An analysis of the form of urban areas in Europe using spatial metrics

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Abstract

This paper presents an analysis of the form of urban areas in the European Union. The analysis is on the basis of spatial metrics estimated using the Urban Atlas database. Metrics are estimated for all 305 cities for which data are available. The analysis is carried out across two dimensions, the region of the urban area (North, Central, East and South EU) and the population size. Original Urban Atlas data are reclassified into 12 land uses and through a map generalization procedure neighbouring patches of the same land use are merged to form larger compact areas. Both landscape and class metrics are estimated and analysed. The results demonstrate that through the use of metrics it is possible to identify different characteristics of the urban form and that they can be used to highlight differences and similarities that exist among EU cities in the North, Central, South and East EU urban areas.

Keywords: spatial metrics, Europe, urban form, comparison, Urban Atlas

1 Introduction

To analyse urban form there is a need for an extensive and detailed dataset with information on land use/cover and also a methodology that can translate land use patterns to indicators. A few years ago the European Environment Agency (EEA) released the Urban Atlas database [4, 5] that provides land use information for the 305 largest EU cities for 2006 and is in the process of updating this database with data for 2012.

Spatial metrics, originally introduced in ecology, have been used extensively as indicators for describing the aggregation/dispersion/proximity patterns of different land use classes in urban areas. A typical application estimates metrics for at least two different years to assess land use changes through time [6, 12, 15, 16, 11]. Other research efforts have used metrics to compare the structure of different cities [8, 13], describe urban form [2], assess the goodness-of-fit of urban growth models [7, 3, 1] and more recently to analyze urban sprawl at the national level in Europe [14].

In this paper spatial metrics are used to highlight similarities and differences in the form of urban areas in Europe. The analysis is carried out across two dimensions, a) the geographic location of the urban area, with EU countries aggregated into 4 groups, North, Central, East and South (Mediterranean), b) the population size of an area. The research reported here is not concerned with the patterns through which urban areas have expanded. It concentrates on analyzing the form of the cities in 2006.

The paper consists of five parts. In the second part there is a presentation of the methodological issues that arise when using UA for estimating metrics and the approach for addressing them. In the third section the estimated landscape metrics are discussed, while in the next section the discussion concentrates on the class metrics. Conclusions are provided in the last section.

2 Spatial metrics and Urban Atlas

2.1 Urban Atlas

The land use classification system in UA recognizes 20 different land use classes, 17 of which represent artificial land, that is land that is developed, built up. Six classes, describe development/built up density levels on the basis of the imperviousness/soil sealing degree parameter (s.d.) [9] and are referred to as “urban fabric” classes. The soil sealing degree parameter represents the loss of soil resources because of the coverage of land by housing, roads or other construction (Maucha et. al, 2010) and takes values between 0% and 100% (non-developed vs fully developed). The group of the remaining 11 classes includes five classes for transport infrastructure (fast transit roads, other roads, railroads, ports and airports), and separate classes for industrial/commercial/public facilities, mineral extraction/dump sites, construction, land without use, green urban areas and sports/leisure facilities. Additionally, there are three classes for non-developed/natural land (agricultural/semi-natural/wetlands, forests and water bodies). The database is a vector database (every land use patch is a polygon), it has been developed from satellite images of 2006±1 year and map scale is 1:10.000. Minimum mapping unit is 0.25 ha (50x50 m). Data are available for the 305 urban areas in EU participating in the “Urban Audit” program that publishes statistical information for European cities on a regular basis (*http://ec.europa.eu/eurostat/web/cities/data/database*). Almost all cities in EU with population exceeding 100,000 participate in the program.

Boundaries of urban areas in UA are specified as in the Urban Audit, that is cities are defined by considering the Larger Urban Zone (LUZ). The LUZ represents the functional urban area around the core city and covers an area significantly larger than what would be normally considered metropolitan area. For the 305 cities in UA artificial land accounts for 15%

of total land (24% if population weighted) with the remaining being natural areas (agricultural, forests, water).

2.2 Methodological issues when estimating metrics with the UA database

Spatial metrics are indicators describing land use distribution patterns. Estimated through mathematical expressions they describe different aspects of the spatial organization of land uses. They can be estimated at the class and/or landscape level. Class metrics consider all patches of the same land use type and therefore describe characteristics of that type. Landscape metrics consider all patches in the urban area, irrespective of land use class, they are therefore indicators of the form of the complete urban area. An extensive list of metrics has been proposed ranging from simple percentage of a land use class in an urban area to mathematically defined fractal dimension or an analysis at the pixel level of the relative proximity of the various land use types. The FRAGSTATS software [10], a software available in the public domain, permits the estimation of an extensive set of metrics.

Traditionally, metrics have been estimated using raster land use maps developed through satellite image classification. With UA the situation is different. Different land uses are available as vector polygons at fine resolution with every city block identified as a patch of some land use class. There are twenty different land use types and the extent of the urban area covers an area of which only 15% on average is built up area. In order to establish the appropriate procedure for the estimation of metrics using the UA several methodological issues have to be considered. The most significant of these are discussed below.

a) Land use class reclassification/aggregation

Metrics could be estimated for all 20 UA classes, their analysis however, would not provide any meaningful insight of the urban form as a whole. It is therefore important to map the original UA classes into a smaller set of classes with the aggregation scheme paying particular attention to the the urban fabric classes. The land use classes used for estimating the metrics of the EU cities are shown in Table 1. The six urban fabric classes are aggregated into four classes, whereas the three “natural areas” are merged into one.

b) Resolution over specification

In UA almost every patch corresponds to a city block. The road between two patches/blocks is classified as a different land use category (other roads). In this way there is a detailed picture of land use distribution; urban form continuity however, is not evident since the road network separates city blocks. An area with patches of the same land use class is presented as an area with several patches, separated by streets. Since the objective is to analyse land use distribution and not the city blocks arrangement, neighbouring polygons of the same land use must be merged into a single patch and in this way reduce fragmentation.

This can be achieved by implementing a map generalization process; two neighbouring polygons of the same land use type are combined to form a single patch/polygon, while the road that separates them is reclassified to a land use type similar to that of the merged polygons. Rather that disregarding completely the road width when merging neighbouring polygons of the same type, an alternative procedure is to merge polygons of the same land use type only if separated by a road of width less than some threshold. By merging only polygons separated by roads of width of 10 or 20 meters, the structure of the city as specified by the large roads and highways. remains intact. Setting the road width high (50 m for example) will force patches on different sides of a freeway to be merged to a single patch if they are of the same type.

The transformation of the original UA map to a map in which neighbouring blocks/polygons of the same class are merged to form a single polygon was accomplished with the ‘Aggregate polygons’ procedure provided in ESRI’s ArcGis software. Using an “aggregation distance” (road width) of 20 m, roads between polygons of the same class were reclassified to this class, thus producing larger patches. The merging of adjacent polygons of the same class reduces drastically the number of patches.

c) Metrics estimation/urban area delineation

Landscape metrics consider all classes, however, class 12 “natural areas” although it accounts for a large part of total land it does not provide information on the form of the built-up areas. Additionally, patches of this class are very different than those of the built-up areas since they are large and in close proximity. It was therefore decided to ignore class 12 when estimating landscape metrics. The same decision was made for class 7 “other roads”. Since part of the road network was reclassified to another land use it was felt that the remaining part of the “roads” land use does not provide meaningful information and therefore should not be considered when estimating landscape metrics.

Since the input maps for FRAGSTATS must be raster, the vector map obtained after the merging of neighbouring patches was rasterized at a resolution of 20 meters per pixel. An example of the final result for London is shown in Figure 1. Using a feature of FRAGSTATS, Class 7 and Class 12 were treated as background in the analysis. With this feature, patches of these two classes are ignored when estimating landscape metrics, they are considered, however, part of the total area and therefore affect the values of metrics such as patch and edge density.

Figure 1: Map of a subarea of London, before and after the polygon aggregation algorithm

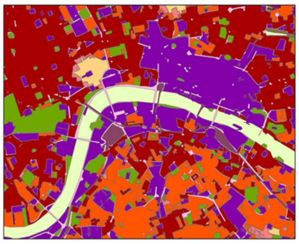

Table 1: Reclassification of land use classes

Land use classes for estimating metrics	Urban Atlas land use class
C_1: Continuous urban fabric (s.d. > 80%)	11100 Continuous urban fabric (s.d. > 80%)
C_2: Dense urban fabric (s.d.: 50% - 80%)	11121 Discont. dense urban fabric (s.d.: 50% - 80%)
C_3: Low to medium density urban fabric (s.d.: 10%-50%)	11220 Discont. medium density urban fabric (s.d.:30%-50%), 11230 Discont. low density urban fabric (s.d.: 10% - 30%)
C_4: Very low density urban fabric (s.d. < 10%)	11240 Discont. very low density urban fabric (s.d. < 10%), 11300 Isolated structures
C_5: Industrial/commercial	12100 Industrial, commercial, public, military, private units
C_6: Fast transit roads	12210 Fast transit roads and associated land
C_7: Other roads	12220 Other roads and associated land
C_8: Railroads	12230 Railways and associated land
C_9: Ports/airports	12300 Port areas, 12400 Airports
C_10: Other uses	13100 Mineral extraction and dump sites, 13300 Construction sites, 13400 Land without current use
C_11: Green areas/sports facilities	14100 Green urban areas, 14200 Sports and leisure facilities
C_12: Natural areas	20000 Agricultural + Semi-natural areas + Wetlands, 30000 Forests, 50000 Water Bodies

3 Landscape metrics

For the analysis of the form of EU urban areas four different regions were identified.

- North EU: UK, Ireland, Scandinavia (Denmark, Sweden, Finland)
- Central EU: France, Germany, Belgium, Netherlands, Luxemburg, Austria
- South EU: Portugal, Spain, Malta, Italy, Greece, Cyprus
- East EU: Former socialist countries (Poland, Hungary, Check Republic, Slovakia, Romania, Bulgaria, Slovenia, Estonia, Lithuania, Latvia)

The population density and some key landscape metrics by region and population size are shown in Table 2.

Population density: Population density was estimated as the ratio of population and total artificial land, and not the ratio of population to total land as it is customary. Population for each city was obtained from Urban Audit and reflects the latest population estimates (years 2012-2014). Irrespective of city size, population density (persons per ha) in the South is higher than in other regions. The difference increases as population increases. For cities with population larger than 1,000,000 the population density of Mediterranean cities is almost double the density of urban areas in other regions. For all regions the density of larger cities is higher than the density of smaller cities.

Patch density, Mean patch size: Patch density is estimated as the ratio of the number of patches and total artificial land rather than total land. Patch density (number of patches divided by area) is not significantly affected by city size. Larger PDs in the South is an indication that patches are more dispersed. This is corroborated by the mean patch size, with patches in cities in the South having the smallest area.

Contagion: The CONTAG metric is a measure of compactness, and takes values between 0 and 100; lower values imply that land use types are maximally disaggregated and higher values that land uses are maximally aggregated (i.e., when the whole urban area is of the same land use type). Irrespective of city size it takes lower values in the urban areas in South EU, an indication of increased levels of mixed uses. Higher values are observed in the North. For all regions the CONTAG metric decreases as population increases.

Average distance to the nearest neighbor (ENN): Values for the average distance to the nearest neighboring patch of the same type, are higher in cities in the East and lower in the South. This is indication of compacts areas in the East and increased mixed land use in the Mediterranean cities, with patches of the same land use being closer together.

4 Class metrics

Although landscape metrics demonstrate to some extent the differences between urban areas in the four regions, it was deemed necessary to examine some class metrics, as there are significant variations in the distribution of urban fabric among the four classes. As shown in Table 3, Continuous Urban Fabric (C_1, s.d. > 80%) in cities with population higher than 2,000,000 represents 2% of urban fabric in North EU, 15% in Central EU, 40% in East and 25% in the South. The class metrics for the four urban fabric classes and the Industrial/commercial class are shown in Table 4. The results demonstrate that there are differences between metrics of different land use types and also that there are regional differences. Usually PD increases as the sealing degree/density decreases. The PD for the “Very low density areas” (s.d. <10%) is high since the class includes the isolated structures that were not affected by the polygon merging process.

Table 2: Landscape metrics for the urban areas in Urban Atlas

	Population density	Patch density PD	Mean Patch size (ha)	CONTAG	ENN (m)
Population < 500,000					
North	18.6	38.8	2.5	57.1	277
Central	20.9	29.8	3.1	53.6	261
East	22.9	30.4	3.5	55.5	312
South	23.5	44.8	2.0	52.4	236
Population 500,000 – 1,000,000					
North	23.1	27.2	3.7	55.6	244
Central	28.1	29.1	3.3	54.1	235
East	22.1	33.3	2.6	54.9	278
South	35.2	44.2	2.0	52.6	197
Population > 1,000,000					
North	18.6	38.8	4.3	55.5	228
Central	20.9	29.8	4.1	53.0	235
East	22.9	30.4	3.8	55.0	241
South	23.5	44.8	3.2	51.9	200

Mean patch size is the highest for C_2 (s.d. 50%-80%), with Mediterranean cites being the exception. For urban areas in the North C_1 accounts for a minimal amount of urban fabric while there is a relatively high percentages of C_2 and C_3 land use. Mean patch size for the latter two classes is the highest. ENN is very high for C_2 an indication that patches of this class are relatively far away and compact.

Urban areas in Central EU are different than those in the North and can be considered to be in the middle of the road between North and South. C_1 represents 15% of urban fabric, mean patch size for C_2 is relatively high but the distance between the patches is less than half of that in the North. Areas of very low density (C_4) account for only 6% in the large cities of this group.

Urban areas in East EU are characterized by the legacy of centralized planning under the socialist/communist regime. Irrespective of city size they exhibit the largest proportion of C_1 and C_2 (in cities with population > 2,000,000 these two land use types represent together 90% of urban fabric versus 43%, 65% and 64% respectively for cities in the North, Central and South EU. ENNs are the highest for the discontinuous low/very low density land use classes (C_3 and C_4, s.d. < 50%).

Cities in the South are different than those in other regions. There is a relatively high proportion of C_1 class, and the average patch size is the highest for this class. Average distance between patches of the class is the lowest, an indication of mixed land use. For C_2 ENN is on par with those in Central and East EU cities, while for the discontinuous low density classes the ENN is smaller than cities in other regions.

5 Conclusions

The results demonstrate that with the use of spatial metrics it is possible to quantify the differences in the form of the cities. Both landscape and class metrics demonstrate that there are differences in the form of urban areas in the North, Central, East and South EU. Cities in the South are characterized by mixed land use patterns. There are areas of low and very low density, but not to the extent found in cities in the North. Cities in the North are different because there is a very small amount of high density areas and urban fabric is dominated by the other three urban fabric classes. Cities in the East are characterized by a compact form, dominated by high densities with relatively small percentage of low density areas. Patches of these areas are also far away from each other in contrast to the North or South. The Central EU cities (France, Germany, Benelux, Austria) are characterized by a compact form, with minimal amount of very low density areas (s.d. < 10%).

The metrics also support the concept that form is affected by the population size. On the average differences between regions are more pronounced as the population increases. On the other hand the differences between North and South are evident in all four urban fabric classes. Central EU urban areas present an interesting case because distribution of urban fabric is the same irrespective of the population size, something that can be attributed to the enactment of land use policies.

Finally, it is clear that with the availability of Urban Atlas, there will be increased levels of research in analyzing the urban form of European cities. Of course the readily available datasets will introduce some new questions, such as methodologies for comparing urban areas at the sub regional level and definition of metrics that account for the pairwise interaction of land uses.

Table 3: Distribution (%) of urban fabric among the four classes (classes denoted by sealing degree, s.d.)

Land use class/ Population	< 500,000	500,000 - 1,000,000	1,000,000 – 2,000,000	> 2,000,000
North EU				
s.d. > 80%	2	3	5	2
s.d. 50% - 80%	25	33	45	41
s.d. 10% -50%	41	47	35	41
s.d. < 10%	33	18	16	16
Central EU				
s.d. > 80%	15	14	17	17
s.d. 50% - 80%	42	43	51	48
s.d. 10% -50%	34	35	27	30
s.d. < 10%	9	8	6	5
East EU				
s.d. > 80%	26	17	18	43
s.d. 50% - 80%	47	46	45	47
s.d. 10% -50%	16	24	25	8
s.d. < 10%	11	14	12	3
South EU/Mediterranean				
s.d. > 80%	16	16	29	25
s.d. 50% - 80%	25	21	24	29
s.d. 10% -50%	38	40	27	37
s.d. < 10%	21	23	20	8

Table 4: Patch density, mean patch size and average distance to patches of the same type (ENN) of the urban fabric and the Industrial/commercial classes (UF classes denoted by sealing degree, s.d.)

	s.d.>80%	s.d. 50%-80%	s.d. 10%-50%	s.d. < 10%	Indust/commer
Patch density (PD)					
North	0.5	1.7	4.3	13.9	5.9
Central	2.0	3.6	4.7	5.5	6,2
East	2.2	4.6	3.3	9.6	5.3
South	2.0	4.6	7.4	14.4	7.9
Mean Patch size					
North	2.7	9.0	5.7	0.8	3.2
Central	3.5	6.3	3.7	0.7	3.4
East	7.0	6.8	2.7	0.6	4.0
South	4.3	2.6	2.7	0.7	2.7
ENN					
North	768	507	253	249	311
Central	368	202	204	395	228
East	405	223	455	439	310
South	295	212	173	226	244

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