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**THE OUTWARD EXPANSION OF THE BUILT-UP AREAS OF MADRID AND
BARCELONA INTO THEIR SURROUNDING METROPOLITAN REGIONS
(1986-2004)**

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The modern process of urbanisation was experienced in Spain later than that compared with other European countries. It was after 1959 when urbanisation 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 20th Century. As a consequence, Spain's seven principal 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.

While traditionally Southern European or Mediterranean cities have been characterised for their more compact urban form, compared to Northern European cities, currently there is considerable concern in Spain over the question of land consumption and the outward expansion of urban areas into surrounding rural areas. This concern can be witnessed within the context of seeking to achieve more sustainable patterns of urban growth, and social and economic, as well as territorial, cohesion, reflecting the contemporary spatial planning policy objectives of the European Commission.

Research carried out between 2003-2006 with funding from the Spanish Central Government, together with complementary funding from the European Commission

under the INTERREG IIB Programme, enabled a comparative assessment to be made of the physical growth experienced by Madrid and Barcelona over the period 1986-2004. Functional approaches to the territorial analysis of the two metropolises have previously contrasted the mononuclear urban form of Madrid, with the more polynuclear form of Barcelona. However this recent research, based upon the interpretation of satellite imagery, has highlighted clear differences in their morphological form. As outlined in this paper, Barcelona's metropolitan urban region has a more compact central area with an important distribution of economic activity in its peripheral area, whereas the central area of Madrid's metropolitan urban region is much greater in spatial and demographic terms, containing a more significant proportion of the urban region's economic activity than the periphery. Further in the case of Madrid there has been a noticeable outward expansion of its morphological core over the period 1986-2004, whereas such expansion of the morphological core of Barcelona over the same period has been minimal. Rather Barcelona has witnessed an outward expansion of development within the metropolitan periphery, leading to a very different metropolitan form to that of Spain's capital.

1. INTRODUCTION

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 travel to work 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 (CPSV, 2001).

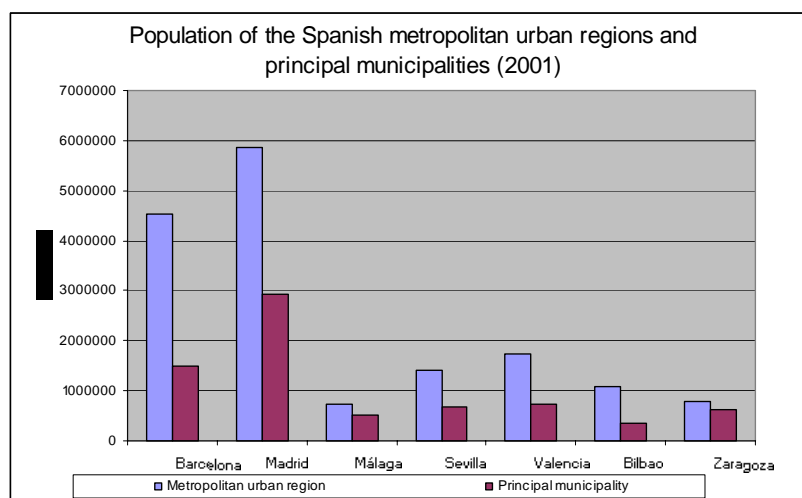


Figure 1. Population of the seven principal Spanish metropolitan urban regions (2001)

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 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 having the highest 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%), followed by 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 (km²)</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 areas by necessity treats the territories as uniform, and is unable to make an obvious distinction between the central cores 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 the 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 km² whereas the central municipality of Madrid has an area of just over 600 km². Clearly these two areas are completely different making comparisons between the two 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 aerial photography and high resolution satellite imagery offers one such viable option. Where permitting, the classification of satellite imagery and the grouping together of different land activities enable territorial analysis to be undertaken, which goes beyond the limits imposed by such analysis which starts

out from an analysis based upon pre-defined 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 Cataluña¹, to examine different aspects of the nature of urban development in Spain, concentrating upon the spatial analysis of large urban areas. This methodology is discussed in the context of the Madrid and Barcelona, Spain's two leading European metropolitan urban regions, through the comparison of satellite imagery over the period 1986-2004.

2 Methodology

2.1 Background

The 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 spatial extent of the functional urban region, resulting from the analysis of the travel to work flows. For this reason the study of the metropolitan dynamics was restricted to the administrative areas corresponding to the Autonomous Community or Region of Madrid and the Metropolitan Region of Barcelona (RMB).

The Autonomous Community or Region of Madrid (simply Madrid henceforth) groups together some 179 municipalities with an area of over 8,000 km² and had 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 km² and has a current population of some 4.7 million inhabitants.

2.2 Data

Satellite imagery was obtained for two dates – 2004 and 1986. The detail of the data for the two years was as follows:

- a) 2004: Spot 5 panchromatic (2.5 metre resolution) and Spot 5 multi-spectral (10 metre resolution) images; and
- b) 1986: Spot 3 multi-spectral (20 m 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 the urban agglomeration, drawing upon the four 2004 images (with 2.5 m and 10 m resolutions) in order to maximise the number of distinguishable land cover classes for the study area. This

¹ 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); and The Urbanization Process on the Mediterranean Coast: towards an unsustainable model of land occupation? a retrospective (1956-2006) and prospective (2006-2026) analysis (SEJ2006-096390/GEO).

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 2004 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		Green urban spaces
	Residential (historic cores)		Residential (historic cores)
	Residential (high density)		Residential (high density)
	Residential (medium density)		Residential (medium density)
	Residential (discontinuous low density)		Residential (discontinuous low density)
	Residential (sparse low density)		Residential (sparse low density)
	Industrial and Commercial		Industrial and Commercial
	Airports		Airports
	Mineral extraction		Mineral extraction
	Landfill sites		Landfill sites
	Principal roads and railways		Principal roads and railways
	Dry land		Ports
	Irrigated land		Irrigated land
	Shrub and/or herbaceous vegetation		Vegetation
	Green open area		Beaches
	Open space with little or no vegetation		Open spaces
	Shallow water		Deep water
	Clouds		Shallow water
			Clouds
			Agriculture
			No-classification

Table 2. Land activity categories obtained from the classification of the 2004 SPOT5 satellite images for Madrid and Barcelona

This process was repeated for the 1986 data, though the lower resolution of the data meant that not all of the land cover classes of the 2004 images were able to be replicated.

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) (in the case of the 2004 data)
- Residential (high density)
- Residential (medium density)
- Residential (discontinuous low density)
- Residential (sparse low density)
- Industrial and Commercial
- Airports
- Ports
- Mineral extraction
- Landfill sites (in the case of the 2004 data)
- Principal roads and railways
- Green urban spaces

In order to establish what could be determined as the morphological centre or core of the metropolitan urban region, an iterative process was undertaken to look for the urban continuity from the centre of the metropolis. This entailed producing an image of the artificial land activities for metropolitan region, 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 territory being studied. The corresponding images showing the spatial extent of the artificial activities, excluding the principal roads and railways, can be seen in Figures 2a-5a, for Madrid and Barcelona in 2004 and 1986.

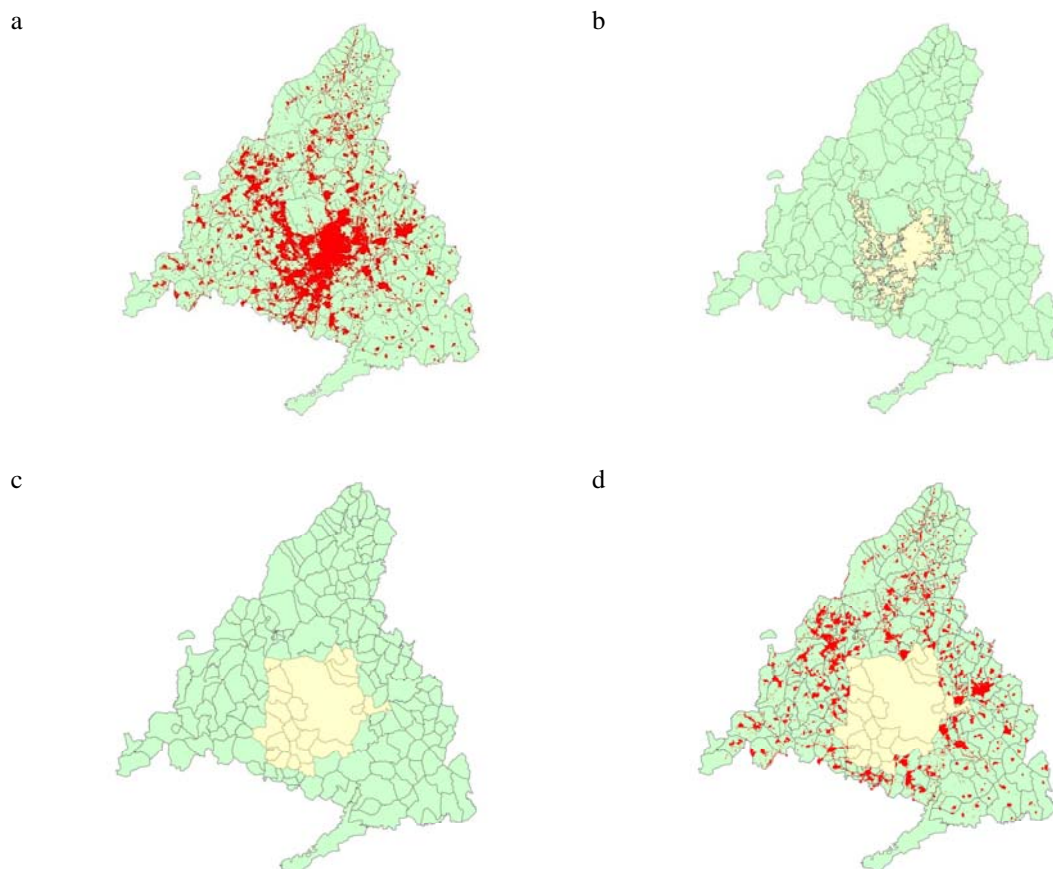
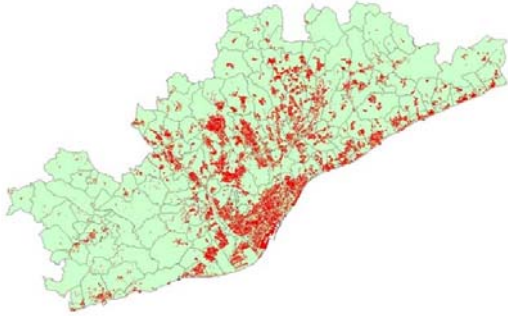


Figure 2 (a-d). Schematic outline of the methodology adopted to determine the morphological core and peripheral area of the metropolitan urban region of Madrid (2004)

From the centre of the metropolitan region, buffer zones were created on the outskirts of the built-up areas lying in closest proximity to the centre, in order to capture the adjoining artificial areas lying within a distance of at less than 200 metres from the central area. The results of the application of these buffer zones are shown in Figures 2b-5b for Madrid and Barcelona in 2004 and 1986.

a



b



c



d

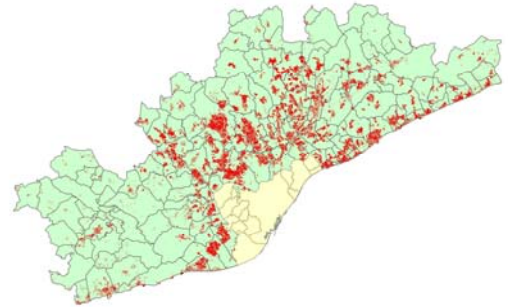


Figure 3 (a-d). Schematic outline of the methodology adopted to determine the morphological core and peripheral area of the metropolitan urban region of Barcelona (2004)

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 morphological cores of Madrid and Barcelona, which are illustrated in Figures 2c-5c, in 2004 and 1986.

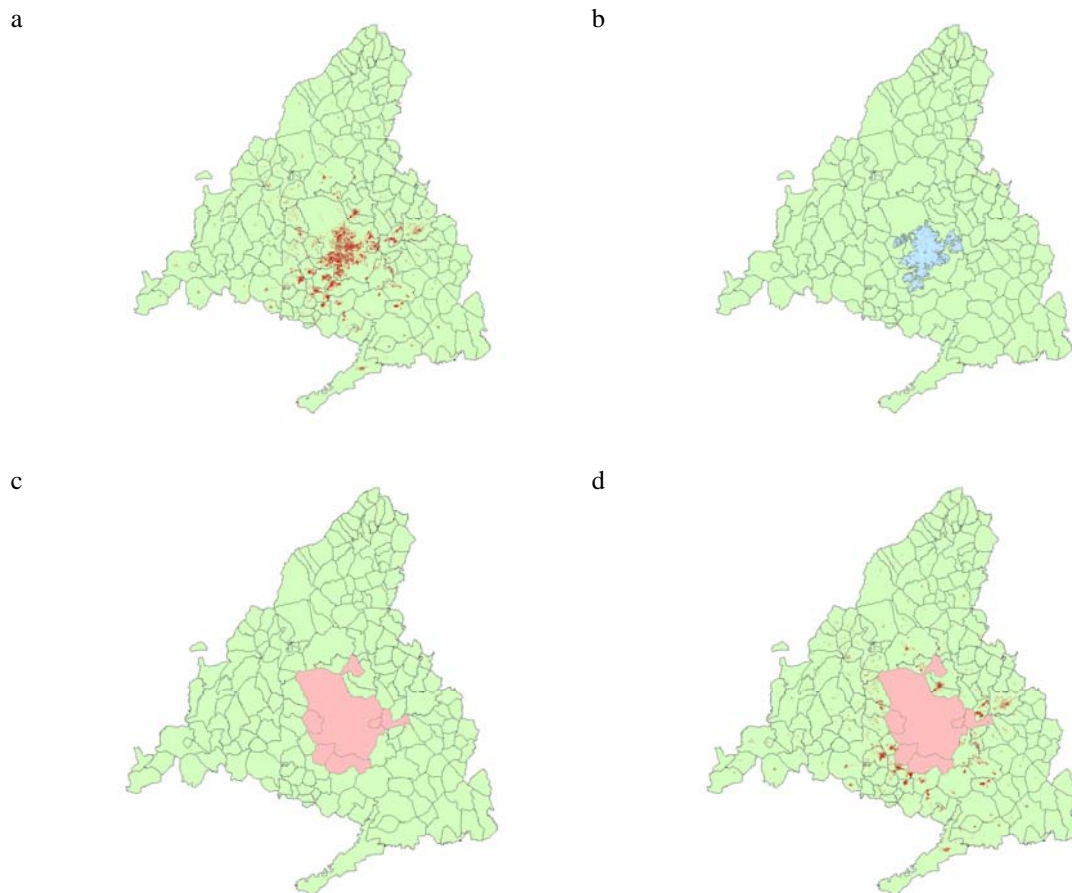


Figure 4 (a-d). Schematic outline of the methodology adopted to determine the morphological core and peripheral area of the metropolitan urban region of Madrid (1986)

Conversely the peripheral areas of the metropolitan urban regions for the two years are represented as the remainder of those areas lying beyond the confines of the morphological cores, as indicated in Figures 2d-5d, in 2004 and 1986.

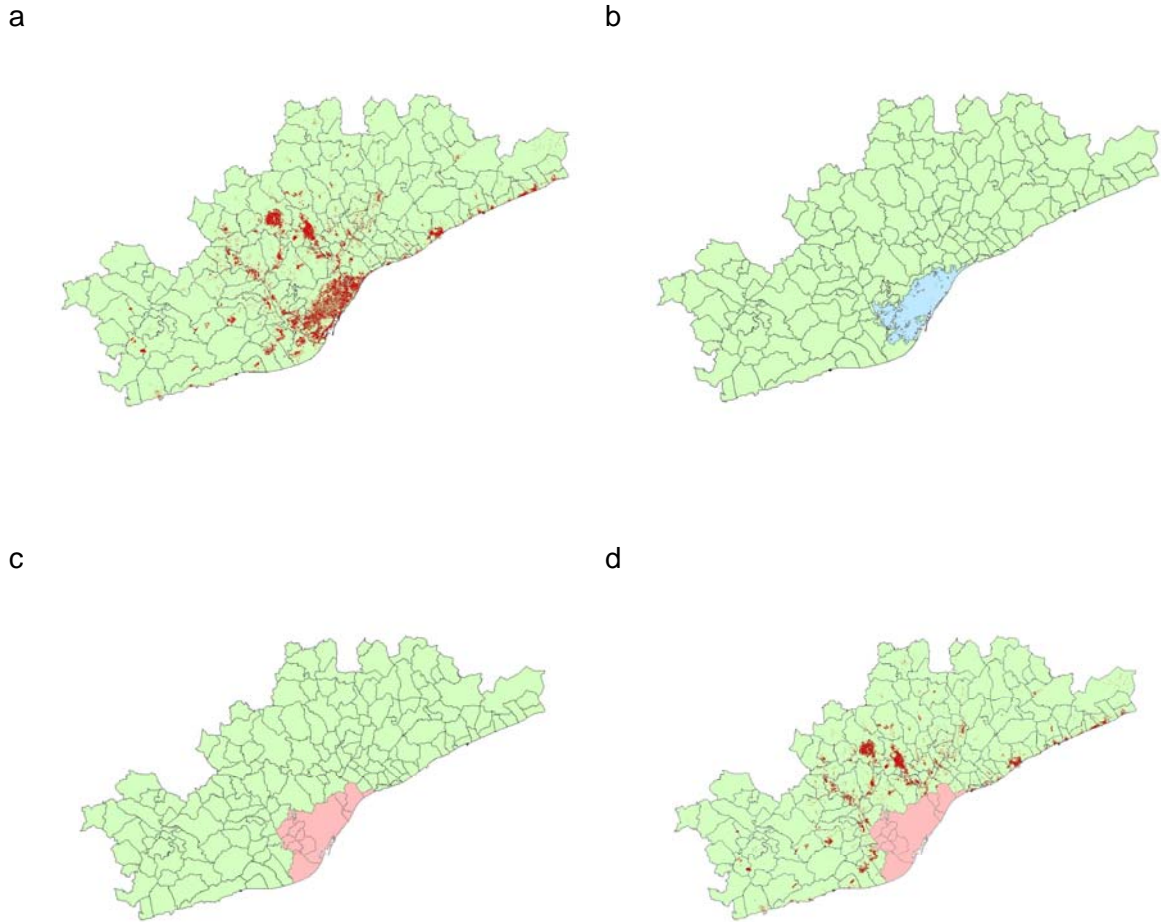


Figure 5 (a-d). Schematic outline of the methodology adopted to determine the morphological core and peripheral area of the metropolitan urban region of Barcelona (1986)

4 Results

In the case of Madrid, the morphological core in 2004 included 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, Torreldones and Villaviciosa de Odón – lying with a maximum distance of 36 km. from the centre of Madrid. This covered an area of 1,374 km², representing 18.5% of the metropolitan territory. (See Table 3) The spatial extent of the morphological core of Barcelona in 2004 was found to be 238 km² in area, representing 7% of the metropolitan territory. This consisted 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.

However the definition of the morphological centres drawing upon the 1986 data and following the same methodology produced very different results in the case of Madrid. Madrid's morphological core for 1986 was found to extend over an area of just over 822 km² and comprised just 6 municipalities - Coslada, Getafe, Leganés, Madrid, Pozuelo de Alarcón and San Fernando de Henares. Over the eighteen year period Madrid's morphological core had expanded by some 552 km². By contrast in the case of Barcelona, the 1986 morphological core covered almost 215 km², comprising 12 municipalities - Badalona, Barcelona, Cornellà de Llobregat, Esplugues de Llobregat, L'Hospitalet de Llobregat, Montgat, El Prat de Llobregat, Sant Adrià de Besòs, Sant Feliu de Llobregat, Sant Joan Despí, Sant Just Desvern and Santa Coloma de Gramenet. Therefore in the period between 1986 and 2004, the magnitude of the Barcelona's morphological core had increased by just 23 km².

Territorial area	Administrative area (km ²)	Area of artificial or developed land (A) (km ²)	Area of non-artificial or non-developed land (B) (km ²)	Total (A+B) (km ²)
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 ²)	Area of artificial or developed land (A) (km ²)	Area of non-artificial or non-developed land (B) (km ²)	Total (A+B) (km ²)
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	3,000.70 (92.64%)	422.44 (76.58%)	2,575.02 (95.85%)	2,997.46 (92.57%)
RMB	3,239.20	551.6128	2,686.424	3,238.037

Table 4. Morphological core and metropolitan periphery of Barcelona (2004)

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 km²* compared with the *238 km² 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.*²

These considerations are further strengthened when looking at the mobility patterns for the two metropolitan urban regions, based upon a more functional analysis through the interpretation of travel to work patterns deriving from the 2001 Census. Figure 6 indicates the dominance of the core municipality of Madrid within the wider spatial configuration, which can be seen as a marked contrast to the hierarchy of sub-centres within the Metropolitan Region of Barcelona.

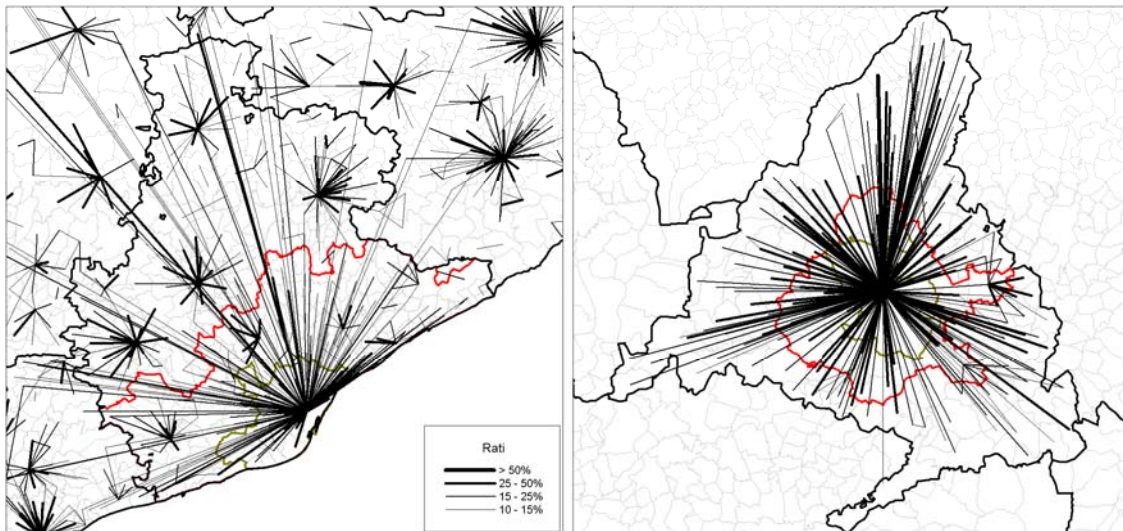


Figure 6. Commuting flows based upon 2001 Census (Fij/PORi>10%) for Barcelona and Madrid

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, 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.

² 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)

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