

**DISTINGUISHING BETWEEN THE MORPHOLOGICAL CORE AND PERIPHERY OF LARGE URBAN AREAS THROUGH TELEDETECTION: THE CASE OF MADRID AND BARCELONA**

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**Summary:** This paper draws upon research focussed upon the urban expansion of Madrid and Barcelona, which uses interpretation of high resolution 2004 SPOT satellite imagery to apply a methodology based upon applying criteria of urban continuity on the edge of large urban areas, to determine the spatial extent of the core and periphery of such urban areas. The resulting morphological centres and urban or metropolitan peripheries provide useful units of analysis, permitting viable comparison between different urban agglomerations.

## 1 Introduction

The modern process of urbanisation was experienced in Spain later than that compared with other European countries. It was after 1959 when the urbanisation process began to advance in an accelerated manner, owing to increasing industrialisation, the crisis of traditional agriculture, general increases in the population and large-scale interregional migrations. Nel·lo (2004) identifies the formation of a series of large metropolitan areas, which dominate the whole Spanish urban system; the consolidation of territorial axis which tended to concentrate population and activities; and the maintenance of the bicephalous nature of the urban network around this time, as the three basic elements of the Spanish urban system in the second part of the 20<sup>th</sup> Century [1]. As a consequence, the seven principal Spanish cities were converted into modern metropolises of a regional, national and in the case of Madrid and Barcelona, European standing, experiencing their major growth in the period 1960-70 in the case of Madrid, Barcelona, Valencia, Bilbao and Zaragoza, and in the period 1970-1980 in Málaga and Sevilla.

In contrast to a number other countries of the European Union, in Spain there is still no standard official definition for the territorial concept of a metropolitan area, and neither for the lower level metropolitan core and peripheral areas. However fortunately owing to the availability of information broken down to the municipality level in the 2001 Census, it has been possible to determine the spatial extent of functional metropolitan urban regions based upon commuting patterns between the place of residence and place of work. The delimitation of these Spanish metropolitan areas has followed a methodology previously developed by the Universidad Politécnica de Cataluña and applied in the case of the principal metropolitan regions of the South Western European territory through the INTERREG IIC Community initiative.[2]

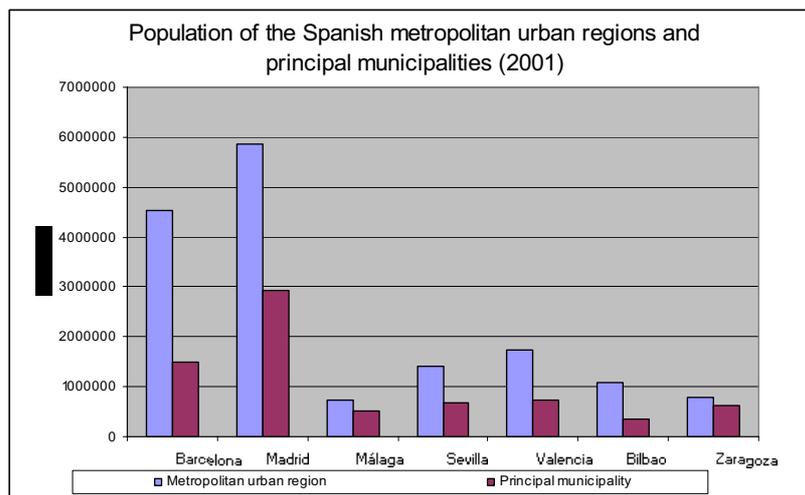


Figure 1. Population of the seven principal Spanish metropolitan urban regions (2001)

The results of this methodology in the case of the seven principal Spanish metropolitan urban regions indicate a metropolitan system dominated by Madrid and Barcelona, in terms of population, resident occupied population (POR) and workplaces (LTL), and followed by the metropolitan territories of Valencia, Sevilla, Bilbao Zaragoza and Málaga, as illustrated in Figure 1 and Table 1.

Throughout the decade 1991-2001 there was a 6% increase in the population of the combined population of the seven Spanish metropolitan areas, compared with a 5% increase in the population of the whole of Spain. The maximum growth during this period took place in the metropolitan region of Madrid (10%), followed by Málaga (9%), Sevilla (7%), Valencia (5%), Barcelona (4%) and Zaragoza (3%). Bilbao was the only one of the seven metropolitan urban regions which lost population during this period (-2%).

Examining the economic structure of the metropolitan urban regions, according to data coming from the 2001 Census, Madrid stands out for the high proportion of local employment in the service sector (75.25%), followed by Málaga (74.99%), Sevilla (70.58%), Bilbao (67.64%), Barcelona (64.86%), Valencia (63.99%) and Zaragoza (63.12%), compared with the Spanish average of 64.17%. By contrast the metropolitan urban region of Barcelona is where there is the greatest concentration of local workplaces in the industrial sector (26.30%), seguido por Zaragoza (24.80%), Valencia (22.21%), Bilbao (22.04%), Madrid (13.97%), Sevilla (12.38%) y Málaga (8.47%). The average value for employment in the industrial sector in Spain was 18.91% in 2001.

	<i>Number of municipalities</i>	<i>Area (Km<sup>2</sup>)</i>	<i>Population (2001)</i>	<i>Occupied resident population (POR)</i>	<i>Local workplaces (LTL)</i>
Madrid	609	27.581	5.793.964	2.613.219	2.528.350
Barcelona	227	4.796	4.539.749	2.020.133	1.903.291
Valencia	152	6.347	1.746.928	719.767	662.263
Sevilla	60	6.842	1.424.843	486.429	454.432
Bilbao	104	2.675	1.106.024	433.985	386.626
Zaragoza	267	15.084	771.854	325.390	312.701
Málaga	26	1.656	726.946	259.292	244.357

Table 1. Comparative indicators of the seven principal Spanish metropolitan urban regions

This approach towards evaluating the demographic and economic state of large urban and metropolitan by necessity treats the territories as uniform, and is unable to make an obvious distinction between the core and peripheral areas of such wider territories. From an administrative point of view such an analysis can be undertaken by grouping different municipalities or other administrative areas together, but what are criteria for determining core and peripheral areas? One option rests upon treating the centres as the areas formed by the principal central municipalities. In the case of Barcelona, the central municipality has an area of just 100 Km<sup>2</sup> whereas the central municipality of Madrid has an area of just over 600 Km<sup>2</sup>. Clearly these two areas are completely different making comparisons between the central municipalities completely unsatisfactory. The built-up form of the centre of the metropolitan urban region of Barcelona extends well beyond the limits of the central municipality into the surrounding territory, but what criteria should be used for establishing the outward limits of this built-up area? It is clearly of interest to be able to analyse the location of population and housing and economic activity within different spaces of such spatial territories from a morphological perspective and in this sense such territorial analysis deriving from the interpretation of high resolution satellite imagery offers one such viable option. The classification of satellite imagery and the grouping together of different land activities enables territorial analysis to be undertaken, which goes beyond the limits imposed by such analysis which starts out from a predefined administrative units, be they municipal, provincial or regional, or smaller variations thereof.

This paper examines the results of a methodology applied through a number of recent and on-going research projects being undertaken by the Universidad Politécnic de Cataluña <sup>1</sup>, to examine different aspects of the nature of urban development in Spain, concentrating upon the territorial analysis of the morphology of urban development within Spain's two leading European and metropolitan urban regions - Madrid and Barcelona.

## 2 Methodology

### 2.1 Background

The spatial coverage of the metropolitan territories of Madrid and Barcelona provided by the satellite imagery proportioned firstly through a European Union funded research project (EURMET of the INTERREG IIIB Programme) did not cover the full extent of the functional urban regions arrived at through the analysis of the travel to work flows. For this reason the study of the metropolitan dynamics was restricted to administrative areas of a lesser extent – that of the Autonomous Community or Region of Madrid and the Metropolitan Region of Barcelona (RMB).

The Autonomous Community of Madrid (simply Madrid henceforth) groups together some 179 municipalities with an area of over 8,000 Km<sup>2</sup> and a 2001 population of 5.4 million inhabitants. By contrast the Metropolitan Region of Barcelona (henceforth Barcelona) consists of 164 municipalities with an area of 3,239 Km<sup>2</sup> and has a population of some 4.4 million inhabitants.

### 2.2 Data

The 2004 satellite imagery base data used for the study of the two metropolitan urban regions was as follows:

<sup>1</sup> SPOT5 Application and Validation Programme (2003-2004) (Monitoring urban sprawl and other urban rural fringe planning and environmental considerations around Barcelona's metropolitan area); INTERREG IIIB Programme (2003-2005) (EURMET Urban expansion of the metropolitan regions of South Western Europe); Barcelona and Madrid: Two converging models of urban development (MCYT BIA2003-07176); Acciones Integradas Hispano-Portuguesas (Measuring residential density of large urban areas with satellite imagery) (2006-2007) (HP2005-0104).

Madrid

Four Spot 5 panchromatic (2.5 metre resolution) and four Spot 5 multispectral (10 metre resolution) images.

Barcelona

Four Spot 5 panchromatic (2.5 metre resolution) and four Spot 5 multispectral (10 metre resolution) images.

### 2.3 Method

The first part of the methodology consisted of the classification of the respective images.

A supervised classification methodology was used for both urban agglomerations, drawing upon the four images (with 2.5 m and 10 m resolutions) in order to maximise the number of distinguishable land cover classes for the study areas. This methodology employed **maximum and minimum likelihood**, **binary encoding** and **parallel piped methods**, prior to **scattergram processes** and the merging of all the data, drawing upon a **subtraction process** to arrive at the final classified image.

The images were classified without being broken down into smaller units. Rather once the initial classification had taken place, errors were searched for and where these occurred, the sections containing them were removed from the overall image, reclassified as single units and then reinserted in the master image in a mosaic form.

The methodology made use of **ER Mapper** and **ENVI** software applications.

This classification process led to the identification of some eighteen (18) land cover categories for Madrid and twenty one (21) categories for Barcelona, as indicated by Table 2.

Madrid	Land activity category	Barcelona	Land activity category
	Forests		Forests
	Green urban areas		Agriculture
	Residential (historic cores)		Green urban spaces
	Residential (high density)		Residential (historic cores)
	Residential (medium density)		Residential (high density)
	Residential (discontinuous low density)		Residential (medium density)
	Residential (sparse low density)		Residential (discontinuous low density)
	Industrial and Commercial		Residential (sparse low density)
	Airports		Industrial and Commercial
	Mineral extraction		Airports
	Landfill sites		Ports
	Principal roads and railways		Mineral extraction
	Dry land		Landfill sites
	Irrigated land		Principal roads and railways
	Shrub and/or herbaceous vegetation		Beaches
	Green open area		Irrigated land
	Open space with little or no vegetation		Vegetation
	Shallow water		Open spaces
	Clouds		Deep water
			Shallow water
			Clouds
			No-classification

Table 2. Land activity categories obtained from the classification of the SPOT5 satellite images for Madrid and Barcelona

These land activity categories were then grouped together in two major groups, to ascertain the 'artificial' activities, or activities representing some form of development. These artificial activities encompassed:

- Residential (historic cores)
- Residential (high density)
- Residential (medium density)
- Residential (discontinuous low density)
- Residential (sparse low density)

- Industrial and Commercial
- Airports
- Ports (in the case of Barcelona)
- Mineral extraction
- Landfill sites
- Principal roads and railways

In order to establish what could be determined as the morphological centre or core of the respective metropolitan urban regions, an iterative process was undertaken to look for the urban continuity from the centre of the two metropolises. This entailed producing an image of the artificial land activities for both metropolitan regions, but this time excluding the land activity category of principal roads and railways. The inclusion of this land activity would have led to an urban continuity throughout the entire metropolitan territories being studied. The corresponding images showing the spatial extent of the artificial activities, excluding the principal roads and railways, can be seen in Figures 3a for Madrid and 4a for Barcelona.

From the centre of both metropolitan regions, buffer zones were created on the outskirts of the built-up areas lying in closest proximity to these centres, in order to capture the adjoining artificial areas lying within a distance of at less than 200 metres from the central area. The result of the application of these buffer zones are shown in Figures in Figures 3b for Madrid and 4b for Barcelona.

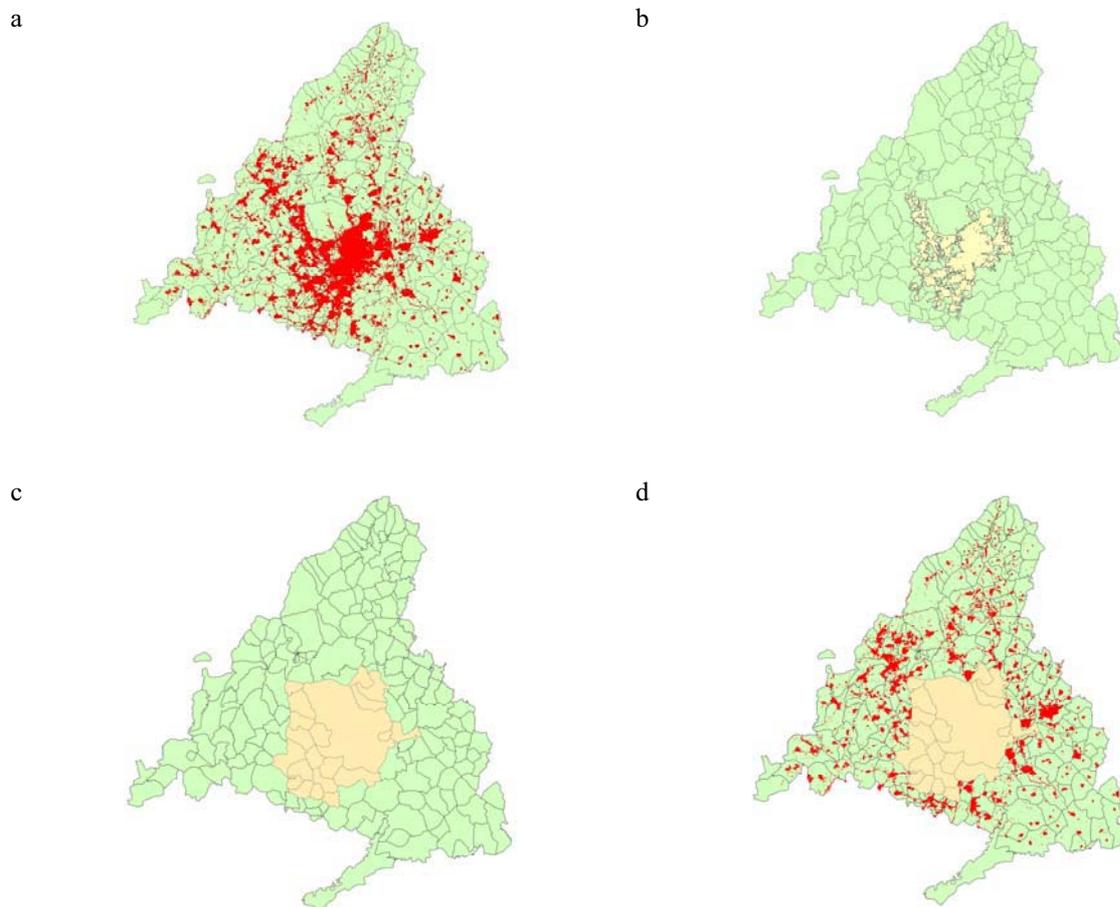


Figure 3 (a-d). Schematic outline of the methodology adopted to determine the morphological core and peripheral area of the metropolitan urban region of Madrid

The fringe areas of this continuum were examined in detail to ensure that the outermost areas contained the principal settlement of the corresponding municipality. Where the fringe area contained the principal settlement of the underlying municipality, the fringe area was added to the core area. However in the case of a fringe area of development not containing the principal settlement of the underlying municipality, and the separation from the principal settlement being of more than 200m, the fringe area was not added to the core areas. This assessment led to the identification of the municipalities comprising the respective morphological cores of Madrid and Barcelona, which are illustrated in Figures 3c for Madrid and 4c for Barcelona.

Conversely the peripheral areas of the two metropolitan urban regions are the remainder of those lying beyond the confines of the morphological cores, as indicated in Figures 3d for the case of Madrid and 4d for the case of Barcelona.

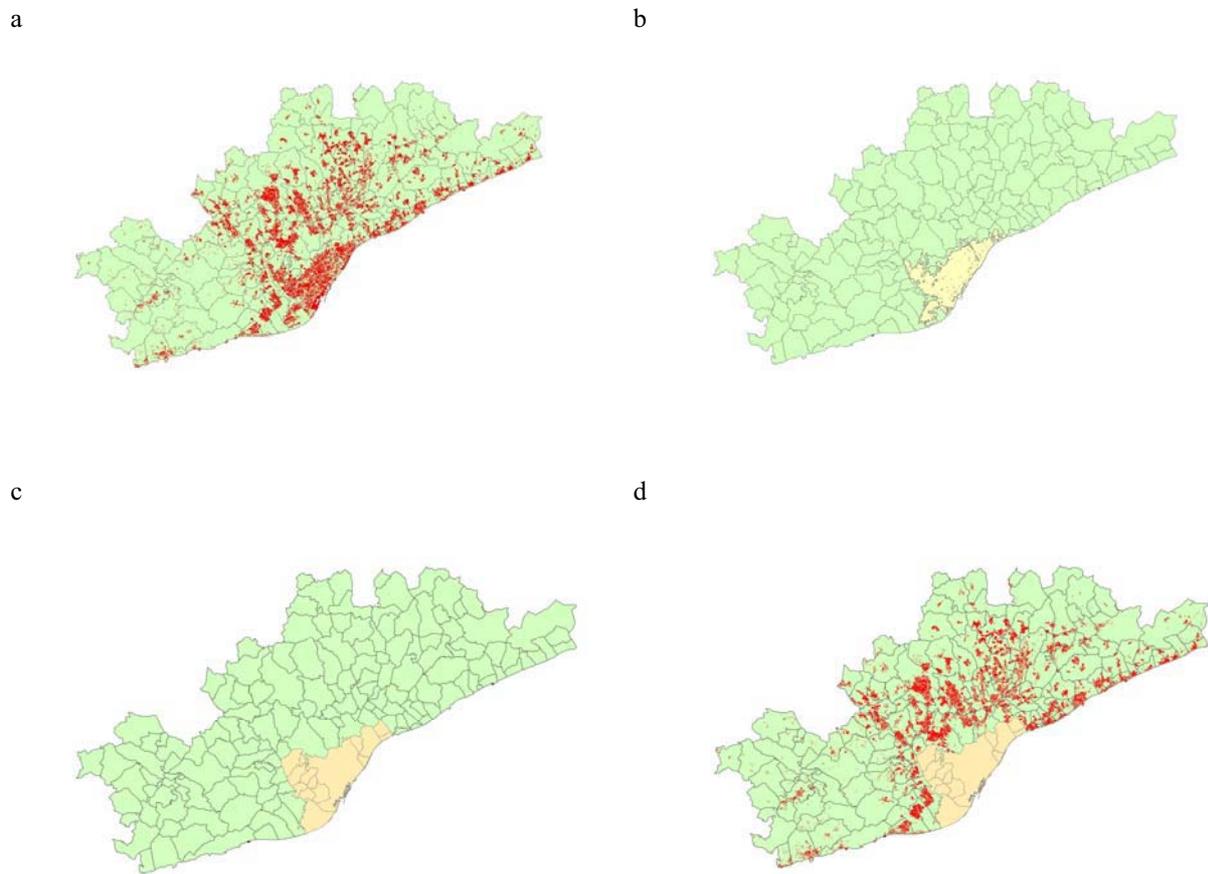


Figure 4 (a-d). Schematic outline of the methodology adopted to determine the morphological core and peripheral area of the metropolitan urban region of Barcelona

#### 4 Results

In the case of Madrid, the morphological core includes a total of 20 municipalities - Alcobendas, Alcorcón, Arroyomolinos, Boadilla del Monte, Coslada, Fuenlabrada, Getafe, Humanes de Madrid, Leganés, Madrid, Majadahonda, Moraleja de Enmedio, Móstoles, Parla, Pozuelo de Alarcón, las Rozas de Madrid, San Fernando de Henares, San Sebastián de los Reyes, Torrelodones and Villaviciosa de Odón – lying with a maximum distance of 36 Km. from the centre of Madrid. This covers an area of 1,374 Km<sup>2</sup>, representing 18.5% of the metropolitan territory. (See Table 3)

By contrast the spatial extent of the morphological core of Barcelona is considerably smaller (238 Km<sup>2</sup>) representing 7% of the metropolitan territory. This consists of some 14 municipalities - Badalona, Barcelona, Cornellà de Llobregat, Esplugues de Llobregat, l’Hospitalet de Llobregat, Molins de Rei, Montgat, el Prat de Llobregat, Sant Adrià de Besòs, Sant Feliu de Llobregat, Sant Joan Despí, Sant Just Desvern, Santa Coloma de Gramenet and Tiana – lying no further than 17 Km. from the centre of Barcelona. (See Table 4)

Another fundamental difference that needs highlighting is that according to the results of the classification of the land activities, in the case of Madrid there is a much higher concentration of residential, and industrial and commercial activity in the morphological core than in the metropolitan periphery. This characteristic is completely different to what is found in the case of Barcelona. In Madrid, 57.4% of all the artificial or developed land for residential activities is found within the morphological core, as is 58.3% of the artificial or developed land for industrial and commercial activities. By contrast, the morphological centre of Barcelona contains just 26.6% of all

the artificial or developed land for residential activities and just 25.5% for industrial and commercial activities. Therefore from this simple comparison it would seem that the metropolitan periphery of Barcelona plays a much more important role in the spatial configuration of the wider metropolitan territory with regard to the localization of residential, as well as industrial and commercial activity, than is the case in Madrid.

Territorial area	Administrative area (Km <sup>2</sup> )	Area of artificial or developed land (A) (Km <sup>2</sup> )	Area of non- artificial or non- developed land (B) (Km <sup>2</sup> )	Total (A+B) (Km <sup>2</sup> )
Madrid (central municipality.)	605.77 (7.55%)	192.982 (28,76%)	412.257 (6,13%)	605.239 (8,18%)
Morphological core	1,374.35 (18.51%)	384.938 (57.37%)	987.604 (14.68%)	1,372.541 (18.55%)
Metropolitan periphery (1)	6,647.45 (82.27%)			
(2)	6,050.36	285.998 (42.63%)	5,739.397 (85.32%)	6,025.395 (81.45%)
CCAA Madrid (1)	8,021.8			
(2)	7,424.71	670.936	6,727.001	7,397.937

Table 3. Morphological core and metropolitan periphery of Madrid

(1) These figures refer to the remaining 159 municipalities of the CCAA Madrid. (2) 153 municipalities, given that the satellite images did not provide full coverage for the following municipalities: Aranjuez, Brea de Tajo, Cenicientos, Colmenar de Oreja, Estremera and Fuentidueña de Tajo.

Territorial area	Administrative area (Km <sup>2</sup> )	Area of artificial or developed land (A) (Km <sup>2</sup> )	Area of non- artificial or non- developed land (B) (Km <sup>2</sup> )	Total (A+B) (Km <sup>2</sup> )
Barcelona (central municipality)	98.21 (3.03%)	67.7985 (12.29%)	33.0297 (1.23%)	100.8282 (3.11%)
Morphological core	238.50 (7.36%)	129.1757 (23.42%)	111.4039 (4.15%)	240.5796 (7.43%)
Metropolitan periphery RMB	3,000.70 (92.64%)	422.44 (76.58%)	2,575.02 (95.85%)	2,997.46 (92.57%)
	3,239.20	551.6128	2,686.424	3,238.037

Table 4. Morphological core and metropolitan periphery of Barcelona

## 5 Discussion and Conclusions

It is important to highlight the fact that although the previous section emphasised the importance of the metropolitan periphery of Barcelona as a place for the location of economic activity, in some cases parts of this peripheral area would realistically form part of the morphological core of Madrid. The application of the same methodology to determine the morphological cores of the two metropolitan urban regions clearly led to the identification of a *morphological core of Madrid of 1,374 Km<sup>2</sup>* compared with the *238 Km<sup>2</sup> of the morphological core for Barcelona*.

With regard to the location of the local workplaces, some 85% of these lie within the morphological core of Madrid, compared with some 57% of the local workplaces of Barcelona within its morphological core.

Looking at the distribution of artificial or developed land in the metropolitan urban regions, in the case of Madrid one finds a *greater proportion of the artificial land in its morphological core (57.4%)* than in its metropolitan periphery (42.6%). By contrast in Barcelona the *greater proportion of artificial or developed land (76.6%) is located in the metropolitan periphery*, with less than a quarter (23.4%) in the morphological core. Furthermore in

the case of Madrid with the exception of Coslado, all the municipalities of the metropolitan territory are characterised by having a greater proportion of non-artificial or undeveloped land than artificial or developed land. However in Barcelona, this tendency does not take form until one arrives at the municipalities lying some 12 Km. from the principal central municipality of Barcelona. Even having said that, there are a number of municipalities lying within the metropolitan periphery where the proportion of artificial or developed land is larger than that pertaining to non-artificial or undeveloped land.

The analysis of different aspects of the population and housing, and economic activity, within the different parts of the two metropolitan urban regions being examined here, back the notion of a *metropolitan territory of Barcelona structured in a polynuclear form*, identifying the importance of sub-centres focussed upon the municipalities of Sabadell, Granollers, Terrassa, Mataró and Vilanova i la Geltrú, which are all found lying with the metropolitan periphery. These five sub-centres proportioned jointly almost 20% of the local workplaces of the entire metropolitan urban region in 2001. By contrast, despite the relative importance of the N-II corridor leading towards Guadalajara within the territorial configuration of Madrid, such sub-centres of a comparable nature with those if Barcelona are not to be found, and it seems that the *metropolitan ambit of Madrid is characterised by a mono-nuclear structure of a classical nature*.<sup>2</sup>

To conclude, in order to comply with the policies of the European Union regarding the promotion of a balanced and polycentric form of regional development [3], it would seem necessary to encourage a functional territorial structure in Madrid and especially in the area of metropolitan periphery, based upon important nodes. Changes in the territorial policies in this way would contribute to correct the existing imbalances within the functional structure of the wider region and avoid the associated negative externalities which the Autonomous Community increasingly has to face.

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<sup>2</sup> It is appropriate to make reference to a study (Font, A. (ed.) (2004) *L'explosió de la ciutat. Morfologies, mirades i mocions*, COAC, Forum Universal de les Cultures Barcelona 2004, Barcelona) of a European scale carried out in recent years, directed towards analysing the morphological transformation of 13 cities in the regions of Southern Europe. Lisbon and Oporto (Portugal); Marseille and Montpellier (France); Emilia-Romana, Genoa, Milan, Naples and Venice (Italy); and Barcelona, Donostia-Bayona, Madrid and Valencia (Spain). In terms of referring to the metropolitan configurations, the spatial structures and forms of urban growth of this study described the morphology of Madrid as "mononuclear, of disperse growth" and that of Barcelona as "polynuclear, with a dominant nucleus and disperse growth". (Font, 2004, p. 332)

MADRID	CENTRE		PERIPHERY		TOTAL	
	Km <sup>2</sup>	%	Km <sup>2</sup>	%	Km <sup>2</sup>	%
<b>Residential activity</b>						
Residential (historic cores)	2.1583	0.56068828	1.5977	0.55864007	3.756	0.5598152
Residential (high density)	7.3704	1.91469994	4.632	1.61959118	12.0024	1.78890466
Residential (medium density)	17.2044	4.46939972	13.9236	4.86842395	31.128	4.63949079
Residential (discontinuous low density)	19.2863	5.01024062	13.8751	4.8514658	33.1614	4.94256007
Residential (sparse low density)	48.8854	12.6995648	36.2734	12.6830913	85.1588	12.6925427
<b>Industrial and Commercial Activity</b>						
Industrial and Commercial	96.5618	25.0850527	69.0573	24.1460695	165.6191	24.6847947
<b>Other categories</b>						
Principal roads and railways	127.3219	33.0759843	99.9495	34.9476098	227.2714	33.8737974
Airports	9.9399	2.58221073	0.0284	0.00993014	9.9683	1.48573105
Green urban areas	56.2092	14.6021589	46.6611	16.3151783	102.8703	15.3323634
<b>Artificial or developed</b>	384.9376	(100)	285.9981	(100)	670.9357	(100)
<b>Non-artificial or undeveloped land</b>	987.6038		5739.3972		6727.001	

Table A.1. Land cover activities of the CCAA de Madrid detected through the interpretation of the SPOT5 satellite imagery

RMB	CENTRE		PERIPHERY		TOTAL	
	Km <sup>2</sup>	%	Km <sup>2</sup>	%	Km <sup>2</sup>	%
<b>Residential activity</b>						
Residential (historic cores)	1.5981	1.23715219	1.9158	0.4535113	3.5139	0.63702293
Residential (high density)	22.0506	17.0702384	33.1098	7.83780591	55.1604	9.99984047
Residential (medium density)	12.0285	9.31173588	41.2749	9.77066172	53.3034	9.66319128
Residential (discontinuous low density)	2.7698	2.14421133	18.1614	4.29919626	20.9312	3.79454574
Residential (sparse low density)	1.4638	1.13318527	15.7445	3.72706375	17.2083	3.11963392
<b>Industrial and Commercial activity</b>						
Industrial and commercial	18.3321	14.1916011	53.6488	12.6998315	71.9809	13.0491714
<b>Other categories</b>						
Principal roads and railways	40.4627	31.3237706	139.5714	33.0395697	180.0341	32.6377669
Airports	3.4477	2.66900044	0.1039	0.02459538	3.5516	0.64385743
Ports	4.9631	3.8421313	0.9328	0.22081394	5.8959	1.06884757
Green urban areas	22.0375	17.0600972	117.295	27.7662639	139.3325	25.2591129
Landfill sites	0.0218	0.01687624	0.6788	0.16068664	0.7006	0.12700938
<b>Artificial or developed</b>	129.1757	(100)	422.4371	(100)	551.6128	(100)
<b>Non-artificial or undeveloped land</b>	111.4039		2,575.0204		2,686.4243	

Table A.2. Land cover activities of the RMB detected through the interpretation of the SPOT5 satellite imagery