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QUANTITATIVE COMPARISON OF CITIES:

Distribution of street and building types based on density and centrality measures

META BERGHAUSER PONT
Chalmers University of Technology, Department of Architecture
meta.berghauserpont@chalmers.se

GIANNA STAVROULAKI
Chalmers University of Technology, Department of Architecture
gianna.stavroulaki@chalmers.se

JORGE GIL
Chalmers University of Technology, Department of Architecture
jorge.gil@chalmers.se

LARS MARCUS
Chalmers University of Technology, Department of Architecture
lars.marcus@chalmers.se

MIGUEL SERRA
University of Porto, Faculty of Engineering, Porto, Portugal
mserra@fe.up.pt

BIRGIT HAUSLEITNER
Delft University of Technology, Faculty of Architecture, Delft, The Netherlands
b.hausleitner@tudelft.nl

JESPER OLSSON
Chalmers University of Technology, Department of Architecture
gusjespol@student.gu.se

EHSAN ABSHIRINI
Chalmers University of Technology, Department of Architecture
ehsanab@chalmers.se

ASHLEY DHANANI
UCL, The Bartlett School of Archicture, Faculty of the Built Environment, London, UK
ashley.dhanani@ucl.ac.uk

ABSTRACT

It has been argued that different urban configurations - planned vs. organic, treelike vs. grid like - perform differently when it comes to the intensity and distribution of pedestrian flows, built density and land uses. However, definitions of urban configurations are often rather abstract, ill-defined and at worse end in fixed stereotypes hiding underlying spatial complexity. Recent publications define morphological typologies based on quantitative variables (e.g. Barthelemy,

2015; Serra, 2013a; Gil et al., 2012; Berghauser Pont and Haupt, 2010) and solve some of these shortcomings. These approaches contribute to the discussion of types in two ways: firstly, they allow for the definition of types based on multiple variables in a precise and repeattable manner, enabling the study of large samples and the comparison between both cities and regions; secondly, they frame design choices in terms of types without being fixed and so open up for design explorations where the relation between the variables can be challenged to propose new types.

This paper explores the typologies defined by Serra (2013a) and Berghauser Pont and Haupt (2010) further, as these target two of the most important morphological entities of urban form, namely the street network and the building structure. The purpose is to gain a better understanding of how types are composed and distributed within and across different cities.

The method is based on GIS and statistical modeling of four cities to allow for a comparative analysis of four cities: Amsterdam, London, Stockholm and Gothenburg. For the street network, we process the Road-Centre-line maps to obtain a clean network model, then run segment angular analysis to calculate the space syntax measures of betweenness at different metric radii, defining the "centrality palimpsest" (Serra, 2013a). For the building structure, we process elevation data to obtain building height, then run accessible density analysis for all building density metrics (FSI, GSI, OSR, L) using the Place Syntax Tool (Berghauser Pont and Marcus, 2014). The street and building types are defined using cluster analysis (unsupervised classification), following a similar approach to Serra (2013a).

The result is a typology of street (´paths´) and building types (´places´), with different profiles of centrality and density across scales. The spatial distribution and frequency of these types across the four cities gives an objective summary of their spatial structure, identifying common as well as unique traits.

KEYWORDS

Typologies, unsupervised classification, city comparison, space syntax, density

1. INTRODUCTION

1.1 GENERAL BACKGROUND AND AIM

The world is currently facing an unprecedented global urbanization, where there will be three billion more people living in cities within the next 25 years. This will set the frame for the future development of our societies and presents unprecedented expectations on the future governance, planning and design of cities and on urban morphology as an essential knowledge base for urban design. In response to this, the objective of an international project under the name SMoL,[1] is to develop and test consistent and sound methodologies and techniques for measuring and comparing central variables of spatial urban form, focusing on the main elements; the street, the plot and the building (Whitehand, 2001; Kropf, 2011) as well as the interplay between them (Marcus et al., 2017). Describing and understanding how these spatial elements influence movement in cities, as the central driver of urban dynamics, will help us better grasp how such flows in turn underpin and structure broader urban processes of a social, economic and environmental kind.

Despite the long tradition of studies in urban morphology, spatial analysis and urban modelling, there is still need to better identify how such research may inform the practice of urban planning and design and from that, build a more consistent theoretical and methodological framework for research, with direct bearings for the professions. We see the direction of typo-morphology as a way forward, as they allow for the definition of types based on multiple variables in a precise

1 Spatial Morphology Lab (SMoL) is a three year project financed by Chalmers foundation, led by Lars Marcus and Meta Berghauser Pont.

and repeattable manner, enabling the study of large samples and the comparison between both cities and regions. What we aim for is to include streets, buildings and plots and the related measures of distance, density and diversity in a taxonomy [2] of cities, where elements in the same group (i.e. cluster, type) are more similar to each other than to those in other groups. This enables us to not only describe traditional urban form as found in historical cores and their immediate vicinities, or what Serra (2013a) calls the city with 'good form', but also the city 'without form', containing late 20th century and contemporary urbanization. This, in turn, enables urban design practitioners to frame design choices in terms of such multi-variable types instead of current, often ill-defined types, at worst stereotypes, hiding underlying spatial complexity (ibid.).

This paper explores street types, following the work of Serra (2013a), with the purpose to, firstly, gain a better understanding of how street types are composed and distributed not only within a city as in Serra (ibid), but also across different cities. Four cities are included in this comparative research: London, Amsterdam, Stockholm and Gothenburg[3]. Secondly, we explore how these street types relate to the distribution of density types, building further on the work of Berghauser Pont and Haupt (2010).

1.2 TYPOLOGIES

Typologies play a role in urban studies since a long time. The classic studies of urban morphology (e.g. Caniggia and Maffei, 2001; Conzen, 1960, Whitehand, 2001; Panerai et al., 1977, Panerai et al., 1999) described either types of singular urban elements with a rather high detail (e.g. types of streets, urban blocks, parcels, buildings) or aimed for a description of complete systems. Traditional typologies focussing on separate elements allow for the understanding of differences of one spatial feature, but lack the interrelation between the elements and between scales. The understanding of the whole system on the other hand requires a reduction of the urban environments to the main elements of the whole urban system on the larger scale and therefore lacks precision.

Further, classic studies focused mainly on qualitative methods, where in recent years this has shifted towards more quantitative methods. Martin and March described already in 1972 the necessity to quantify in order to achieve a higher precision in the understanding of urban form in their seminal book "Urban Space and Structures". They elaborated that a quantitative approach towards urban form and structure became relevant with the aim for understanding entire spatial systems and specifically the relation between its elements or as Steadman described it: "understanding relationships and setting out ranges of choice." (Steadman, 2016, p. 296). They explained further that quantification is an important step towards a comparative assessment of urban environments, which represents one of the main purposes of a typology.

Only recently, studies of urban morphology have (again) been aiming for classifications or typologies based on quantitative description of spatial elements. Berghauser Pont and Haupt (2010) developed a multi-variable approach towards built density and Barthelemy (2015) identifies classes of street patterns applying a multi-variable approach, using urban block shape and area. Although Berghauser Pont and Haupt as well as Barthelemy elaborate their typologies in a multi-variable approach, they focus in their description on features each belonging to a specific scale. The research of Serra (2013a; 2013b; Serra et al., 2016) on the other hand, approaches the understanding of the metropolitan structure in a multi-variable, but also multi-scalar way. Gil et al. (2012) use similar methods with the aim to compare two neighbourhoods in a multi-variable and multi-scalar approach. The integration of street and urban block typologies with different detail is leading to a more precise description of the neighbourhoods. In this paper we will draw from these experiences and compare whole cities.

2 We should here make a distinction between typology and taxonomy. The former is primarily conceptual, the latter empirical (Bailey, 1994) using statistical analysis to find similarities in the data (cluster analysis). We will combine the two following what Bailey (1990) called "the operational or indicator level". For the sake of simplicity we will, however, use typology in the paper where one also could read taxonomy.

3 A fifth city in Sweden will be added to be able to compare three Swedish cities with similar growth patterns but of different size, besides the comparison of three main cities in Europe.

Gil et al. (2012) as well as Hausleitner and Berghauser Pont (2017) use similar methods with the aim to compare neighbourhoods respective whole urban systems in a multi-variable and multi-scalar approach.

1.3 STUDY AREA

Three main cities in Europe are selected for comparison in this study because they, on one hand, carry certain socio-economic and historical similarities, while on the other hand, vary in their regional structure; Stockholm as the planned finger-city where green and blue wedges cut deep into the city centre, London as the organic growing concentric conurbation and Amsterdam as part of the poly-central conurbation Randstad. A fourth city was added, that is Gothenburg, to see whether another Swedish city will show more similarities with its 'bigger brother' Stockholm than with the other two European cities. The study areas aim to include the whole urbanized part of the cities or, in other words, their metropolitan areas, which span out of their mere municipal borders. For this reason, we used the Urban Morphological Zone (UMZ) boundaries, as they are defined by the European Environment Agency (EEA) and the Eurostat for all European cities.[4]

However, because of the highly irregular boundaries of the UMZs which could become problematic to the syntactical analysis of the networks, what was instead used as the boundary of each study area, was the convex hull of each UMZ. Finally, to address the possible 'boundary effect' to the calculation results, the area which was analysed was at least 25km larger than the study area in all directions.

2. METHOD

The central methods used in this paper can be divided into methods for editing the main datasets to arrive at the network and density model, spatial analysis and statistical analysis which will be discussed in the sections below. The sequence of the methods and how they relate to one each is explained in Table 1 below.

Task	Data Sources	Steps	Description
1. Street network types	Road centre line	1. Edit map	Remove errors, duplicates, isolated lines
			Snap endpoints
			Generalisation
		2. Spatial analysis	Angular betweenness centrality
			(radius 500 – 30000m)
		3. Statistical analysis	Standardize results
			PCA analysis
			Cluster analysis
2. Built density types	Laser data	1. Edit map	Create Digital Height Model (DHM)
			Calculate average building height
			Correct errors

4 Urban morphological zones (UMZ) are defined by Corine land cover classes considered to contribute to the urban tissue and function. A UMZ can be defined as "a set of urban areas laying less than 200m apart" (source: http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2006 (download date 13-7-2016)

	Building footprints	2. Spatial analysis	Floor Space Index
			Ground Space Index (radius 500 m)
		3. Statistical analysis	Standardize results
			Cluster analysis
3. Comparative analysis of street and density types			

Table 1 - Summary of the methodology

2.1 NETWORK MODEL

The street network models are based on the national road database of each country; the NVDB (Nationell Vägdatabas) for Sweden, the NWB (Nationaal Wegenbestand) for the Netherlands and the OS MasterMap ITN (Integrated Transport Network) for the UK.[5] In all cases the source maps show sufficient detail and coverage of the road network, but also the same basic representational principles. All roads are represented with one line irrespectively of the number of lanes, except from Motorways and Highways which are represented with two lines, one for each direction, again irrespectively of the number of lanes.

We processed the original Road-Centre-line maps with two objectives; first to create line segment maps on which we could apply Angular Segment Analysis and second to create comparable representations of the street network, both in the types of roads included and in the level of detail. For the purposes of this analysis we used the motorized network of each area.

The processing of the original Road-Centre-line maps involved sorting and editing procedures, where the same rules were applied to all cities. First, we sorted out roads where cars are not allowed access (e.g. pedestrian streets, alleys, paths, bicycle lanes); second , we followed the same editing and generalizing procedure for all maps aiming to remove errors, but most importantly to optimize representation and reduce calculation time by reducing the number of line-segments and finally, to increase comparability between networks. This process, before the final segmentation of the Road-Centre-lines to line-segments, included removing duplicate and isolated lines, snapping and generalizing[6] .

To obtain a detailed multi-scale centrality description of the four metropolitan regions we carried out network centrality analysis of the street network models, calculating angular betweenness centrality (i.e. choice) with different metric radii, from 500m to 30km. To provide a uniform and continuous sampling of centrality the radius are equally spaced and have a small interval (i.e. 500m) in smaller distances up to 10km, where one observes greater variation in centrality values, and a larger interval (i.e. 5km) above 10km up to 30km. This results in a series of 24 radii per street segment. [7]

5 The Road-Centre-line maps used, come from the official road authorities; Trafikverket for Sweden, Ordnance Survey for the UK and Rijkswaterstaat-CIV for the Netherlands. The downloads were done from May to October of 2016. The NVDB is open access and was downloaded from the Trafikverket website (https://lastkajen.trafikverket.se, date of download 15-5-2016, last update 8-11-2015). The NWB is also open access and was downloaded from the Rijkswaterstaat website (http://www.rijkswaterstaat.nl/apps/geoservices/geodata/dmc/nwb-wegen/geogegevens/shapefile/Nederland_totaal/, download date 12-10-2016, last update 6-12-2016. The ITN was delivered upon request from the Ordnance Survey (https://www.ordnancesurvey.co.uk, download date 29-11-2016, last update 3-10-2016).

6 The snapping threshold used was 2m (end points closer than 2m were snapped together). The generalizing threshold used was 1m (successive line segments with angular deviation less that 1m were merged into one).

7 The software used for processing the original Road-Centre-line maps were FME Desktop 2016, Mapinfo Pro 15.0 and PST (Place Syntax Tool , plugin for Mapinfo Pro 15.0). The software used for analysing the processed line-segment maps was PST.

2.2 DENSITY MODEL

The density model is based on laser dataset [8], including coordination and elevation values for each point collected from LIDAR (Light Detection and Ranging). A Digital elevation model (DEM) and Digital surface model (DSM) was extracted from the laser dataset with an average resolution of 2m. Then, DEM was subtracted from DSM to make a new surface model called Digital height model (DHM) which contains the real height values of the features on the ground. Finally, building footprints were added and the average height value of the area covered by each footprint was considered as the height of each building.[9] Buildings with no or incorrect heights (too high, too low, zero or negative values) were corrected using google street view or similar online services. In cases where it was impossible to find the building height using above-mentioned methods, we used a buffer around each building separately and considered the average height value of the surrounding buildings as the height of the building(s) in question. [10]

To obtain a density description of the four metropolitan regions we carried out an accessible density analysis using two variables: Floor Space Index (FSI) and Ground Space Index (GSI). The radius used is 500m which has proven to be the most accurate distance to capture building types as is discussed extensively in Berghauser Pont and Marcus (2014). Firstly, the average height of the buildings derived from the height model was multiplied with the built up area to calculate the built volume to then divide by 3m to arrive at an estimation of gross floor area (GFA). Secondly, the denominator B of the simple fraction of density A/B is arrived at by calculating the area of the convex hull using the end points of the street segments that are reached through the network within a radius of 500m using PST. The numerator A is the total GFA, respectively total built up area, within the same radius of 500m.

2.3 STATISTICAL ANALYSIS OF STREET CENTRALITY

To be able to describe and compare the metropolitan regions based on multi-dimensional centrality results, we perform two main statistical analyses in R software: Principal Component Analysis (PCA) as a means of dimensionality reduction and of extracting the most representative centrality scales of each region; and k-medoids clustering to classify the street segments based on their individual centrality profile, obtaining a centrality typology of streets.

For the statistical analysis of the results we only consider the segments contained in the study area and ignore all others to avoid using values affected by edge effect. Furthermore, we only consider the values of segments that are part of the main component of the graph, ignoring values of smaller "islands" [11]. As a first step, all centrality measures are converted to z-scores to be able to compare and combine them irrespective of the value ranges.

Next we run PCA on the betweenness centrality results separately for each city following the method proposed by Serra (2013a; 2013b). With the PCA results we make a scree plot to identify the number of components that explains most of the variation in the data. To choose the number of components to be extracted, one should look for an elbow in the plot's curve or consider components with an eigenvalue close to 1 or greater. We then rotate the selected number of principal components (using the VARIMAX rotation method), so that the correlation of each component with each of the original variables is either maximized or minimized. This operation makes the existing associations between the principal components and the original variables clearer. After this step one can explore what each rotated component represents in terms of centrality, plotting their loadings (i.e. the correlations between each component and the original variables) in the y-axis and the radius in the x-axis. Each component corresponds to a specific range in the metropolitan centrality continuum of scales. How the components'

8 Lantmäteriet (https://www.lantmateriet.se/)

9 It should be noted that building heights of Amsterdam and London were received in ready-to–use formats: 3dBAG from ESRI (http://www.esri.nl/) and Ordnance Survey (https://www.ordnancesurvey.co.uk/) respectively. Further, it should be noted that for London, the dataset for building height was smaller than the study area based on the UMZ. This will be corrected, but the data was not available for this paper.

10 The buffer distance chosen varied according to the average density of buildings in that area.

11 Islands are small isolated groups of street segments that are not connected to the main street network.

loadings of each city differ or, on the contrary, resemble each other, is an interesting object of comparison and discussion on their urban configuration.

These principal components are also an appropriate input to the next step of unsupervised classification with clustering. The orthogonality between components ensures that the variables used for clustering have the lowest possible correlation, which is desirable because co-linearity is known to bias clustering results. We use the k-medoids clustering algorithm (also known as Partitioning Around Medoids, PAM) similar to k-means, which uses a case as the centre of every cluster instead of the cluster mean, making it more robust to the presence of outliers. The k indicates that the algorithm can identify any number of clusters but this number (k) must be defined a priori. For this purpose one has to calculate the algorithm for a range of k values, for example between 2 and 25, and make the scree plot. The identification of an elbow in the plot is again an indication of a suitable number of clusters.

The clustering analysis is performed on the data of the four cities combined using the results of the PCA[12] . From this data we have excluded all the cases where the betweenness value is 0 in every analysis radius, which indicates dead ends and already represents a uniquely identifiable class of paths. Once the cluster solutions are calculated we create a series of boxplots of the centrality profile of every cluster, plotting along the y-axis the cluster's betweenness values (z-score) and along the x-axis the metric radii. The final stage in defining a typology of street centrality involves the comparison of the centrality profiles of the cluster solutions and choosing one that contains a small set of clearly distinctive profiles.

2.4 STATISTICAL ANALYSIS OF DENSITY

The clustering analysis of the density model is similar to the described method above, but does not need the PCA as only one radius is used (i.e. 500m). Fuzzy c-means clustering is used in Matlab, which allows each data point to belong to two or more clusters with varying degree of membership. This is done on the basis of the distance between each data point and each cluster centre, comparable to the clustering method k-medoids clustering described in the former section. As mentioned, the number of clusters (k) has to be chosen by the user, a priori. In the case of density, we know that each cluster corresponds to a building type described by GSI and FSI following Berghauser Pont and Haupt (2010) and choosing a number of clusters comes down to estimating the number of building types. Further, since we also have an idea about where a specific building type is located on the GSI/FSI graph we can estimate its centre (ibid, p.191). The building type centres are therefore used as set starting points for the clusters. From this data we have excluded all the cases where the GSI value is 0, which indicates areas without buildings and already represents a uniquely identifiable class.

The iteration process then uses the cluster centres to update the membership grades and calculates the sum of the distance between every data point and every cluster centre with the membership grades as weights. The closer a data point is to a centre of a cluster the larger membership grade it is assigned to the cluster. The iteration stops when the change in sum of the distance from one iteration to the next is less than ε or when n iterations has been done, where *ε* and *n* are set in advance. The output is the membership grades of all data points to all clusters when the sum of the distance between each data point and each cluster centre is minimized.

3. RESULTS

The street network and buildings models of the four study areas (Amsterdam, Gothenburg, London and Stockholm) have been analysed and the betweenness centrality and density results were processed statistically, following the methods described in the previous section, producing one set of network centrality types (´paths´) and one set of building density types (´places´). These results and the relation between the two sets are described next.

12 Due to the size of the data set, we used a faster version of the PAM algorithm, called CLARA (Kaufman and Rousseeuw, 1990), which runs on samples of the entire data set.

3.1 CENTRALITY TYPES

The first step of the statistical analysis (PCA) reduced the 24 radii of betweenness centrality results to three rotated components that meet the two scree plot test conditions, and explain 94% to 97% of the total variance of the original variables. The charts in Figure 1 represent the loadings of the three components and show the radii dominating each one. The components correspond to the natural scales of the four cities' betweenness centrality structure, namely: the city scale, the *neighbourhood* scale and the *metropolitan* scale. This is in line with the findings of previous work by Serra (2013a; 2013b), albeit then only within the context of a single metropolitan region (Porto's, Portugal). The dashed line marks the transition between scales and reveals a small difference between cities: in Gothenburg and Stockholm the neighbourhood scale is up to 2500m while in Amsterdam and London it is up to 3000m; in most cities the city scale stops at 10km, except in Amsterdam where it extends up to 12km.

This division of the extended centrality structure of the four cities into just three dominant centrality partitions is, in itself, quite remarkable. It corroborates the findings of (Serra 2013a; 2013b), suggesting that such basic, triple structure of cities, might in fact be general. With hindsight, one could say that the centrality continuum of large urban areas would naturally

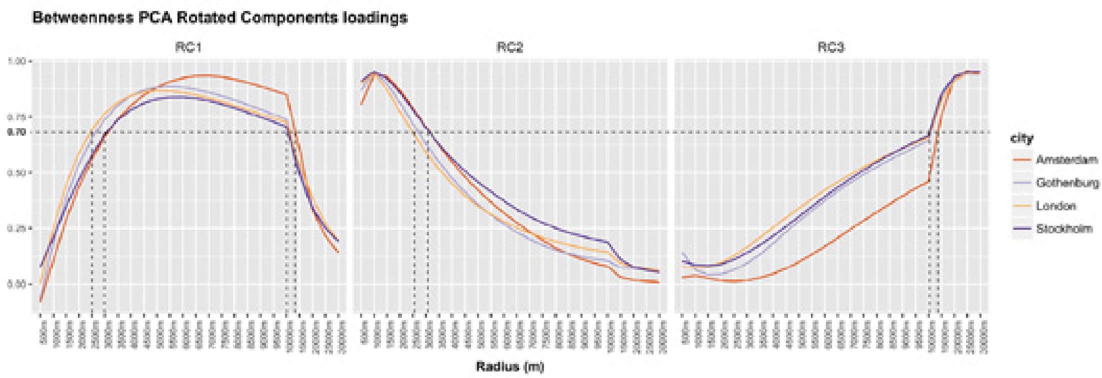

Figure 1 - Charts showing the loadings of each rotated component for every betweenness centrality radius.

be divided in this way: into neighbourhood-scaled, city-scaled and regional-scaled structures. However, these results provide solid evidence that this is indeed so, moreover in a rather regular way. They show that, underneath the visible morphologic variability of the four studied cities, their spatial structures (as described by betweenness centrality) are characterized by only three basic centrality regimes and, therefore, by only three basic spatio-functional scopes.

These dominant scales are the variables used to identify the centrality types of the street segments of the four cities, and results in a typology of five 'path' types that have different roles and constitute different structures. Four types are the result of the clustering analysis and their profiles are presented in the boxplots of Figure 2. These types include: 'pulp' (cluster 1) representing the mass (60 – 70%) of street segments that do not play a significant role in the urban structure at any scale, and correspond what has been previously termed as 'background network' in space syntax literature; 'metropolitan' (cluster 2) with the segments of increasing betweenness at higher scales; 'neighbourhood' (cluster 3) with segments that have a high betweenness at lower scales but become irrelevant at the large scales; and 'city' (cluster 4) with segments that have a consistently high betweenness at most scales, but dropping clearly at the most local and regional scales. The fifth type has a betweenness value of zero at all scales, representing the dead ends as a clearly distinct type.

The spatial distribution of these 'path' types (Figures 3 and 4) reveals their individual identity and demonstrates their role in the four cities. But it also shows some differences in the way the four cities are structured at these different scales. Amsterdam presents a very homogeneous core

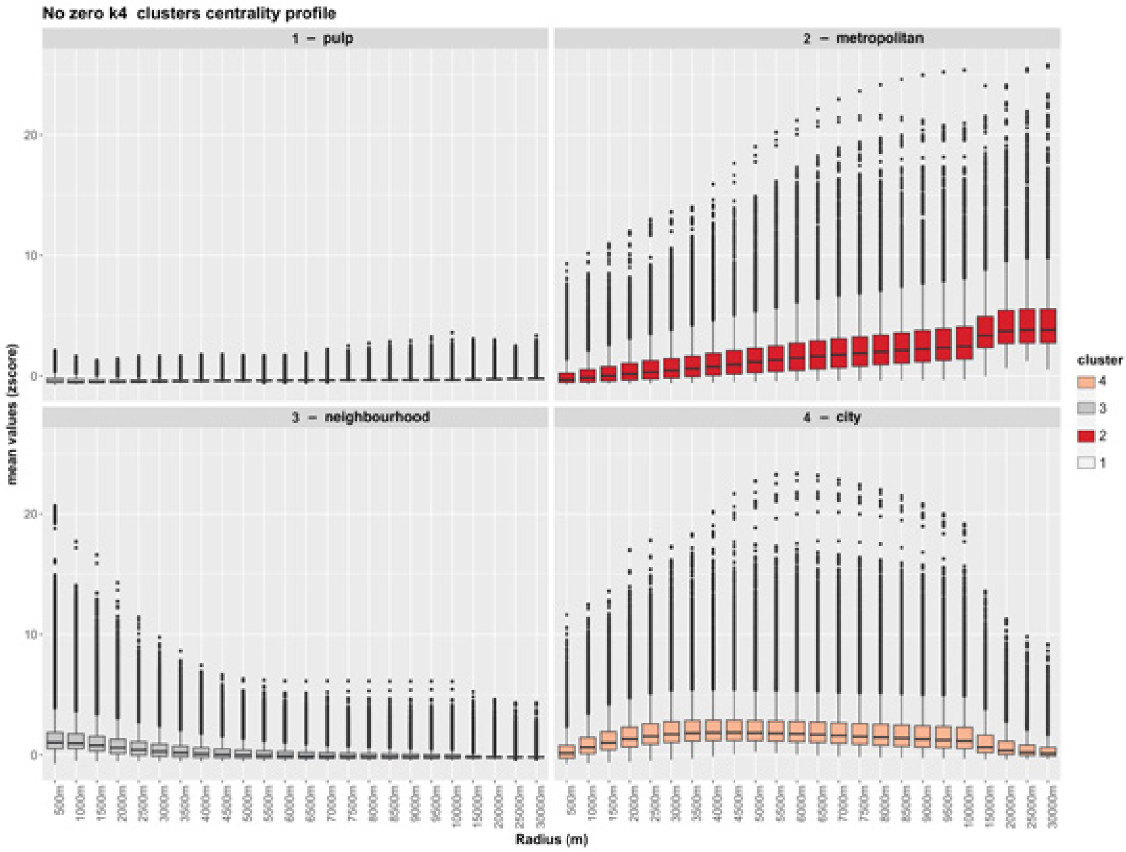

Figure 2 - Boxplots showing the distribution of betweenness centrality values in each cluster for every radius distance.

structured by a city scale network, similar to London but in this case multiplied several times due to its size; while Gothenburg and Stockholm show an encroachment of the metropolitan scale to their historical cores, which radiates out and the city scale structures hang from and connect these metropolitan branches. Neighbourhood scale structuring paths also appear more concentrated forming grid-like structures in Amsterdam and London, as opposed to the two Swedish cities.

Figure 3 - Maps of the four cities showing the spatial distribution of path types.[13]

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Figure 4 - Maps of the city centre of the four cities, at the same scale, showing the spatial distribution of path types.[14]

Despite these spatial differences, the overall composition of the four cities in terms of path types is rather similar (Figure 5 a and b). The main aspect of note is the pairing of Amsterdam and London on one hand, and Gothenburg and Stockholm on the other hand in having similar path centrality profiles, with the Swedish cities having a smaller share of neighbourhood types, versus a higher share of city and metropolitan types.

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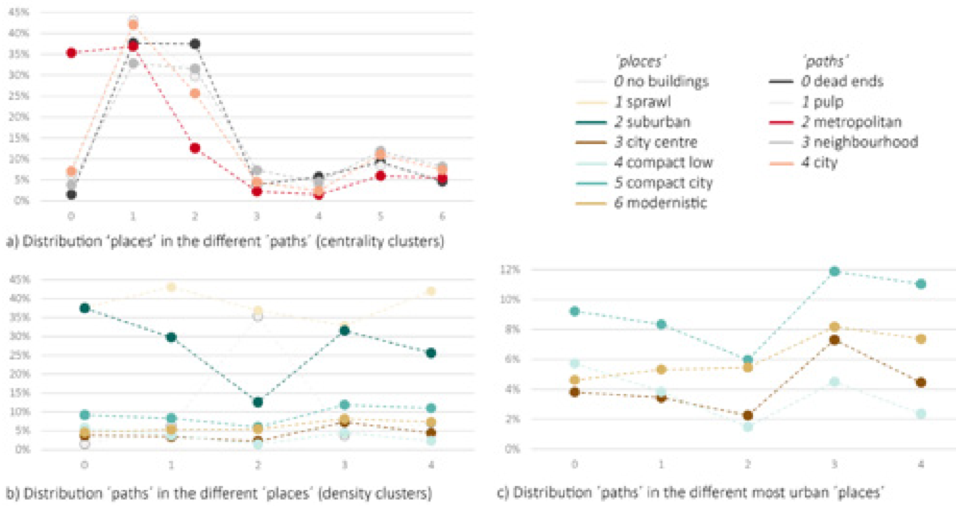

Figure 5 - Charts showing the distribution of ´paths´ (a and b) and 'places' (c) types in the four cities.

3.2 DENSITY TYPES

The density variables FSI and GSI are used to identify density types and results in a typology of seven 'places´. Their profiles are presented in the Spacematrix charts of Figure 6 and include: ´no buildings´ (cluster 0) where density is zero; ´sprawl´ (cluster 1) with low FSI and GSI; ´suburban´ (cluster 2); ´compact low´ (cluster 4) where both FSI and GSI get slightly higher. Then we have three types with higher average building height: ´city centre' (cluster 3) with the highest combination of FSI and GSI; ´compact city´ (cluster 5); and 'modernistic' (cluster 6) with a more spacious urban layout.

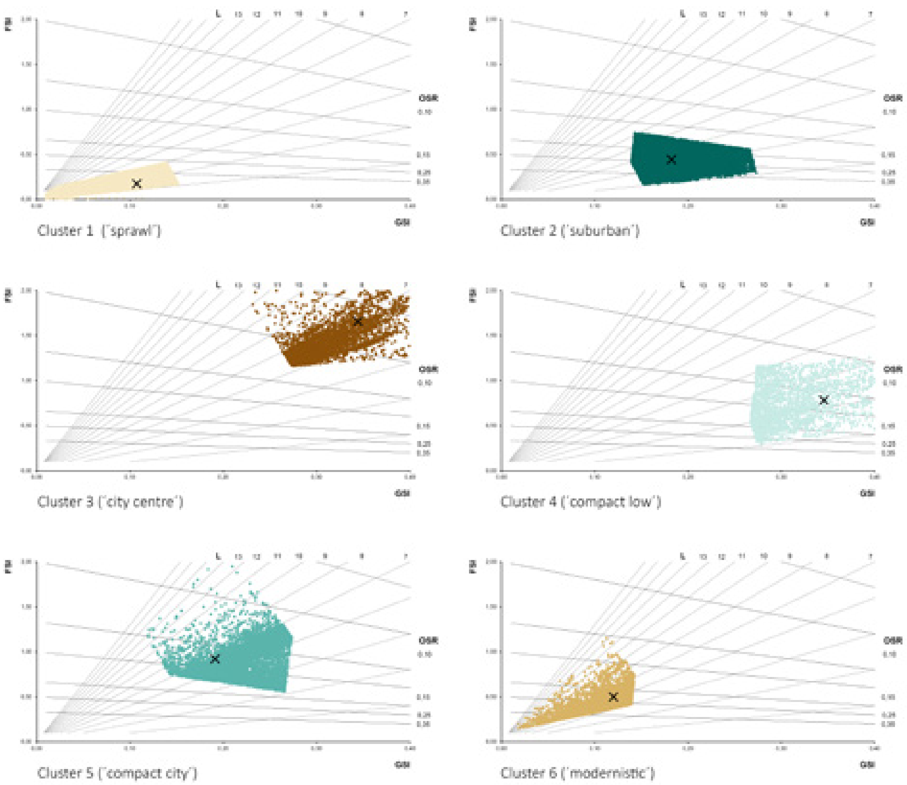

Figure 6 - Spacematrix charts showing the distribution of FSI and GSI values in each cluster.

Figure 7 - Maps of the four cities showing the spatial distribution of 'place' types.

Figure 8 - Maps of the city centre of the four cities, at the same scale, showing the spatial distribution of 'place' types.

3.3 RELATION ‘PATHS’ AND ‘PLACES’

When looking at the relation between centrality and density types, two things are interesting to discuss: first, how the types group and whether certain combinations dominate; secondly, whether this is similar for all four cities.

In figure 9 (a) we can see how places are distributed within each path type. Paths of the metropolitan type, for instance, often come along with places of the sprawl type or with areas with no buildings at all. Figure 9 (b) shows how paths are distributed within each place type, in other words, which paths dominate in which places. The sprawl type, for instance, is combined with all path types in similar frequencies as the suburban type drops when it comes to the metropolitan type. Looking in more detail into the frequencies of the denser places (see figure 9 c), we find that compact city groups most often with the paths at neighbourhood scale, followed by city scale.

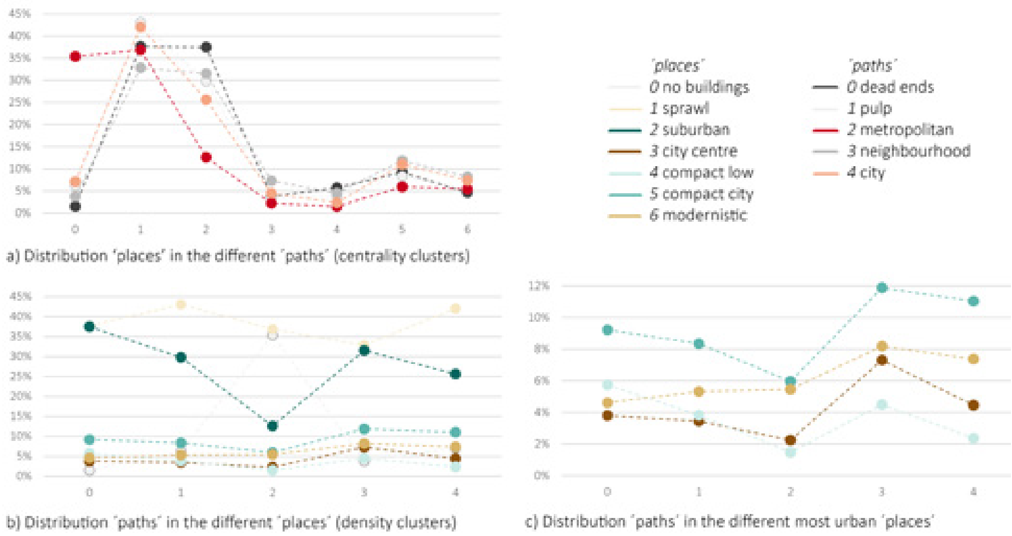

Figure 9 - Charts comparing the frequency of ‘place’ in ‘path’ types a), and the frequency of places in path types b) and c).

When looking at the differences of this grouping in the four cities, we see how Amsterdam and London show similar patterns as well as Stockholm and Gothenburg. The only exception is the path of the metropolitan type where London performs different form the others. This can maybe be explained by the fact that the size of London is so different from the others that what is captured in the metropolitan path in London actually is representing the city scale. We would need to add analysis at higher radii to test this hypothesis.

4. DISCUSSION

We have shown that working with types is a fruitful way to compare whole cities in terms of ´paths´, defined through the clustering analysis using the betweenness centrality measure through all scales and ´places´, defined through the clustering analysis using the accessible density measures FSI and GSI at radius 500m. These types are absolute and all-encompassing concepts existing across the different cities that summarise the complexity of various analysis measures and scales.

The proposed combination of PCA and clustering to define paths may seem complex and one needs to question whether only PCA is informative enough on its own. Figure 10 shows how the rotated component RC1 (representing the city scale) shows similarities to the path ´city´. However, RC1 also covers in a continuous scale all other paths in the network, and ‘city’ paths have high values on more than one scale. This discrete identification of the paths’ profile makes cluster analysis an important complement to PCA, capturing the overlapping of scales. The streets of the path type ´city´ have for instance overlap both with the higher and the lower scale. Something similar can be seen when comparing the analysis of a single density variable such as FSI with the places defined through cluster analysis using two density variables (i.e. FSI and GSI). The map showing the places is more informative as it not only informs us which numeric density we have at hand, but also which building type is dominating the area.

Figure 10 - Maps of the same area in Amsterdam representing the rotated component RC1, the paths based on clustering, FSI and the places based on clustering.

Besides the clustering in types, it is worth mentioning how in all four cities, three basic centrality regimes were found and that, underneath the visible morphologic variability, their spatial structures are characterized by only three basic spatio-functional scopes. Further, the main aspect of note is the pairing of Amsterdam and London on one hand, and Gothenburg and Stockholm on the other hand in having similar path and place profiles. The results show a clear relation between denser places and paths of the city and neighbourhood type. On the other hand, paths of the metropolitan type are often found in combination with the least dense places.

A lot of interesting new questions were discussed while working at this paper and studying the results of which we want to mention three.

Firstly, when seeing the interesting grouping of cities, that is, Amsterdam with London and Gothenburg with Stockholm, we are eager to add more cities. One trajectory is to add more Swedish cities of different size, to see whether we can speak of a typical Swedish city with great similarities in the distribution and frequency of both centrality and density. Another trajectory is to add more main cities in Europe to see how many types of city we have in Europe. This can easily be extended even further to other continents.

Secondly, we can add the other core variables of spatial urban form as we discussed in the introduction where the two most important additions we see now are 1) the closeness centrality measure of integration and 2) the patterns of plots that will make the trilogy of the main elements of urban form; the street, the plot and the building, complete.

Thirdly, except for the association between the types as was discussed in this paper, it would be interesting to develop a typology based on the pairing of types using cross tabulation. The same density clusters (places) can hold very different paths and, depending on this grouping, might perform very different in terms of social and economic outcome. Correlating these "combined types" with pedestrian and vehicle flows and economic activities is therefore an extremely interesting next step.

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