URBAN FORM ANALYSIS EMPLOYING LAND COVER AND SPATIAL METRICS – THE CASE OF THE LISBON METROPOLITAN AREA

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Abstract

In order to face the challenges of urban planning, there is an increasing need to monitor and quantify urban occupation. This study, conducted within the research project "FURBS: Sustainable Urban Form - Methodological development for Portugal (PTDC/GEO/69109/2006), seeks to examine the urban form of the Lisbon Metropolitan Area (LMA), and its occupation between 1990 and 2000, using spatial metrics.

The LMA congregates nearly 3 million inhabitants, around 26% of the Portuguese total population. A relevant characteristic of the region is that it has been subject to a constant opening of new areas of urbanization, which had caused in this region, an increase of 18.6% of housing units between 1991 and 2001, while the total population grew only 4.3%.

In this study, we sought to apply the use of spatial metrics to CORINE Land Cover urban classes, analysing the evolution of urban area with a wide range of spatial metrics in order to quantify the urban evolution in the region. Spatial metrics have been used in ecology studies where they are known as landscape metrics. These metrics represent the geometric characteristics of the landscape units and the spatial relationships between them.

Only recently these metrics started to be used to analyse and classify the urban form in a more systematic way. The applications of quantitative indicators are one of the methodologies showing greatest potential in characterizing urban form, allowing researchers a tool to evaluate the urban form. In a nutshell we aim to contribute to the knowledge of the LMA and to the development of one of the most innovative approaches to the study of urban dynamics.

1. Introduction

In the last decade in Portugal, the discussion about urban form has been growing importance, related with sustainable urban development and urban and regional policies. The process of territorial planning is in nature complex and requires tools to analyse a comprehensive set of information. In order to meet the challenges of regional planning, there is an increasing demand to monitor and quantify urban dynamics.

This study, conducted within the research project "FURBS: Sustainable Urban Form - Methodological Development for Portugal" (PTDC/GEO/69109/2006), aims to contribute to the main objective of the project, which is to develop a methodology to assess the evolution of urban form in Portugal.

In the case of this study, we resorted to spatial metrics to evaluate the urban occupation in the Lisbon Metropolitan Area (LMA). For this purpose, we intended to apply an appropriate methodology for the characterization of urban form, which can serve for subsequent applications in the analysis of cities.

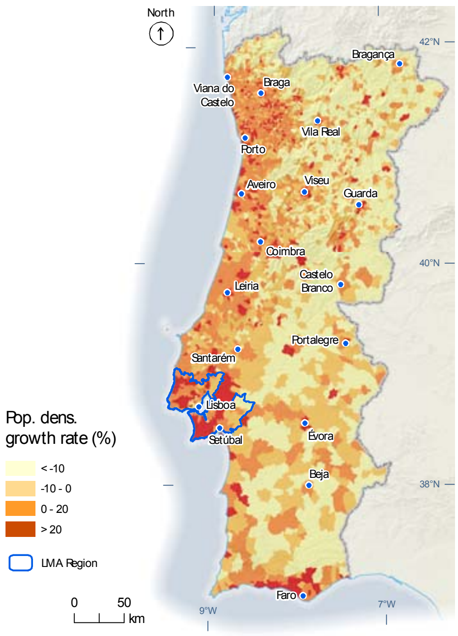
The analysis of urban form can have different dimensions depending on the scale and the objective of the work being done. However, regardless of scale and objectives, the analysis must be made on datasets, required for the analysis of spatial structure. In this study, we used a specific set of Corine Land Cover classes in order to represent built up areas. Thus, we intended to test the application of quantitative morphological indices in order to draw a general characterization of the occupation of the LMA territory, and, at the same time, to quantify the urban form.

The calculated spatial metrics are a number of indices, which represent the morphological characteristics of urban form and the spatial relationships among patches that compose it. The application of spatial metrics is one of the methodologies that have greater potential in the characterization of urban form.

Between the last two national censuses (1991-2001), the population growth in mainland Portugal in about half million people, was marked by a differentiated spatial distribution. On a national scale, and roughly, it was found that most of the population growth took place in a range of 50 km along the coast and in the remaining of the mainland, under the polarizing ability of cities. In the 90’s, while the two metropolitan areas (Lisbon and Oporto) and the main cities, experienced population growths that came to reach 171%, in fact most of the remaining mainland registered a decline in population density (figures 1 and 2).

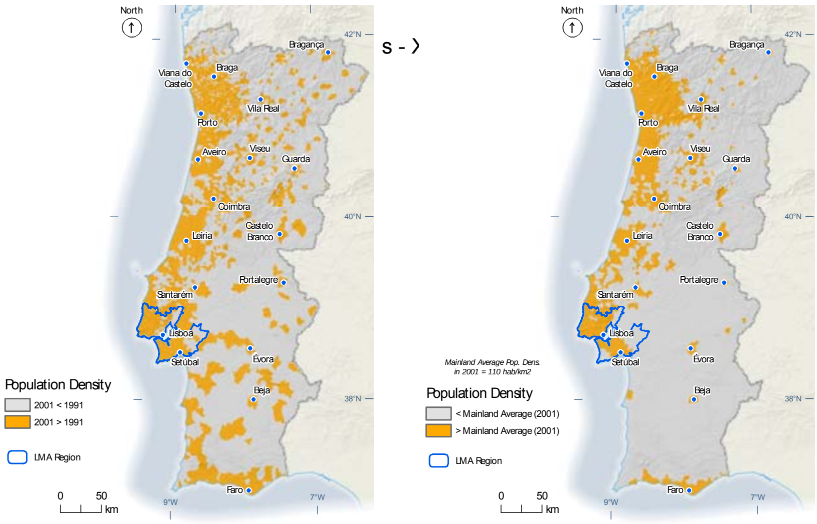
In total, approximately 29% of mainland Portugal had an increase in population density in the decade between 1991 and 2001. Also in 2001, only 18% of mainland Portugal area had a density higher than the average (110 Hab/km2). However, these 18% suffered a strong urban pressure that reflected in the fragmentation of the urban fabric. Nationally, the region of greatest population growth was the Metropolitan Area of Lisbon, hence the choice for this study.

Figure 1. Population density growth rate in civil parishes, between 1991 and 2001



Source: National Institute of Statistics - XII & XIV general census of Population

Figure 2. Left, variation of population density in civil parishes, between 1991 and 2001
Right, civil parishes above and below the 2001 mainland average



Source: National Institute of Statistics - XII & XIV general census of Population

2. Study Area

The LMA consists of 18 municipalities, organized into two groups separated by the Tejo river. The river constitutes not only a physical division, but also a division between demographic behaviours. The municipalities comprising the Metropolitan Area are: Alcochete, Almada, Amadora, Barreiro, Cascais, Lisboa, Loures, Mafra, Moita, Montijo, Odivelas, Oeiras, Palmela, Sesimbra, Setúbal, Seixal, Sintra and Vila Franca de Xira (figure 3).

The LMA has the highest concentration of population and economic activity in Portugal. In its eighteen municipalities, which constitute 3.3% of national territory, there are almost 3 million inhabitants, about ¼ of the Portuguese population. At the economic level, it concentrates about 25% of the workforce, 30% of total corporations, 33% of jobs and it contributes with over 36% for the national GDP (INE, 2001). In distinction to the other Metropolitan Area in the country (Oporto), the LMA presents a much more concentrated land occupation. In 2001, the region had a population density eight times the average for the country (INE, 2001).

Figure 3. LMA municipalities

The LMA main emphasis relies in the fact that it represents about 26% of the national population, with nearly 3 million inhabitants. In 1950, 5% of LMA area concentrated 69% of its population; in 2001, these 5% of area concentrated 45% of the population (Marques da Costa and Marques da Costa, 2008). This was accompanied by a process of residential decentralization and relocation of economic units.

Although the city of Lisbon maintains its structural role in shaping the LMA, since it holds ¼ of the total population that live in places with more than 2000 inhabitants (INE, 2001), the consolidation of new poles point to an increasingly polycentric organization. Following the logic of a model of urban development based on the use of individual transport, which leads to the progressive increase of the urban fabric (Marques da Costa and Marques da Costa, 2008).

An important feature of the region is that it has been subject to a constant opening of new areas of urbanization, which has caused that in the region, the total housing units has increased 18.6% between 1991 and 2001, while the population grew only 4.3% (Marques da Costa and Salgueiro, 2008). In 2001, the population entering the region for reasons of work or study was more than twice that who left (INE, 2001). The city of Lisbon attracts daily an amount equivalent to 75% of its population (INE, 2001).

3. Methodology

3.1 Data Processing

There is no universal way to represent the urban area of a region. One of the most common ways resorts to remote sensing to extract built-up areas. For the purpose of this study, we resorted to a product derived from remote sensing, used in most of the studies of European regional land occupation. The Corine Land Cover (CLC) for 1990 (CLC’90) and 2000 (CLC’00).

CLC has a mapping unit of 25 ha, and this must be taken into account in a study of urban geography. Obviously, a minimum mapping unit of 25 ha yields insufficient for a detailed study of urban dynamics, nonetheless, CLC is currently the only land occupation spatial data covering all of Portugal, with two time references shots (1990 and 2000). In addition, given the free nature of CLC, it is an appealing source to test methodological applications.

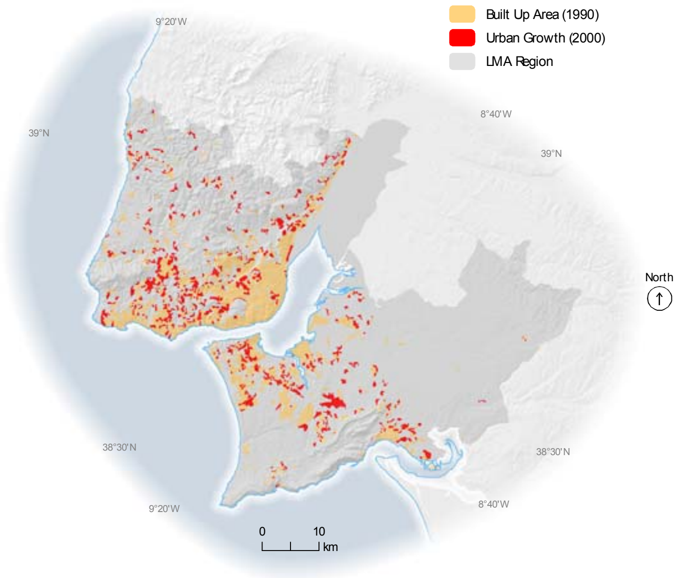
CLC'90 resorted to satellite images from 1985 to 1987, while CLC'00 resorted to images from 2000 (Caetano, *et al*., 2005). For the sake of generalization, we will refer CLC’90 to the year 1990, and CLC’00 to 2000. For the study carried out, we aggregated the following Corine land cover classes to represent the built-up area in the study territory.

- *Continuous urban fabric (111 according to CLC code)*
  - In this class, buildings and transport network infrastructures occupy most of the land. The presence of non-linear areas of vegetation and bare soil is atypical (Néry, 2007).
- *Discontinuous urban fabric (112 according to CLC code)*
  - Buildings occupy most of the land. The buildings, roads, and areas are associated with artificial areas with vegetation and bare soil, which occupy a significant but discontinuous area (Néry, 2007).
- *Industry, commerce and general equipment (121 according to CLC code)*
  - Most of the class surface is occupied by artificial areas without vegetation (concrete, asphalt, tarmac, dirt, etc…); there are also buildings present and/or vegetation (Néry, 2007).
- *Road and rail networks and associated spaces (122 according to CLC code)*
  - Roads and railways, including associated equipment (stations, platforms…), with minimum width of 100 m (Néry, 2007).
- *Port areas (123 according to CLC code)*
  - The infrastructure of port areas, including piers, docks and marinas (Néry, 2007).
- *Airports (124 according to CLC code)*
  - The airports: runways, buildings and associated areas (Néry, 2007).
- *Areas under construction (133 according to CLC code)*
  - The areas under construction, excavation of soil or rock, movements of land (Néry, 2007).

- Sports and leisure equipment *(142 according to CLC code)*
  - o Camping, sports arenas, recreation parks, golf courses, etc (Néry, 2007).
  - o Through a spatial analysis operation, the patches of this class where only selected if they were contiguous to the remaining selection of built-up area.

The selected classes were combined into one single class to identify the built-up area in each of the municipalities of the study area. Then each patch was awarded the respective municipality, through its database attributes. Thus, after the calculation of spatial metrics for the patches, it was possible to calculate measures of location (mean) and dispersion (coefficient of variation) for each municipality, taking into account the membership of each patch to a municipality.

Figure 4. CLC patches representing built-up areas for the LMA



3.2 *Urban Form through Spatial Metrics*

What is the best way to quantify and analyse the urban area of a territory, mainly at larger scales where the population density and population growth rates have subtle differences? Secondly, how to assess the urban form of cities where the use of administrative boundaries is no longer feasible? Unfortunately, traditional approaches through the analysis of population density of administrative units, and monitoring of the built-up area based on the evolution of land occupation, are insufficient to quantify the morphological dimension of the urban form. In this context, the spatial metrics appear as one of the best alternatives, given the fact that they are quantitative indices calculated only based on polygons describing the urban morphology.

After obtaining the dataset that contains the elements of urban form to consider, we must find a way to quantify the morphology. In the last two decades, a significant progress been made, trying to measure and analyse spatial patterns that help to characterize the urban form. However, we must take into account that there is no defined set of specific indicators for use in urban geography, as the significance of spatial metrics varies with the objective of the study, and the characteristics of the urban landscape under investigation (Clifton, *et al.*, 2008).

For the analyses carried out, we calculated the spatial metrics for CLC patches. These metrics consist of quantitative indices that represent the geometric characteristics of the units of landscape. Spatial metrics have been recurrently used in ecology studies where they are known as landscape metrics. Landscape metrics were developed in the late 1980s and incorporated measures from both information theory and fractal geometry based on a categorical, patch-based representation of a landscape (Herold, *et al*., 2005).

Patches are defined as homogenous regions for a specific landscape property of interest, in the case of this study, the built-up area. Only recently, these indices were used to analyze and classify the urban form on a more systematic way (Huang, *et al*., 2007).

There has been a growing interest in the application of spatial metrics to urban environment analysis. Parker, *et al*. (2001) denounced the spatial metrics for socioeconomic, urban and rural integrated models. He also investigated theoretical urban land use patterns resulting from spatial metrics application. The authors also state that spatial metrics can be used as an improved spatial representation of urban characteristics.

Alberti and Waddell (2000) proposed specific spatial metrics for urban land use/cover models that incorporate human and ecological processes. Furthermore, empirical studies have substantiated the use of both spatial metrics and remote sensing in urban environment, establishing them as a priority for future exploration and city evaluation (Batty and Longley, 1994; Alberti and Waddell, 2000; Parker, *et al*., 2001; Clarke, *et al*., 2002).

There has been an increasing interest in applying spatial metrics in urban environments, because these help in bringing out the spatial component in urban structure (both intra and inter-city) and in the dynamics of change and growth processes (Herold, *et al*., 2005).

The methodology that has been developed under the FURBS project implies that the calculation of metrics is made on vector representations of urban patches relying on Geographic Information Systems (GIS), thus enabling the simultaneous calculation for several territorial units. These units can be administrative (municipalities, regions, countries) or result from any kind of spatial analysis (i.e. isochrones). This methodological framework is still in its early stages, but proving to be very worthy.

The methodology being developed is based on the work of Mcgarigal, *et al*., (2002). As it stands, it allows the calculation of 15 metrics, from which we selected 4 for this study: *Percentage of built-up area*, *nearest neighbour index*, *centrality index* and *compactness index*. Choosing a methodology directed to the representation from vector patches apart from the more standard methods relying in raster datasets, allow us to simultaneously calculate several territorial units at the same time, while providing an easy integration with other alpha-numerical attributes of the territorial units. A crucial feature, since the FURBS project is intended to incorporate morphological indicators of urban form with sustainability indicators. Table 1 presents the selected indices applied in this study.

Table 1. Spatial metrics applied

Index	Formula	Description
POcup	$POcup = \frac{\sum_{i=1}^{n} area_i (100)}{AUT}$ $area_i$ = area of patch i AUT = municipality area	POcup quantifies the percentage of the municipality area comprised by the selected CLC patches representing built-up area Unit: Percent Range: 0 < POcup ≤ 100
MVP	$MVP = \frac{\sum_{i=1}^{n} dist_i}{n}$ $dist_i$ = distance from patch i to nearest neighbouring patch, based on patch edge-to-edge euclidian distance n = total number of patches in the municipality	MVP indicates the average distance of the patches from a municipality to the closest patch. MVP has a value of 0 when all patches are contiguous in the municipality Unit: Meters Range: MVP ≥ 0, without limit

CVVP	$CVVP = \left(\frac{\sigma VP}{MVP} \right) \times 100$ σVP = Standard deviation of the municipality nearest neighbour index MVP = Municipality mean nearest neighbour index	CVVP is equal to the standard deviation of the municipality nearest neighbour index divided by the municipality mean nearest neighbour index then multiplied by 100 to be expressed in percentage Unit: Percent Range: CVVP ≥ 0, without limit
MCENT	$MCENT = \frac{\sum_{i=1}^{n} Dist_i / R}{n}$ $Dist_i$ = The distance from the centroid of $patch_i$ to the major municipality town R = Radius of a circle with area equal to the total municipality area n = total number of patches in the municipality	MCENT is the average distance among the municipality patches, to the major municipality town To minimize the bias of the urban scale, the average distance was divided by the radius of a circle with the total municipality area Unit: Meters Range: MCENT ≥ 0, without limit
CVCENT	$CVCENT = \left(\frac{\sigma CENT}{MCENT} \right) \times 100$ σCENT = Standard deviation of the municipality centrality index MCENT = Municipality mean centrality index	CVCENT is equal to the standard deviation of the municipality centrality index, divided by the municipality mean centrality index, then multiplied by 100 to be expressed in percentage Unit: Percentage Range: CVCENT ≥ 0, without limit
MCOMP	$MCOMP = \frac{\sum_{i=1}^{n} COMP_i}{n}$ $COMP_i$ = $patch_i$ perimeter divided by the minimum perimeter possible for a maximally compact patch of the corresponding $patch_i$ area n = total number of patches in the municipality	MCOMP equals patch perimeter divided by the minimum perimeter possible for a maximally compact patch of the corresponding patch area. MCOMP = 1 when the patches are maximally compact and increases without limit as patch shape becomes more irregular Unit: None Range: MCOMP ≥ 1, without limit
CVCOMP	$CVCOMP = \left(\frac{\sigma COMP}{MCOMP} \right) \times 100$ σCOMP = Standard deviation of the municipality compactness index MCOMP = Municipality mean compactness index	CVCOMP is equal to the municipality standard deviation compactness index, divided by the mean municipality compactness index then multiplied by 100 to be expressed in percentage Unit: Percentage Range: CVCOMP ≥ 0, without limit

Source: Adapted after Mcgarigal, *et al*., (2002); Huang, *et al*., (2007)

Thus, the spatial metrics were calculated for the patches from the aggregation of CLC classes.

4. Results and Discussion

Since our intention was to evaluate the progress of urban occupation in the LMA, we proceeded to the calculation of rates of change for each index. Thus showing the trend in percentage change in each of the municipalities, between 1990 - 2000. The measure of the difference in the spatial metrics between time (t +1) and (t) can be used to indicate the change in land development (Jha, *et al*., 2008). This can be expressed as:

$$\Delta S = S(t+1) - S(t)$$

In which ΔS is the change in the spatial metric (S) between time (t+1) and (t). Since we wanted the spatial metric rate of change, this can be expressed as:

$$\%\Delta S = \left(\frac{S(t+1) - S(t)}{S(t)} \right) \times 100$$

The results are in table 2. We included the population growth rate, in order to compare the population growth with the spatial occupation increase.

Table 2. LMA spatial metrics rates of change between 1990 and 2000

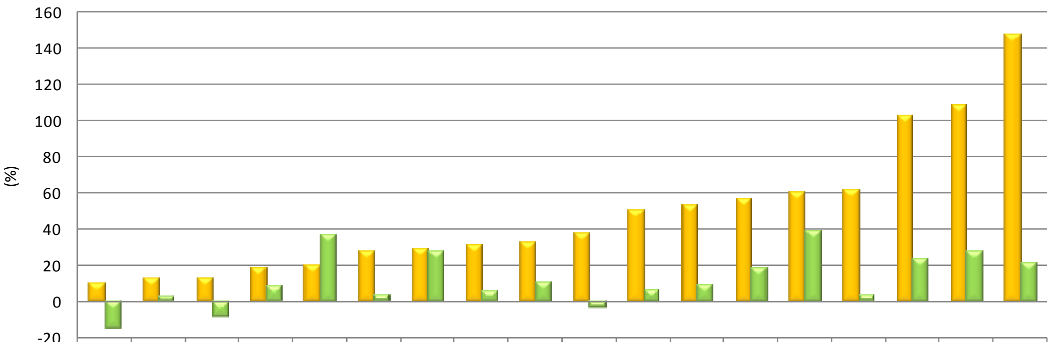
MUNICIPALITY	%Δ POP	%Δ POcup	%Δ MVP	%Δ CVVP	%Δ MCENT	%Δ CVCENT	%Δ MCOMP	%Δ CVCOMP
Alcochete (ALC)	27.90	108.80	-64.79	-28.23	-19.65	-2.13	17.71	45.37
Almada (ALM)	6.00	31.52	-17.97	16.98	-3.24	-4.35	-0.79	-10.42
Amadora (AMA)	-3.20	38.06	0.00	0.00	15.16	-11.45	-2.99	-2.20
Barreiro (BAR)	-7.90	13.30	-8.33	5.11	11.45	0.31	-1.18	-16.43
Cascais (CAS)	11.30	33.14	-49.40	-23.43	1.50	-2.88	-2.71	3.45
Lisboa (LIS)	-14.90	10.71	0.00	0.00	9.49	-4.14	-3.74	7.29
Loures (LOU)	3.60	28.24	2.74	20.96	9.44	11.68	-3.41	-1.64
Mafra (MAF)	24.30	103.50	-21.81	-8.67	-2.52	-12.34	4.31	27.09
Moita (MOI)	3.60	61.95	-65.69	71.32	4.83	-8.25	10.63	-2.37
Montijo (MON)	8.70	19.06	-12.13	7.59	-6.55	0.94	1.00	0.53
Odivelas (ODI)	2.90	13.01	0.00	0.00	-30.54	-0.60	4.57	3.65
Oeiras (OEI)	7.10	50.16	-43.34	8.19	4.61	-15.73	11.41	0.31
Plamela (PAL)	21.70	147.71	-41.47	7.61	14.91	-15.98	-1.43	8.07
Seixal (SEI)	28.50	30.03	-64.60	116.36	9.43	-3.54	6.80	-19.44
Sesimbra (SES)	37.90	20.19	-33.58	25.73	17.30	-9.86	5.18	1.30
Setúbal (SET)	9.90	53.57	-46.56	40.95	7.04	-7.77	-2.90	-2.70
Sintra (SIN)	39.40	60.23	-19.17	1.63	5.04	-3.30	13.22	23.61
Vila Franca de Xira (VFX)	18.70	56.93	-59.96	44.59	-3.98	9.03	0.85	9.50
LMA Mean	12.53	48.90	-30.34	17.04	2.43	-4.46	3.14	4.17

In figure 5 we can assess the growth of built-up area, and the population growth rate, in the LMA municipalities. Between 1990 and 2000, all the municipalities saw their built-up area increasing, however, the following had a rate of change above LMA average: Oeiras, Setúbal, Vila Franca de Xira, Sintra, Moita, Mafra, Alcochete and Palmela.

These last three with rates of change exceeding 100%. If we compare this with population growth, this growth rate was more moderate. Sintra stands out as one of municipalities of the periphery of Lisbon that had the higher net migration rate, hence the highest growth rate.

Moreover, there is a loss of population in Lisbon, an occurrence common to historical cities, but that extended in the last decade to the contiguous municipality of Amadora and on the other side of the river in Barreiro. In Barreiro, this occurrence is linked to the trend of population loss of declining industrial areas.

Figure 5. Rate of change in municipality percentage of built up area (POcup) and population growth (Pop), between 1990 and 2000



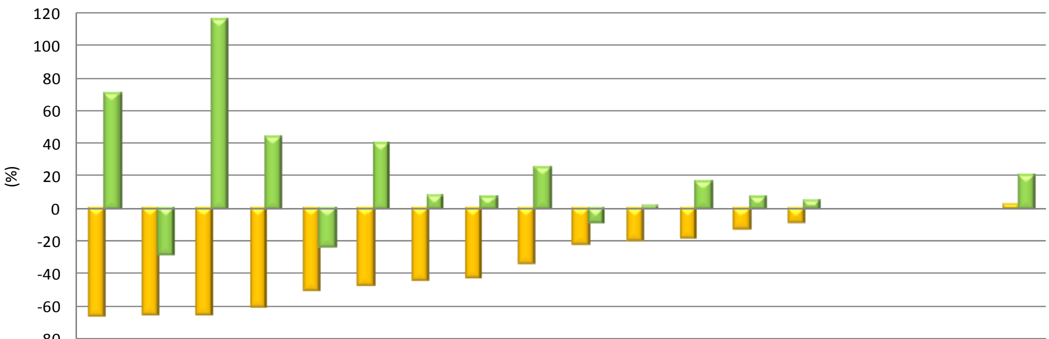
	LIS	ODI	BAR	MON	SES	LOU	SEI	ALM	CAS	AMA	OEI	SET	VFX	SIN	MOI	MAF	ALC	PAL
POcup	10.71	13.01	13.30	19.05	20.19	28.23	30.02	31.52	33.13	38.06	50.16	53.57	56.93	60.22	61.94	103.5	108.8	147.7
Pop	-14.9	2.9	-7.9	8.7	37.9	3.6	28.5	6	11.3	-3.2	7.1	9.9	18.7	39.4	3.6	24.3	27.9	21.7

Source: Table 2

Figure 6 represent the evolution of the nearest neighbour index. Lisboa, Amadora and Odivelas had no change, since these municipalities are quite consolidated in their urban fabric; hence, the patches are contiguous, which result in a nearest neighbour index of zero. On the other municipalities, we see that at the exception of Loures, all of them saw a negative rate of change for the mean nearest neighbour index, which is easy to explain by the increase in built up area resulting in the shortest distance among the patches. Once again we see a trend in the municipalities of the south side of the river (Moita, Alcochete, Seixal) leading the decline in the mean nearest neighbour index, showing that there, the built-up was more contiguous to existent areas.

If we analyze the behaviour of the rate of change for the coefficient of variation for this index, we see that Alcochete, Cascais and Mafra saw a homogenisation of values of the index in their built-up area. On the other hand, other municipalities had a rate of change of the coefficient of variation of the index exceeding 100% (Seixal).

Figure 6. Rate of change in the mean (MVP) and the coefficient of variation (CVVP) of the nearest neighbour index, between 1990 and 2000

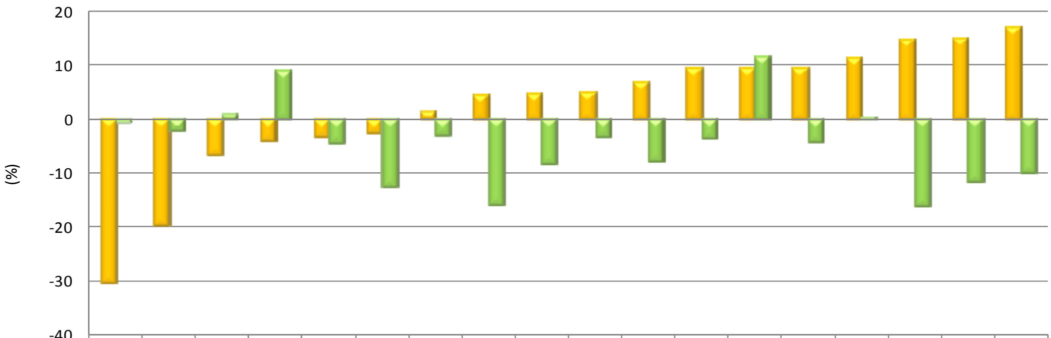


	MOI	ALC	SEI	VFX	CAS	SET	OEI	PAL	SES	MAF	SIN	ALM	MON	BAR	LIS	ODI	AMA	LOU
MVP	-65.6	-64.7	-64.6	-59.9	-49.4	-46.5	-43.3	-41.4	-33.5	-21.8	-19.1	-17.9	-12.1	-8.33	0	0	0	2.741
CVVP	71.31	-28.2	116.3	44.58	-23.4	40.95	8.189	7.614	25.73	-8.66	1.631	16.97	7.589	5.114	0	0	0	20.96

Source: Table 2

Figure 7 shows the centrality index, this index is the mean distance from the centroid of each municipality patch to the major municipality town. We can assume the departure from the municipality major town indicating a process of urban sprawl, as such we see that the south side highlights another trend. As for the municipalities that had a decrease of the centrality index, Odivelas and Alcochete stand out. Almost all municipalities had a decrease in the coefficient of variation of the index showing that in general the values soften in the 1990s.

Figure 7. Rate of change in the average (MCENT) and coefficient of variation (CVCENT) of the centrality index, between 1990 and 2000

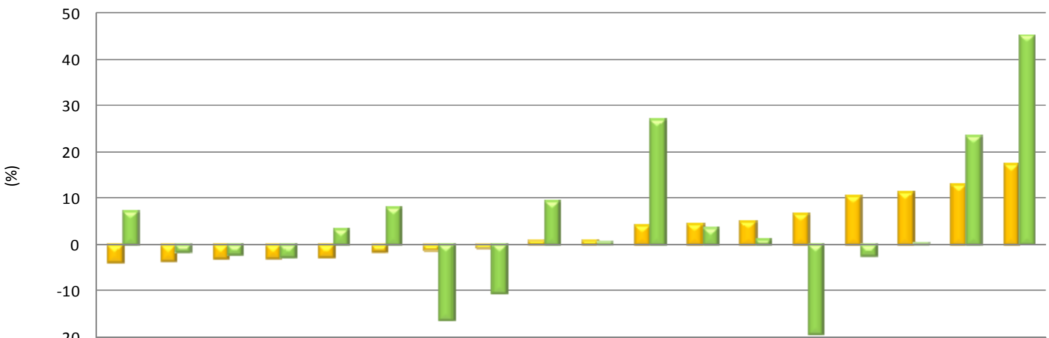


	ODI	ALC	MON	VFX	ALM	MAF	CAS	OEI	MOI	SIN	SET	SEI	LOU	LIS	BAR	PAL	AMA	SES
MCENT	-30.5	-19.6	-6.54	-3.98	-3.23	-2.52	1.501	4.612	4.826	5.037	7.038	9.429	9.439	9.492	11.45	14.91	15.15	17.29
CVCENT	-0.59	-2.12	0.938	9.031	-4.34	-12.3	-2.88	-15.7	-8.25	-3.29	-7.77	-3.53	11.67	-4.14	0.311	-15.9	-11.4	-9.85

Source: Table 2

Finally, figure 8 graphically represents the rate of change for the compaction index. We see that the index has not changed very significantly, still there was a tendency for dispersion. With the majority of the municipalities with positive rates of change for the index mean, noting an increase in dispersion for their urban patches, noticeable Moita, Oeiras, Sintra and Alcochete.

Figure 8. Rate of change in the mean (MCOMP) and coefficient of variation (CVCOMP) of the compactness index, between 1990 and 2000



	LIS	LOU	AMA	SET	CAS	PAL	BAR	ALM	VFX	MON	MAF	ODI	SES	SEI	MOI	OEI	SIN	ALC
MCOMP	-3.73	-3.40	-2.98	-2.90	-2.70	-1.43	-1.18	-0.78	0.848	1.004	4.305	4.573	5.176	6.796	10.62	11.40	13.22	17.70
CVCOMP	7.288	-1.64	-2.20	-2.69	3.445	8.072	-16.4	-10.4	9.497	0.533	27.08	3.653	1.299	-19.4	-2.36	0.314	23.61	45.36

Source: Table 2

For the last step on this study, we used a technique of multidimensional data analysis: clusters analysis. This analysis was meat to classify the municipalities under analysis against the calculated spatial metrics. In terms of geographical analysis, the clusters define regions with clustered similar characteristics. The technique adopted was the hierarchical clustering. The starting point of this technique is based on building a matrix of similarities or differences between the municipalities, with an initial group, equal to the number of units in analysis (18), which describes the degree of similarity, or difference, between any two pairs of municipalities. The selected method of aggregation was the group average. In this method the distance between two classes, "a" and "b" is the average of the distances between all elements of "a" and all elements of "b", one process widely used in a numerical taxonomy because of the clearness of its meaning.

The resulting clusters represent groups of municipalities given the similarity of shared values with the spatial metrics of urban form.

The hierarchical cluster analysis resorted to the four calculated metrics for 1990 and 2000: percentage of the municipality area comprised by built-up area; coefficient of variation of the municipality nearest neighbour index; coefficient of variation of municipality centrality index and coefficient of variation of municipality compactness index. The results of applying the algorithm of clustering are represented in the dendogram of figure 9 and 10.

Figure 9. Dendogram and resulting map using average linkage for 1990

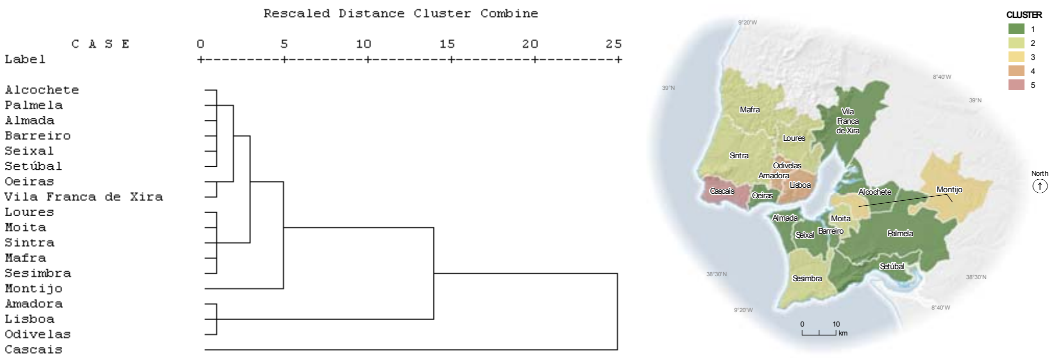
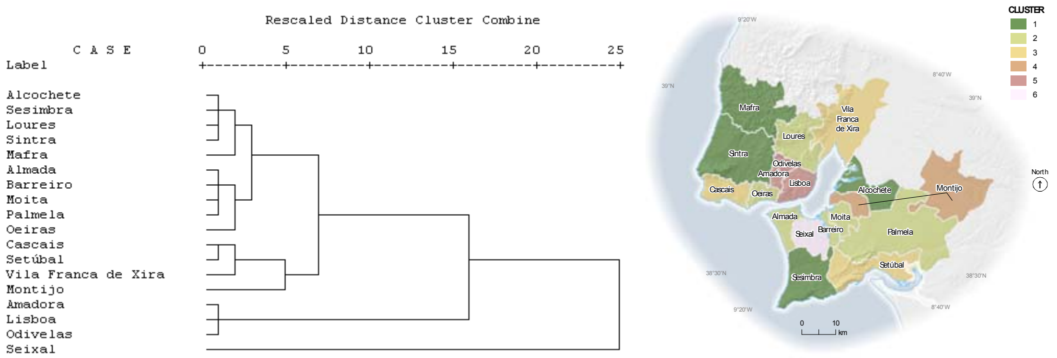


Figure 10. Dendogram and resulting map using average linkage for 2000



From the clustering results, we see that in the beginning of the 90's the clustering pattern was clearly visible between north and south of the river. We see that in 2000 the group of municipalities clusters is based not so much in a North/South opposition, but that they now have a greater differentiation. This pattern of occupation recorded in urban soil is explained by factors based on the mobility of the region.

Until 1998, the only way to make the river crossing between the two sides was through the 25 de Abril bridge, or by ferryboat. In 1991, the Portuguese government decides to build a second crossing over the river. In 1995, the construction started and the bridge was inaugurated in 1998. The year 1998 also coincided with the opening of the rail crossing on the 25 de Abril bridge. Thus, in 1998 the two sides won a rail link and a new road bridge. The result was the sudden increase of the property market in the south, where the prices were a lot cheaper. A clear example on how spatially relevant decisions alter the spatial structure of an urban region.

5. Conclusions

The analysis of spatio-temporal urban growth pattern, in combination with spatial metrics, can provide a unique source of information on how various spatial characteristics of urban form change over time. This allows important insight into urban spatial structure changes and the evolving urban growth dynamics. As such, the proposed approach applied here, leads to an improved understanding and representation of urban dynamics and helps to develop alternative conceptions of urban spatial structure and change patterns.

In the case of the LMA the urban expansion has been set up by the population growth within the boundaries of the cities resulting from high migration rates, and a strong component of property speculation. These two factors ultimately triggered a divergent movement to peripheral areas. Small outlying settlements in the outskirts started to expand in a few years. Nevertheless, what we can also see is that the fast urban land expansion in the region was not a result of fast urban population growth. In fact, the built-up area had an increase rate much higher than the population growth. One should take into account that in recent decades there was a shift from a more compact development that favoured higher densities, to a more extensive use of land. This was strongly dependent on transport infrastructures (Aguiléra and Mignot, 2003).

In summary, the results of the methodology applied, meet the type of occupation of the LMA territory, i.e., it was possible to quantify the urban form showing that the occupation on the north side of the river is presented with a greater density of agglomerations more closer to each other, while the southern occupation is more diffuse. In the north side there are also many more urban patches and they are smaller on average, in terms of area, with their counterparts in the south. In general, the density decreases apart from the municipality of Lisbon to the peripheral municipalities in a concentric way. The polarizing role of Lisbon in its metropolitan area is much stronger on the north side. The populations of the south municipalities are less attracted by the capital, due to constraints imposed by river crossing.

The organization of the LMA also reflects the structural role of the main axes of communication access to Lisbon and morphological differentiation reveals a north-south clustering pattern, which in spite of being prevalent, has lessen in relation to the past, when it was more noticeable. Overall, what we must emphasize in the methodology applied, is that it is particularly useful for evaluation between different periods, allowing to quantify the urban occupation in different time periods. For future development, given the limitations of the spatial database used, we soon count to develop the research with urban patches extracted with remote sensing using images from different time intervals, thus revealing the whole potential of this methodology in the evaluation of the urban form.

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