to regional continuum forms here a pioneering position. Not only due to his methodological proposition to make use of a road-centre line data for his analysis, but by focusing on a collection of cities in the regional context. The application of network analysis in the field of regional studies opens up the possibility of new understandings of spatial relations. Space syntax, applied to a regional scale however unveils some challenges as it is theorised in a fundamentally local context, the human body in space, which has not been explored so far in a regional context.

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 some commonalities and differences do reveal (Table I). The most apparent observation is a non-defined usage of the term 'region'. This is rooted in difficulties with the very definition of the entity itself and most obvious in the difference of model sizes, which range from 20 to 950km. Particularly the term metropolitan area seems to be often used synonymously for region, which makes the comparative application of findings problematic. Additionally to differences in model sizes, does come 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 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, a not consistent use of space syntax measures and their respective scales of analysis are present. All of this is on one hand due to the constant development of analytical procedures and technologies in the field and on the other due to the developmental stage of regional studies in the field of space syntax. This situation poses difficulties in the comparability of findings.

When this study refers to the term region and PUR, it builds on concepts of 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, south-east Asia) and trans-national territories, regions that are across two or more adjacent states (EUREGIO, ARGE), this studies interest is of the third kind and can be described as sub-national territory (ibid., p.14). Sub-national regions are within one independent nation and share, contrary to trans- and supra-national territories, the same political and socio-economic systems. As stated earlier 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 hence characterised by a clustering of human activity leading to a complex spatial organisations. Polycentric urban regions are such polycentric entities. They consists of a number of historically distinct, political and administratively independent cities in close proximity to each other (Kloosterman and Lambregts, 2001, p. 718). Important is the lack of a dominating central city and a rather even distribution of a smaller number of similar sized cities with equal economic importance and a greater number of smaller cities (ibid., p.719). This is because regions that feature a dominating central city 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 interest in using PURs as cases studies is because of their inherent complexity of their spatial organisation.

Contrary to the explorations in space syntax studies in metropolitan and regional form are the majority of preceding studies applying network analytical approaches to the scale of the 'city'. The city in these studies is mostly 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). Most recently Hillier *et al.* (2012) have pointed out, in their study of 50 different cities that there seemingly is a globally occurring dual relation between a global and local structures of cities. This dual relation has been theorised by Hillier as the *generic city* (Hillier, 2014). The 50 different cities, Hillier et al. compared in their 2012 study varying in size significantly. So are the three smallest networks in their list of cities, Mytiline, Nicosia and Venice approximately 1km, 1,5km and 5km wide, whereas the largest networks include Istanbul, Bejing and London with approximately 26km, 34km and 64km. The largest system is hence 64 times larger than the smallest system. For Hillier et al. (2012, p. 164) such a comparison is nevertheless appropriate, because they developed a method to normalise betweenness centrality deriving with a range of comparable values, which they argue 'permit direct comparison of radii within and across cases' from 'local to global'. They argue that their analytical approach allows comparison 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 here, as 'scale' could be better described as 'resolution' and does not sufficiently account on scale as a whole.

While they do not specify what they refer to as 'local', they proceed in their analysis to investigate the 'global pattern' of each city comparing radius *n*, or in other words all segments with all for each case. Such a comparison is here seen as rather problematic due to the following reasons: 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 example are a cut outs of larger continuous metropolitan agglomerations and areas at the border of the model are hence not representing a fragmented network of the real world situation. A study by Gil (2015, p. 2), demonstrated 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 example 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 ≥ 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 through out 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 sets. Here, 'local' refers to an individual cell and its rule, while 'global' describes the agglomerated object as a whole, that is all individual cell's together, and their subsequent 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 and 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 does become 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 hence 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 scale less model becomes spatialised–and hence starts to incorporate scales–in forms of buildings, neighbourhoods and settlements of ranging size, 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 here considered 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 Hiller 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 missed to provide (ibid., p.xii). Such global properties reveal indeed 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) focused on finding patterns of spatial relations and their geometric network properties, as well as stressing the importance of distance in human spatial organisation. It comes hence rather surprising that this strand of though was not incorporated or converged, which might be an explanation of the vague concept of scale in space syntax literature. However, Hillier and Hanson have expressed their appreciation for the theories of von Thünen (1826), Christaller (1933) and Lösch (1940), but did 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 view on a quote by Peter Haggett from 1965 exemplifies the very proximity of his thinking to the one of Hillier and Hanson.

> *'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 authors see the entry point of analytical ventures in understanding 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 during 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 has been established. While the majority of space syntax studies puts the focus of their research on the city, quantitative geography departed early on towards an understand of regions as integrated systems of different settlements. 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).

We believe that particularly Walter Christaller's Central Place Theory (CPT) (1933) of hierarchical order can bring valuable insights into the emergence of scales. This is because, 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, up to now there has not been a better self-consistent theory of economically driven human spatial organisation. Christaller analysed and categorised different sized urban areas and their relationship based on retail services to their surrounding rural area (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 compete with trades of the same kind spatially. This leads subsequently 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 central located offer more goods and services and have larger populations. Relative locational centrality is the fundamental determent for his notion. For Christaller, albeit investigating a fundamental spatial phenomena–the hierarchical spatial distribution and size of cities–his conceptualisation of the city is one of abstract nodes within a networked economy. Nevertheless, Christaller's central place system does not come without any spatiality. For Christaller spatiality is thought of as distance and market area (Figure 1:1b). Ultimately, regions are for him networks of nodes with edges of a given radius. His central place system is hence divided in seven hierarchical level of urban from (Table II), ranging from a small town Marktort with a population of a 1,000 up to large scale cities Landstadt with populations larger than 500,000. Each hierarchy features a potential market population as well as a given market radius.

Figure 1 shows how his theory manifests if mapped to 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. Particular for his model is that relationships are inherently one directional, this means that each lower class depends on the level above. Since each level is characterised by a, for the hierarchy relevant, cluster of particular economies, horizontal interdependencies are considered as redundant and hence none existent. This implies that interregional relationships do only exist on the level of large metropolitan cities. Many authors have extended the theory, Berry (1961), Bourne et al (1978) and Haggett (1969) among others (See Coffey (1998) for an extensive review).

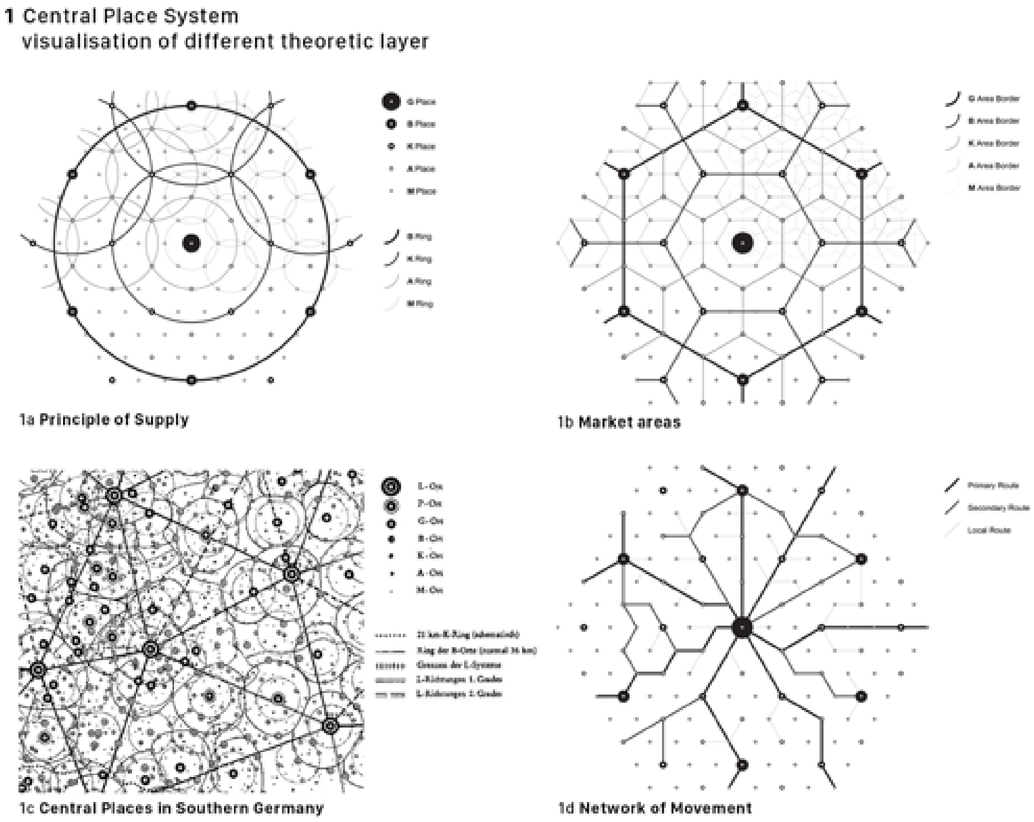

Figure 1 - Central Place Systems featuring the principle of supply (1a), market areas (1b) and resulting networks of movement (1d). Also, mapping of the theoretic central place system in a real world example of Southern Germany (1c: Christaller, 1933, p. 338).

What differentiates Christaller's CPT theory from a space syntax approach is that distance albeit metric in nature is theorised as direct connecting 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 was to understand the distribution of cities, rather than the immediate morphology that such a process produces. Space syntax, on the other hand provides methods and tools to explore the morphology of spatial configurations and if Christaller's theory has validity then there is more human activity on scales of market spaces than on other scales. This would subsequently 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) and this is particularly the case 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 talking of scale is that spatial patterns are usually related to a precise scale and different processes might lead to similar spatial pattern (ibid., p.89). A situation that 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 cross comparisons of different scales, albeit their potential meaningless outcome.

Apart from these data related aspect of scale in physical geography a large body of work in human geography has been dealing with scale on a theoretic level. Here, the focus is in particular on understanding how 'the production of *scale* is implicated in the production of space' (Marston, 2000)[1]. Erik Swyngedouw (2004, p. 129) argues, that the social and physical transformation of the world is taking place in an 'interlocked and nested geographic scale'. For Swyngedouw social life is process-based, and 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 'Socio-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 'Starting analysis from a given geographic scale seems [...] to be deeply antagonistic' (ibid., p.132). For him differently to Christaller's CPT, are scales not primarily shaped by economic activity, but by human activity and the very nature of social life. Swyngedouw further emphasizes that scales incorporate complex power structures that govern social relations (ibid., p.131). This is 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 (2013, p. 10) has put it in his typology of urban levels of 'being in or out of the network'.

Based on these two notions, one can conceptualised scale, in the context of space syntax. Scale, is hence 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. 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

Serra and Pinho (2013) have dealt in their seminal study on the structure of the metropolitan city of Oporto with a similar problem. They investigated closeness centrality structures on 15 different radii and proposed a principle component analysis (PCA) to arrive with a reduced dimensionality of these radii (ibid., p.186). Their findings consisting 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 was to arrive with 'variables that are contained, albeit not explicitly, in the original one' (ibid., p.189). As outlined in the previous section the aim of this study is to unveil 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 confused as similar, or in the case of PCA as a simpler form of EFA, this is assumption is not correct, because PCA is using a different mathematical model than

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.

EFA and is different in several aspects (Widaman, 2007; Fabrigar and Wegener, 2011). This is because 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). PCA derived components' main purpose is to explain as much variance as possible from the original measured variables, rather than to explain the correlations among them (ibid., p.31). In this sense PCA is an efficient method to represent information in measured variables. EFA on the other hand produces common factors. These factors are unobservable latent constructs that are conjecturally cause the measured variables (Costello and Osborne, 2005; Fabrigar and Wegener, 2011, p. 31). Different to a PCA, which constructs components directly from the measured variables does the EFA common factor model divide the variance in measured variables into common variance and unique variance (Figure 2).

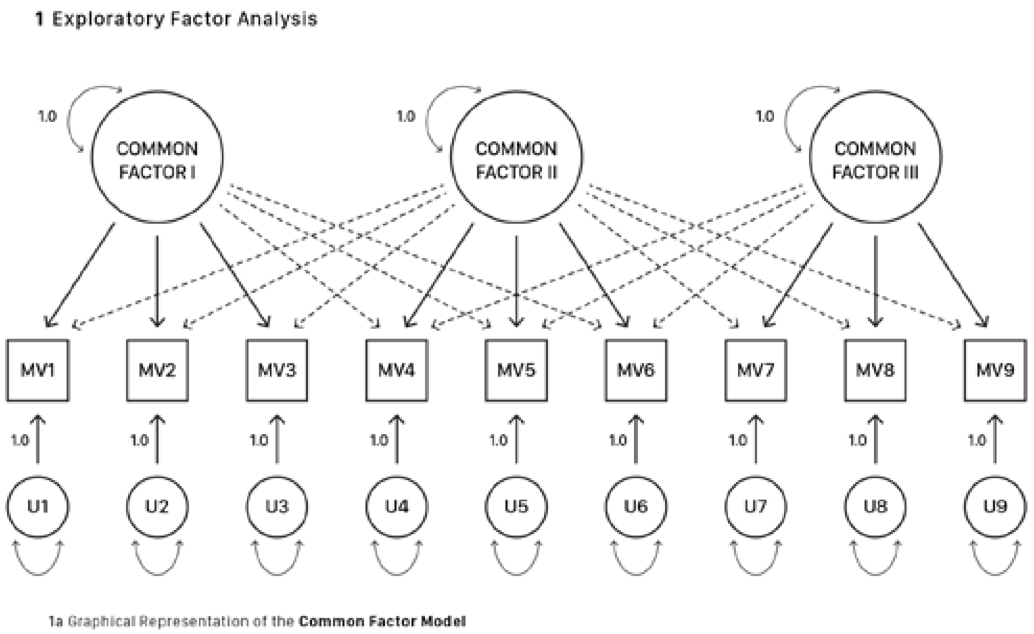

Figure 2 - Illustration of the Common Factor Model for an example involving three common factors and nine measured variables.

The reasons why EFA has been chosen over the proposed PCA are, because a) the general aim of this research is to identify latent constructs (spatial scales) that are presumed to cause the measured variables (centrality pattern), to inform a broader theory building and is 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 for this research, and c) different to PCA does EFA generate parameter estimates that allow a generalisation beyond the measured variable collection on which they are based (Widaman, 2007). This means PCA resulting components and component loadings change with every adding or removal of additional 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 measured variable collection (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 hence employ an EFA to extract latent centrality structures, conceptualised as spatial scales that are presumed 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 (from here onwards GE) and the British region of Nottinghamshire, Derbyshire and Yorkshire (from here onwards UK). Both regions are strongly influenced by processes of industrialisation and comparable in their historic development. The real world street network models for both regions are based on OpenStreetMap road-centre line data. The models boundary are of circular shape with a diameter of 230km centred on the approximated geographic mid point of each region, this is to avoid edge effects in 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 on consistent network coverage and 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, the study makes use of a randomly generated street network on a regional size as a mean of testing if spatial scales are an intrinsic part of spatial networks. Automated street network generation does not form a trivial task. While there are several approaches dealing with street network generation in general, approaches that produce entirely random networks are scarce. This study will build on the algorithmic approach of an Erdös-Rényi random planar graph (ERPG), proposed by Masucci et al. (2009). Different to the ERPG are most of the available procedures to generate street networks parametric in nature. Such parametric approaches use either a set of generative rules in order to arrive with street networks (Parish and Müller, 2001; Marshall and Sutton, 2013), others 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) introduced *CityEngine*, a procedural method that allows consideration of global goals and local constraints. Sun et al. (2002, p. 42) for example identified a series of existing frequent pattern in real world networks and created a matching pattern template for each. Through the application of different pattern templates they are able to generate new street 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. Most recently Marshall and Sutton (2013) presented the simulation tool *NetStoat* to model the growth of street network. Their tool explored the potential of generative street layouts. This list 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. It stays in question if these network structures are comparable to structures of regions. Moreover, none of the parametric approaches can be considered as random in 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 pattern of emulated human shaped configurational environments. Contrary, 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's are *O(n2)* problems (Gerke *et al.*, 2008), and hence take 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, introduces the ERPG proposed by Masucci et al. (2009, p. 261) a selection process that tests each edge on 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, we 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 with a higher comparability.

The final ERPG, will hence feature equal number 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 is in their spatial distribution of each segment, or in other words, the ERPG is a graph that does not inherent the effect of human action in its emergence. This will allow a comparison with the morphology shaped by human interaction and a morphology that is random in nature in order to identify centrality pattern 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 with the outlined ERPG, this study developed an algorithm using R (2016) 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 a Euclidean space of circular shape and a diameter of 230km. Differently to Masucci et al. (ibid., p.261), to overcome the long time needed to compute a model of more than 1 million edges, 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. 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 and subsequent a line segment 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 II). Any following line segment is then evaluated against possible line intersections and dismissed if true, in order to arrive with a planar graph. The algorithm proceeds until a previously defined maximum number of segments are generated. Figure 1 shows a detailed section of each of the models on a scale of 1:10,000. 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 on 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 show 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 economic functioning of urban space (Hillier, 2009) and Christaller's CPT is focused on the spatial organisation of economic activities, it makes hence sense to investigate on those centrality patterns that can be related to the theoretical positioning of spatial organisation of economic activities, moreover, b) initial tests have shown that closeness centralities generates unexpected outlier where the network structure forms linear cluster, see appendix I. Although this issue can be resolved with the method provided in appendix I (exhibiting how to detect such outlier segments) further tests are need on the effect of such outliers on centrality patterns across different radii.

Because there is no established method to select radii so far, 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. Moreover, 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 scale of they exist. If each of the scales correlates strongly with the next one, the assumption can be made that there is no hidden scale between the two, which is not covered by the analysis. The selected radii 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 and this study can hence build on a very large data set to ground observations on.

4. ANALYSIS AND DISCUSSION

We will first start with the results of our random graph model, ERPG, for ASA SLW betweenness centrality to evaluate what kind of patterns might be expectable by human shaped models of regional scale and polycentric urban morphology (Figure 4:1a & 1b). The EFA derived with four different factors for the ERPG model. These four factors are presumed to cause the centrality patterns to emerge. The diagram in Figure 4:1a and 1b, shows the regression coefficient of each radius for the respective extracted factor (I-IV). Every of the 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 precise then the remaining factors II-IV. Radii between 6,100 and 33,800m can be associated with factor II, radii between 500 and 6,100m to factor III and finally radii between 100 and 500m are influenced by factor IV.

The fact that EFA derives with these factors and that they form a clear pattern in their rotated factor loadings gives insights into general behaviour of centrality patterns in planar graphs. Independent of how the spatial configuration is structured, there are always shortest paths and accessibility advantaged and disadvantaged locations in the system. However, these shortest

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.

paths do presumably not exhibit large variation throughout different radii of comparable distance, but between radii of significantly different distance. This leads to a hierarchy switch of one scale to another, 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 hierarchy switches between two spatial scales are not sudden, but exhibit 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 we will 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 mechanism of optimisation embedded into their evolutionary being. Barthélemy (2011, p. 59) has pointed to the existence of such spatial network characteristics as indicator of 'evolutionary processes'.

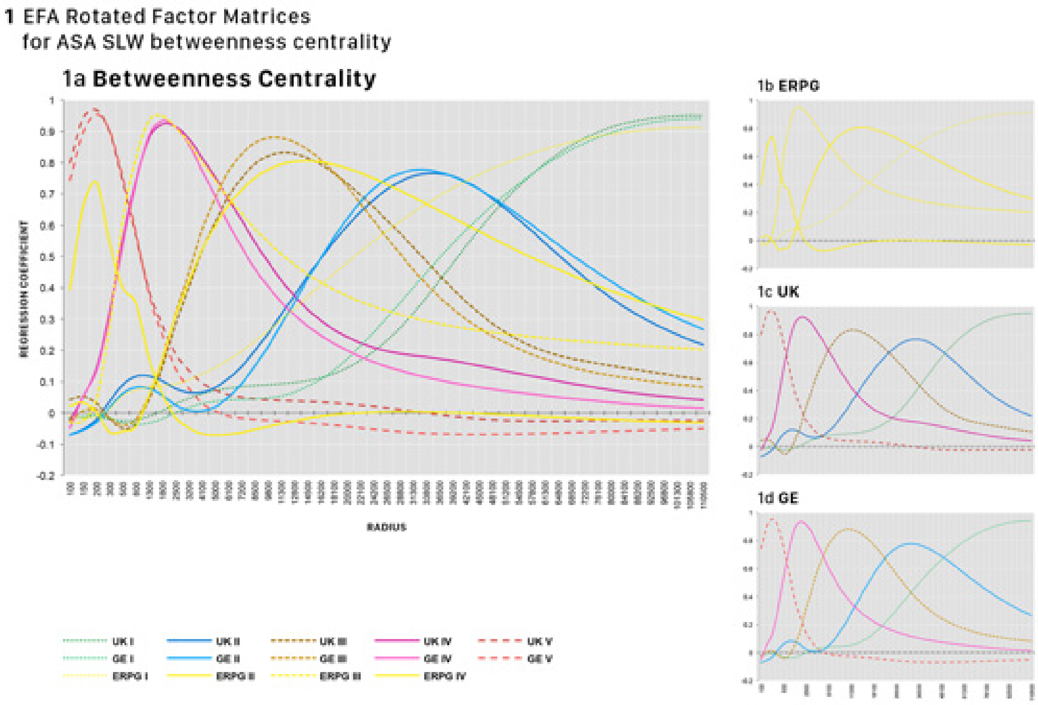

Figure 4: 1a: Explorative Factor Analysis rotated factor loadings for 49 metric distances of ASA SLW between centrality for three case studies: United Kingdom (UK), Germany (GE) and ERPG. Extraction method: Principle Axis Factoring. Rotation method: Equamax with Kaiser Normalisation. Rotation converged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

Both, the UK and GE model, show strikingly similar pattern in their factor loadings (Figure 4:1c & 1d). The EFA derived 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 do feature an additional factor and exhibit a clearer constitution 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. It has been argued that betweenness centrality gives insights into the location of economic activities (Hillier, 2009), giving one conjecture about the emergence of theses spatial scales. Walter Christaller's CPT (1933) pointed to a hierarchical relationship between different 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 taking place in a local neighbourhood, while specialised services such as the service of a lawyer would benefit being situated at centres of higher hierarchy, as they need to extend their market area in order to suffice the need of frequent customers. We can make the presumption that certain activities take place more often than others, so is the daily commute to a workplace inherent part of the majority of the population, while for example the activity of buying a new electrical goods less so. 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 in such a way that these repetitive everyday activities are more effectively distributed through the system, then they might be legible through spatial scales. Moreover, the spatial product of this process will have an impact on the possibility of future activities and subsequently influence the former. One could hence start to make assumptions of the nature of these extracted spatial scales.

If we compare those radii that the derived factors (spatial scales) predict the strongest, with those radii predicted by Christaller's CPT for different market areas (Table IV), it becomes possible that there is a relationship. The found factors form a strong similarity with the defined radii of Christaller's CPT. Three of the five derived factors exhibit estimate parameters on exactly those radii, that Christaller estimated for each of his central place hierarchies. An exception form very local centrality patterns (factor IV and V), this might be because smaller centrality pattern are stronger influenced by cultural process then they are by economic activity. Whereas three of Christaller's seven central place types can be explained through the derived factors, four remaining seem not to be expressed through 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 expressed enough to form independent spatial scales. If one follows this assumption it is worth considering the intersection area of each of the latent centralities as points of interest, these intersections are points that can load to either of the two factors. Table IV (light grey radii) include additional sub category of potential spatial scales between the found factors. Again we find rather strong similarities with the distances in Christaller's CPT and the derived factors.

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 give insights into the economic processes and human activity pattern that are behind their formation and that Christaller's theory can to a certain extend explain the spatialisation of the two European regions. Very little has been said so far to the actual spatial configurations that the different factors produce. Following the strategy proposed by Serra and Pinho (2013) one can visualise each factor through their respective loadings. Figure 5 illustrates such a loading plot for each factor for each of the three models, UK, GE and EPRG. The factors include loadings at different intensity for each segment and are hence able to illustrate a rich pattern. Here, only loadings above a standard deviation of 2.0 are highlighted in red (Figure 5). This way of visualisation will increase the distinctive difference between each factor and help interpretation of their morphologic nature. With view to Figure 5, the observed pattern that was observable in the rotated factor loadings is now mapped on the respective spatial network. Again, both regions UK and GE are showing very comparable pattern on all five factors. The ERPG model seems to be comparable to the factors II – V of the UK and GE models, however, it lacks a spatial pattern that is comparable to the first factor of the real world models. While the radii that can be 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 for scaling effects of optimisation processes embedded in human activity. A view on a zoomed in section will highlight how human shaped networks differ 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, gives 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 cluster of lines. The fact that each scale exhibits such linear networks is a strong indicator for an inherent optimisation processes. The ERPG on the other hand shows comparable line cluster, whereas their morphology differs significantly. Here the spatial scale pattern is more zigzag in nature (Figure 6:1c & 1f). This is because the network simply 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 presumed optimisation process seems hence to be legible 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. Moreover, the finding point to the constraints and problems a 'one city' theorisation produces. Without considering surrounding cities and their hinterland of any urban area, a full picture of its spatial morphology will not be possible. The third factor (Figure 6:1a & 1b) exemplify this strong intercity relationship. Each of the cluster in factor III comprise of several cities, it stays out of question that this pattern cannot be observed with a focus on one independent city only.

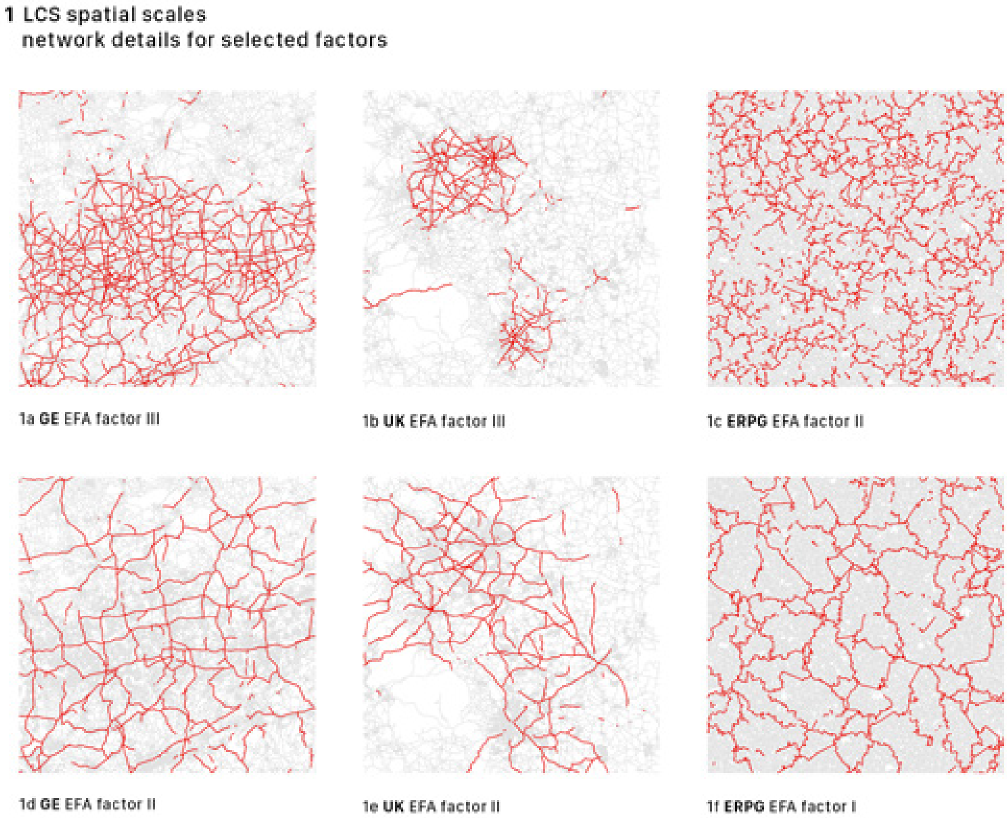

Figure 6 - Details of latent centrality structures, EFA factor loadings for two selected factors of the three models GE, UK and ERPG. Values above a standard deviation of 2.0 are highlighted in red.

What one should seek instead of employing the dichotomy of 'local' and 'global' is to unveil the inherent spatial scales hidden in each network by investigating a large array of different radii and extracting latent centrality structures. Differently to Christaller's CPT, what the findings cannot confirm is the hierarchical configuration he theorised. It seems that his core notion of the distribution of centres seems reasonable while the actual network this hierarchical distribution generates is of more complex nature than his (Figure 1:1d). The morphology of the found spatial scales point to a much more complex pattern and relationships between cities and their hinterland more recent theories have argued for (Sassen, 1991; Taylor, 2004). Polycentric urban regions are particularly characterised by this complex spatial relationships.

This poses challenges for urban policies trying to address change on local levels, because if these strategies do not comprehensively understand the spatial reality of cities as intrinsically linked to different spatial scales and their surrounding urban areas the outcomes might have a very different effect than set up in the aims. Although this research has started from the point of view of the region, it is believed that these findings have a strong informal character for any analytical investigation interested in understanding the city. However, further research is needed to compare the found spatial scales 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. Difficulties do also arise in the attempted application of space syntax concepts that are developed in the context of independent cities. Instead this study tried to link concepts of quantitative geography to overcome this difficulty through an initial sketch of the concept of spatial scales. The findings supported 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 pattern in polycentric urban regions and random planar graph networks. The analysis compared 49 different betweenness centralities pattern through an exploratory factor analysis and derived with 5 different factors. The morphology of real world and random networks share similarities in latent centrality structures, but are very different in their morphology. These 5 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 has pointed to an optimisation process that might underlie the formation 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 unveiled a complex intercity and interregional network that is shaped an reshaped over time. Further research is needed to investigate whether the found spatial scales have relevance in a socio-economic context and can hence be of use to inform regional policymaking.

REFERENCES

Abler, R., Adams, J. S. and Gould, P. (1971) *Spatial Organization: The Geographer's View of the World*. Englewood Cliffs: Prentice-Hall.

Barthélemy, M. (2011) 'Spatial networks', *Physics Reports*, 499(1–3), pp. 1–101. doi: 10.1016/j.physrep.2010.11.002.

Batten, D. F. (1995) 'Network Cities: Creative Urban Agglomerations for the 21st Century', *Urban Studies*, 32(2), pp. 313–327. doi: 10.1080/00420989550013103.

Camagni, R. and Salone, C. (1993) 'Network Urban Structures in Northern Italy: Elements for a Theoretical Framework', *Urban Studies*, 30(6), pp. 1053–1064. doi: 10.1080/00420989320080941.

Cermasi, O. and Psarra, S. (2013) 'Space Syntax , Landscape Urbanism And The Peri-Urban Condition : The case of Bologna and Modena in Italy', in Kim, Y. O., Park, H. T., and Seo, K. W. (eds) *Proceedings of the Ninth International Space Syntax Symposium*. Seoul: Sejong University, pp. 1–18.

Chen, G., Esch, G., Wonka, P., Müller, P. and Zhang, E. (2008) 'Interactive procedural street modeling', *ACM Transactions on Graphics*, 27(3), p. 1. doi: 10.1145/1360612.1360702.

Christaller, W. (1933) *Die zentralen Orte in Süddeutschland: Eine ökonomisch-geographische Untersuchung über die Gesetzmäßigkeit der Verbreitung und Entwicklung der Siedlungen mit städtischen Funktionen*. 1st edn. Jena.

Coffey, W. J. (1998) 'Urban Systems Research: Past, Present and Future | An Overview', *Canadian Journal of Regional Science*, 21(3), pp. 327–364.

Costello, A. B. and Osborne, J. W. (2005) 'Best Practise in Exploratory Factor Analysis: Four Recommendations for Getting the Most From Your Analysis', *Practical Assessment, Research & Evaluation*, 10(7), pp. 1–9. Available at: http://pareonline.net/getvn.asp?v=10&n=7.

Fabrigar, L. R. and Wegener, D. T. (2011) *Exploratory Factor Analysis*. Online. Oxford: Oxford University Press. doi: 10.1093/acprof:osobl/9780199734177.001.0001.

Figueiredo, L. and Amorim, L. (2007) 'Decoding The Urban Grid: Or Why Cities Are Neither Trees Nor Perfect Grids', in *6th International Space Syntax Symposium*. Istanbul, Turkey, p. 006:1-006:16. doi: 10.1017/CBO9781107415324.004.

Freeman, L. C. (1977) 'A Set of Measures of Centrality Based on Betweenness', *Sociometry*, pp. 35–41. doi: 10.2307/3033543.

Gerke, S., Schlatter, D., Steger, A. and Taraz, A. (2008) 'The Random Planar Graph Process', *Random Structures and Algorithms*, 32(2), pp. 236–261. doi: 10.1002/rsa.20186.

Gil, J. (2013) 'Analysing the configuration of integrated multi-modal urban network', *Geographical Analysis*, 46, pp. 368–391. doi: 10.1111/gean.12062.

Gil, J. (2015) 'Examining "Edge Effects": Sensitivity of Spatial Network Centrality Analysis to Boundary Conditions', in Kayvan, K., Vaughan, L., Sailer, K., Palaiologou, G., and Bolton, T. (eds) *Proceedings of the 10th International Space Syntax Symposium*. London: Space Syntax Laboratory, The Bartlett School of Architecture, University College London, p. 147:1-147:16.

Haggett, P. (1965) *Locational Analysis in Human Geography*. 1st edn. London: Edward Arnold (Publishers) Ltd.

Haggett, P. and Chorley, R. J. (1967) *Models in Geography*. London: Methuen.

Haggett, P. and Chorley, R. J. (1969) *Network Analysis in Geography*. 1st edn. London: Edward Arnold (Publishers) Ltd.

Hall, P. and Pain, K. (2006) *The Polycentric Metropolis: Learning from Mega-City Regions in Europe*. Edited by P. Hall and K. Pain. London: Earthscan.

Hanna, S. (2009) 'Spectral Comparison of Large Urban Graphs', in Koch, D., Marcus, L., and Steen, J. (eds) *Proceedings of the 7th International Space Syntax Symposium*. Stockholm: KTH Royal Institute of Technology, p. 039:1-039:11.

Hanna, S., Serras, J. and Varoudis, T. (2013) 'Measuring the structure of global transportation networks', in Kim, Y. O., Park, H.-T., and Seo, K. W. (eds) *Ninth International Space Syntax Symposium*. Seoul: Sejong University.

Harvey, D. (1969) *Explanation in Geography*. London: Edward Arnold.

Hillier, B. (2009) 'Spatial Sustainability in Cities: Organic Patterns and Sustainable Forms', in Koch, D., Marcus, L., and Steen, J. (eds) *Proceedings of the 7th International Space Syntax Symposium*. Stockholm, Sweden: Royal Institute of Technology (KTH), pp. 1–20. Available at: http://discovery.ucl.ac.uk/18538/ (Accessed: 7 June 2013).

Hillier, B. (2014) 'The Generic City and its Origins', *Architectural Design*, 84(5), pp. 100–105. doi: 10.1002/ad.1815.

Hillier, B. and Hanson, J. (1984) *The Social Logic of Space*. Cambridge: Cambridge University Press.

Hillier, B. and Iida, S. (2005) 'Network and psychological effects: a theory of urban movement', (1987), pp. 475–490.

Hillier, B., Leaman, A., Stansall, P. and Bedford, M. (1976) 'Space Syntax', *Environment and Planning Series B*, 3, pp. 147–185.

Hillier, B., Yang, T. and Turner, A. (2012) 'Normalising least angle choice in Depthmap and how it opens up new perspectives on the global and local analysis of city space', *The Journal of Space Syntax*, 3(2), pp. 155–199.

Karimi, K., Parham, E. and Acharya, A. (2015) 'Integrated sub-regional planning informed by weighted spatial network models : The case of Jeddah sub-regional system', in Karimi, K., Vaughan, L., Sailer, K., Palaiologou, G., and Bolton, T. (eds) *Proceedings of the 10th International Space Syntax Symposium*. London: Space Syntax Laboratory, The Bartlett School of Architecture, University College London, p. 71:1-71:16.

Kloosterman, R. and Lambregts, B. (2001) 'Clustering of Economic Activities in Polycentric Urban Regions: The Case of the Randstad', *Urban Studies*, 38(4), pp. 717–732. doi: 10.1080/00420980120035303.

Kloosterman, R. and Musterd, S. (2001) 'The Polycentric Urban Region: Towards a Research Agenda', *Urban Studies*, 38(4), pp. 623–633. doi: 10.1080/00420980120035259.

Krenz, K. (2015) 'Capturing Patterns of Shrinkage and Growth in Post-Industrial Regions: A Comparative Study of the Ruhr Valley and Leipzig-Halle', in Karimi, K., Vaughan, L., Sailer, K., Palaiologou, G., and Bolton, T. (eds) *Proceedings of the 10th International Space Syntax Symposium*. London: Space Syntax Laboratory, The Bartlett School of Architecture, University College London, p. 72:1-72:18.

Krenz, K. (2017) 'Employing Volunteered Geographic Information In Space Syntax Analysis', in *Proceedings of the 11th Space Syntax Symposium*. Lisbon, Portugal: Instituto Superior Técnico, University of Lisbon, p. 388:1-388:30.

Krenz, K., Kostourou, F., Psarra, S. and Capille, C. (2015) 'Understanding the City as a Whole: An Integrative Analysis of Rio de Janeiro and its Informal Settlements', ISUF 2015 *XXII international Conference: City as organism. New visions for urban life*, pp. 647–660.

Lam, N. S.-N. and Quattrochi, D. A. (1992) 'On the Issues of Scale, Resolution, and Fractal Analysis in the Mapping Sciences', *Professional Geographer*, 44(1), pp. 88–98.

Law, S. and Versluis, L. (2015) 'How do UK regional commuting flows relate to spatial configuration ?', in Karimi, K., Vaughan, L., Sailer, K., Palaiologou, G., and Bolton, T. (eds) *Proceedings of the 10th International Space Syntax Symposium*. London: Space Syntax Laboratory, The Bartlett School of Architecture, University College London, p. 74:1-74:21.

Lösch, A. (1940) *Die räumliche Ordnung der Wirtschaft. Eine Untersuchung über Standort, Wirtschaftsgebiete und internationalem Handel*. Jena: Fischer. doi: 10.2307/2573862.

Marshall, S. and Sutton, M. (2013) 'Explorations in Generative Street Layouts', in Carmona, M. (ed.) *Explorations in Urban Design: An Urban Design Research Primer*. Farnham: Ashgate, pp. 181–192.

Marston, S. A. (2000) 'The social construction of scale', *Progress in Human Geography*, 24(2), pp. 219–242. doi: 10.1191/030913200674086272.

Marston, S. A., Jones, J. P. and Woodward, K. (2005) 'Human geography without scale', *Transactions of the Institute of British Geographers*, 30(4), pp. 416–432. doi: 10.1111/j.1475-5661.2005.00180.x.

Masucci, A. P., Smith, D., Crooks, A. and Batty, M. (2009) 'Random planar graphs and the London street network', *European Physical Journal B*, 71(2), pp. 259–271. doi: 10.1140/epjb/e2009-00290-4.

Meentemeyer, V. (1989) 'Geographical perspectives of space , time , and scale', 3, pp. 163–173.

Mohamed, A. A., van Nes, A., A.Salheen, M., Kohlert, C. and Schwander, C. (2013) 'The Socio-Economic Implications of the Spatial Configuration in Greater Cairo Metropolitan Area', in *Proceedings of the Ninth International Space Syntax Symposium*. Seoul: Sejong University, p. 095.1-095.18.

Morrill, R. L. (1970) *The Spatial Organization of Society*. Belmont, California: Duxbury Press.

van Nes, A. (2009) 'Analysing Larger Metropolitan Areas. On Identification Criteria for Middle Scale Networks', in Koch, D., Marcus, L., and Steen, J. (eds) *Proceedings of the Seventh International Space Syntax Symposium International Space Syntax Symposium*. Stockhilm: KTH Royal Institute of Technology, p. 121.1-13.

Van Nes, A. (2007) 'Centrality and Economic Development in the Rijnland Region: social and spatial concepts of centrality', in *Proceedings of the Sixth International Space Syntax Symposium 6th International Space Syntax Symposium*. Istanbul, Turkey, p. 015.1-16.

Parish, Y. I. H. and Müller, P. (2001) 'Procedural Modeling of Cities', in *28th Annual Conference on Computer Graphics and Interactive Techniques*, pp. 301–308. doi: 10.1145/383259.383292.

Peponis, J., Allen, D., Haynie, D., Scoppa, M. and Zhang, Z. (2007) 'Measuring The Configuration Of Street Networks', in *Proceedings of the Sixth International Space Syntax Symposium*. Istanbul, Turkey, p. 002:1–002:16.

Psarra, S., Kickert, C. and Pluviano, A. (2013) 'Paradigm lost: Industrial and post-industrial Detroit – An analysis of the street network and its social and economic dimensions from 1796 to the present', *URBAN DESIGN International*. Nature Publishing Group, pp. 1–25. doi: 10.1057/udi.2013.4.

Quattrochi, D. A. and Goodchild, M. F. (eds) (1997) *Scale in Remote Sensing and GIS*. Boca Raton,: Lewis Publishers.

Read, S. (2013) 'Intensive urbanisation: Levels, networks and central places', *The Journal of Space Syntax*, 4(1), pp. 1–17.

Salheen, M. and Forsyth, L. (2001) 'Addressing distance in the space syntax syntactical model', pp. 93–110.

Sassen, S. (1991) 'The Global City: New York, London, Tokyo', in. Princeton, New Jersey: Princeton University Press, p. 480.

Scott, A. J. (ed.) (2002) *Global City-Regions: Trends, Theory, Policy*. Oxford: Oxford University Press.

Serra, M., Hillier, B. and Karimi, K. (2015) 'Exploring countrywide spatial systems: Spatio-structural correlates at the regional and national scales', in Karimi, K., Vaughan, L., Sailer, K., Palaiologou, G., and Bolton, T. (eds) *Proceedings of the 10th International Space Syntax Symposium*. London: Space Syntax Laboratory, The Bartlett School of Architecture, University College London, p. 84.1-84.18.

Serra, M. and Pinho, P. (2013) 'Tackling the structure of very large spatial systems - Space syntax and the analysis of metropolitan form', *Journal of Space Syntax*, 4(2), pp. 179–196.

Sun, J., Yu, X., Baciu, G. and Green, M. (2002) 'Template-based generation of road networks for virtual city modeling', in Proceedings of the *ACM symposium on Virtual reality software and technology - VRST '02*. New York, New York, USA: ACM Press, p. 33. doi: 10.1145/585740.585747.

Swyngedouw, E. (2004) 'Scaled Geographies: Nature, Place, and the Politics of Scale', in Sheppard, E., Mcmaster, R. B., and Swyngedouw, E. (eds) *Scale and Geographic Inquiry: Nature, Society, and Method*. Blackwell Publishing Ltd, pp. 129–153. doi: http://dx.doi.org/10.1002/9780470999141.ch7.

Taylor, P. J. (2004) *World City Networks, A Global Urban Analysis*. New York: Routledge.

Team, R. C. (2016) 'R: A language and environment for statistical computing.' Vienna, Austria: R Foundation for Statistical Computing. Available at: http://www.r-project.org/.

von Thünen, J. H. (1826) *Der isolierte Staat in Beziehung auf Landwirtschaft und Nationalökonomie*. 1st edn. Stuttgart.

Trippl, M., Maier, G. and Tödtling, F. (2012) *Regional- und Stadtökonomik 2: Regionalentwicklung und Regionalpolitik*. Springer-Verlag.

Turner, A. (2001) 'Angular Analysis', in *Proceedings of the Third International Space Syntax Symposium*. Atlanta, p. 30.1-30.11. Available at: http://discovery.ucl.ac.uk/35952/.

Turner, A. (2005) 'Could A Road-centre Line Be An Axial Line In Disguise?', *Proceedings 5th International Space Syntax Symposium*, pp. 145–159.

Turner, A. (2007) 'From axial to road-centre lines: a new representation for space syntax and a new model of route choice for transport network analysis', *Environment and Planning B: Planning and Design*, 34(3), pp. 539–555. doi: 10.1068/b32067.

Turner, A. (2009) 'Stitching Together the Fabric of Space and Society: An Investigation into the Linkage of the Local to Regional Continuum', in Daniel, K., Marcus, L., and Steen, J. (eds) *Proceedings of the Seventh International Space Syntax Symposium*. Stockholm: KTH Royal Institute of Technology, pp. 1–12. Available at: http://eprints.ucl.ac.uk/16184/ (Accessed: 24 June 2013).

Ugalde, C. M. de, Fujita, C., Bauermann, C. N. and Jobim, G. M. F. (2015) 'Identifying city-regional structures in Rio Grande do Sul, Brazil', in Karimi, K., Vaughan, L., Sailer, K., Palaiologou, G., and Bolton, T. (eds) *Proceedings of the 10th International Space Syntax Symposium*. London: Space Syntax Laboratory, The Bartlett School of Architecture, University College London, p. 86:1-86:14.

Watson, M. K. (1978) 'The Scale Problem in Human Geography', *Grafiska Annaler*, 60B(1), pp. 36–47.

Widaman, K. (2007) 'Common Factors Versus Components: Principals and Principles, Errors and Misconceptions', in Cudeck, R. and MacCallum, R. C. (eds) *Factor Analysis at 100: Historical Developments and Future Directions*. Mahwah, New Jersey: Lawrence Erlbaum Associates, Publishers, pp. 177–204. 1. Appedndix

6. APPEDNDIX

1 ASA Closeness Centrality Outlier Detection

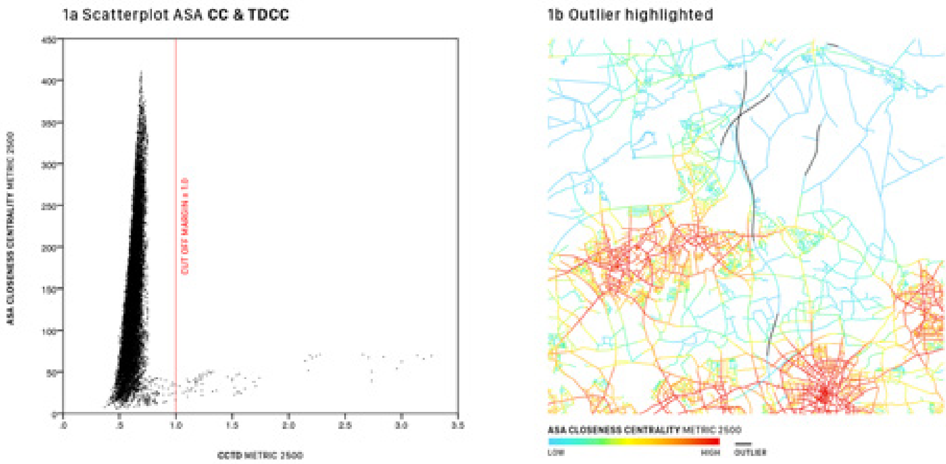

Figure 1: 1a Scatterplot of ASA Closeness Centrality and CCTD radius metric 2500, highlighted in red the cut off margin ≥ 1.0. 1b Detail section of a ASA Closeness Centrality metric 2500 with outliers highlighted in black.

In this paper we have applied angular segment analysis on closeness centrality in a regional context. There is one problem arising from such an application. There are some few cases of high values cluster in areas of low urbanisation where lower values would have been expected. This is particularly the case on small radii (100 – 2500m), but measureable up to a radius of 5km in the investigated cases. One can compare this effect to a similar problem that Hillier et al. (2012, p. 191) were facing when introducing 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 and dead ends are very common for rural or less-urbanised areas. Highway systems also exhibit this effect. Because partial urbanised areas and rural structures are very common in large cities and in intrinsic part of regions, it is necessary to detect such outlier. While the majority of outlier cases can be identified by visual comparison. Some cases are outlier in lower value ranges and are difficult to identify as such visually. These exceptional cases can only be identified through a comparison with values of their immediate surrounding segments and make it difficult to clean the data manually. However, all segments with unexpected high value share a common characteristic, namely very low total depth (TD) values in relation to the value of closeness centrality (CC). This allows an objective reproducible method to identify outliers, even in cases where a visual comparison of the data would have not allowed detection. This relation between TD and CC allows us to equation a straightforward way to detect outlier in ASA closeness centrality values. By adding the constant of 3 to CC and TD and subsequent dividing the logarithm of CC by the logarithm of TD of the respective radius, one arrives with a new set of values.

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

In the case that the new value is equal or above 1 the segment can be considered as 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 as outliers, whereas the distance to the left indicates the amplitude of the outlier effect.