CARLOS MARMOLEJO DUARTE*, NANCY RUIZ ESTUPI ÁN, MOIRA TORNÉS FERNÁNDEZ**

Is the Polycentrism a Desirable Feature in the Construction of Sustainable Residential Environments?

Revisiting its Conceptualization from the Travel-to-work Perspective: an Analysis for the Biggest Metropolitan Areas in Spain

Abstract

The urban form is an important issue on explaining quality of life or housing environments, since it has implications in terms of social, environmental and economic aspects. In this paper, taking as case study the seven biggest metropolitan areas in Spain, we explore whether urban form, understood as polynucleation (morphological) is related to polycentricity (functional) understood as the level of interconnections depicted by journey-to-work mobility. We found a high correlation between the morphological and functional sides of polycentrism, nonetheless, polycentricity succeed in understanding the kind of relations among subcenters, namely it permits to foreseen the kind of transportation systems needed in each of the studied cities. In terms of social, economic and environmental sustainability, it is exposed the discussion on whether a high level of polynucleation and interlinking would be more desirable in the construction of the house of tomorrow.

Keywords: Urban Structure, polycentrism, polycentricity, residential environments, Metropolitan Areas, Spain

Introduction

The study of polycentrism has been applied along urban territories in order to identify and explain the components of the structure as well as the transformation of cities in metropolitan systems, with their impact on the social, demographic, economic and environmental. It is clear the need to go beyond the paradigm of monocentric city and conveniently to penetrate in the analysis of the current metropolis as large artifacts, composed by a series of settlements which are in fact related to each other. In practical terms, the study of polycentrism is responsible for identifying subcenters that integrate urban systems, as well as measuring the magnitude of the phenomenon in urban reality.

Meanwhile, in regard to the degree of polycentrism of an urban area, can be clearly identified two currents that have been widely studied, almost always independent of one another. The first is related to morphological analysis linked to the analysis of the density and shape of population distribution and employment in their cores and its hinterland. The second trend is related to the functional analysis tied to the study of flows that arise between different cores and their hinterland, linking complementary areas. The separate study of both approaches cannot delve into issues as relevant as some regions tend to be more functionally polycentric than morphological (Burger and Meijers, 2012). By contrast, integrating both tasks would lead to conclude that the coincidence of morphologic and functional polycentrism would be symptomatic of the existence of places that are not only dense, but also that structure territory and become structural places.

A further development of the measurement of functional polycentrism is presented by Green (2007) proposing the “functional polycentricity” concept, emphasizing the term polycentrism related to the simple morphological polynucleation, from functional related to the network operation of the system. According to Green,

* Carlos Marmolejo Duarte, Associate Professor, Center for Land Policy and Valuations, Universitat Politècnica de Catalunya, Barcelona Tech.
** Nancy Ruiz Estupi án, Moira Tornés Fernández, Universitat Politècnica de Catalunya, Barcelona Tech.

functional polycentricity level is not defined by the proximity between nodes but by the relationship between them. Based on the methods of social network analysis, has proposed the indicator of "network density" that attempts to measure how much flows are balanced between the nodes: the more connected they are and such distribution is more uniform, the higher functional polycentricity level is in the system.

The first chapter of this paper reviews the state of the art of the constituent elements of polycentrism studies; the second will examine very closely the study of functional polycentricity; in the third apart it will present the methodology, as well as the scope and sources of information for the study; and finally, the fourth chapter presents the results of measuring polycentricity phenomenon in Spanish metropolitan areas, and offers insights into how this issue might play an important role in the construction of sustainable residential environments.

State of the Art: morphology and functionality

The empirical study of polycentrism has used different methods of analysis, which may differ, depending on the criteria used, into two spheres almost always independent each of other. The first is the morphological criterion, about the study of the shape and distribution of the population density or workers in the various cores that make up a metropolitan area and their respective hinterlands. The second criterion, conceived from the functional sphere is about connectivity relationships, that is to say, the amount and intensity of flows between members that make up the metropolitan phenomenon and complementary relationships created from these. Thus, the terms polynucleation, referring to the morphological approach and polycentricity to the functional, become the pillars of research of modern metropolis transformations, and integrating both approaches lead to genuine study of polycentrism (for further discussion see Marmolejo et al., 2013). All approximations already seen answers two fundamental issues in the study of polycentrism: the detection and identification of the cores that make up the area, whether they are called sub-centers in the metropolitan scale or centers in regional; and to measure the magnitude of the phenomenon in territorial dimension and dynamics it involves. What follows is a review of existing literature, taking as reference the criteria which, as we saw, underlying the study of polycentrism.

Morphological approach

From the point of view of the morphology of cities, the polynucleation basically refers to the plurality of urban centers in a given territory, and more specifically to the balanced distribution in size and importance of these urban centers and interaction with their areas of influence. Under this perspective, a polycentric development policy can be considered as one aimed at the distribution of the economic functions on space, attempting the territorial balance through the modulation of urban hierarchies (Burger and Meijers, 2012).

Regarding the detection of the components of a polycentric environment it can be said that the element of analysis has been largely associated to density workers and their distribution in space. From this point of view, specialized literature has developed four methods as follows:

a. Employment density peaks which consists in identifying alterations or peaks over surrounding areas by analyzing the spatial distribution of the density function based on Geographic Information Systems tools, being candidates to subcentres those local employment peaks found. This method was used in the first instance by McDonald (1987) and taken up by McDonald and McMillen in 1990.

b. Reference thresholds, which take into account both the density (jobs per square kilometer) and absolute values or critical mass of jobs, of which are highlighted works by Giuliano and Small (1991), McDonald and McMillen (1998) and Garcia-López (2007).

c. A third approximation of density consists of parametric methods that determine subcentres by analyzing the positive residuals on an employment density function, as in the study of McDonald and Prather (1994).

d. Finally, using non-parametric methods to identify local employment density peaks, considering the specific local two-dimensional space through the use of local or geographically weighted regression, where McMillen and McDonald (1997), McMillen (2001) Craig and Ng (2001) and Readfearn (2007) are pioneers.

Meanwhile, in terms of dimensioning and measurement of the phenomenon of polynucleation at a metropolitan scale, mainly highlights three practices:

a. The rank size distribution used by Hall and Pain (2006) Meijers (2008) and Burger and Meijers (2012) measures the equipotential centers through their demographic size. The flatter the rank-size relationship is more uniform the distribution of the population, which can be interpreted as a higher rate of polycentrism.

b. The analysis of the distribution of employment / population among centers through indicators such as percentage or as integrated indicators as entropy studied by Marmolejo et al (2012) and Masip and Roca (2012).

c. The spatial distribution under the criterion of measurement of the distance of the cores using spatial autocorrelation of density or GINI indicator, introduced by Tsai (2005).

Functional approach

The concept of polycentrism approached from the functional perspective refers to the analysis of flows that for very different reasons occur between the cores and their hinterland linking complementary functional areas. However, it is implied that a number of prominent flows themselves do not guarantee the polycentric deve-

lopment of an urban or regional area, for which also necessary to have some balance in emerging relationships such connectivity. In this sense the more diverse (i.e. multidirectional), bidirectional (i.e. reciprocal) and dense (i.e complementary or not self-contained / self-sufficient) is the network of flows greater is polycentricity. The polycentricity seems closer to the concept of polycentrism of the ETE which presupposes that such development reinforces the cores own economy by enabling network economies (Boix and Trullen, 2012), complementary to the agglomeration within concentrations of economic activity.

The functional approach is derived from the theory of systems of cities (Berry, 1964; Pred, 1977; Dematteis, 1985), which is opposed to the central place theory (Christaller, Losch 1933, 1954) as an evolution of the same and thus is best inscribed in the field of geography. In recent literature three methods are applied to detect subcenters by route of flow analysis:

a. The attraction ratio (multipurpose travelers attracted / employed people) using the criterion of identifying areas that attract significantly more journeys than others after controlling for the number of jobs on the contributions of Gordon, Richardson & Giuliano (1989), Gordon & Richardson (1996).

b. The spatial interaction models, with criteria for identifying areas where attracted flows are higher than predicted by a gravity model that controls the mass of both the attractor and emitting area and the distance between them as Camagni applications (1994); Trullen & Boix (2000).

c. That of the subsystems under the criteria for identifying areas that structure functional subsystems, understood by them all the areas connected by high values of interaction (VI). The VI is the bidirectional strength of connection of two zones being calculated from flows, once mass controlled, used by Roca & Moix (2005) Roca, Marmolejo & Moix (2009) Roca, Arellano & Moix (2011).

On the other hand, functional methods for the measurement of polycentrism from the functional perspective have been primarily used on a regional scale where the interaction between the different centers is not as obvious as it is the interaction that arises between the subcenters within a metropolitan area. In Europe, in contrast to North America where the polycentric performance mainly derives from concentrated decentralization from central cities, the European polycentricity derives priority, but not limited to, the incorporation of formerly independent centers, and therefore the emphasis has been the measurement of the functional relationships between the centers attached to the network. The following briefly describes the three methods developed for this purpose:

a. The spatial distribution that Goei et al. (2010) applies to measure bivariate relationships between centers unexplained by their mass and the distance between them.

b. The indices based on mobility, for example internal centrality index, the rate of relative interaction, dominance, entropy of flows, symmetry index, etc. This family of methods has been used by authors such as Boix (2002); Limtanakool et al. (2007, 2009), Burger and Meijers (2011), Gallo and Garrido (2012); Vi uela et al. (2012).

c. Based on social networks analysis, whose criterion is the measurement of inequality in the distribution of flows among centers, used by Green, N. (2007) and on which we delve into the next chapter, as it represents the body of the present work.

Funcional polycentricity in metropolitan areas

Within the family of methods oriented to study the polycentrism from a functional perspective, it highlights the contribution of Nick Green (2004, 2005, 2007). Green retakes graph theory used in geography (Haggett, 1965; Chorley and Haggett, 1967 and Tinkler, 1977) according to which could be understood regions as formed by cities that act as nodes in a network whose vertices allow establishing complementary relationships of people, material, energy and information. This perspective allows us to incorporate aspects of the topography of the region, as the number of nodes or zones, and furthermore the level of interlinking (diversity, bidirectionality and complementarity). Therefore, the author considers that this is the appropriate framework for analyzing what he calls “functional polycentricity”. Such that different topographies (position of the nodes or zones) can have the same topology (shape, and intensity of connection between them), which is extremely useful when the derived indicator is used to compare urban systems with territorial conditions or different scale.

As with any system, the number of interlinkages may be important, and the difficulty of implementing the functional polycentricity indicator lies not so much in the complexity of estimation, but especially in lack of information. Thus, the interlinking could be measured, among others, by financial flows, emails, online shopping, phone calls, flows of buyers, leisure, medical services or to visit friends, and work trips of course.

For Green it is enough to have more than one node or area in the system and likewise there are links between them to make it possible to calculate the functional polycentricity. The theoretical development of functional polycentricity index can be consulted in the original publications (Hall and Pain, 2006, and Green, 2007). Here we will just simply say that the steps involved in the estimation, in the case of labor mobility are:

1) First, density of network interaction is calculated in terms of commuting Δ_c as follows:

$$\Delta_C = \frac{L}{L_{\max}} \quad (1)$$

Where L is the total number of flows or movements of employed persons in the different nodes/zones in the urban system (metropolitan area in our case); Lmax is the difference be-

tween the working population of the system and the resident employed population in the smallest node.
2) With the previous network density is calculated specific index of in-commuting polycentricity or inflows to each zone ($P_{SF\text{-}IC}$) as follows:

$$P_{SF-IC} = 1 - \frac{\sigma_{IC}}{\sigma_{IC\max}} . \Delta_c \quad (2)$$

Where σ_{IC} is the standard deviation for in-commuting of analyzed areas, while σ_{ICmax} is the standard deviation between the largest inflows and zero (since it makes reference to nodal degree of the simplest network with two nodes, where the first takes a value of zero and the second takes the largest in receiving flows).
In the same way is calculated specific index of out-commuting polycentricity or outflows ($P_{SF\text{-}OC}$):

$$P_{SF-OC} = 1 - \frac{\sigma_{OC}}{\sigma_{OC\max}} . \Delta_c \quad (3)$$

3) Then, as a previous step to calculate the General Functional Polycentricity Index, it is necessary to derive a complementarity modifier φ (fi), since total resident employed population (REP) equals the total work places (WP) because are only taking into account the flows that start and end within the urban system, and therefore specific indexes are complementary. This modifier is calculated as follows:

$$\phi = 1 - \sigma\left(\frac{\sigma_{OC}}{\sigma_{OC\max}}, \frac{\sigma_{IC}}{\sigma_{IC\max}} \right) \quad (4)$$

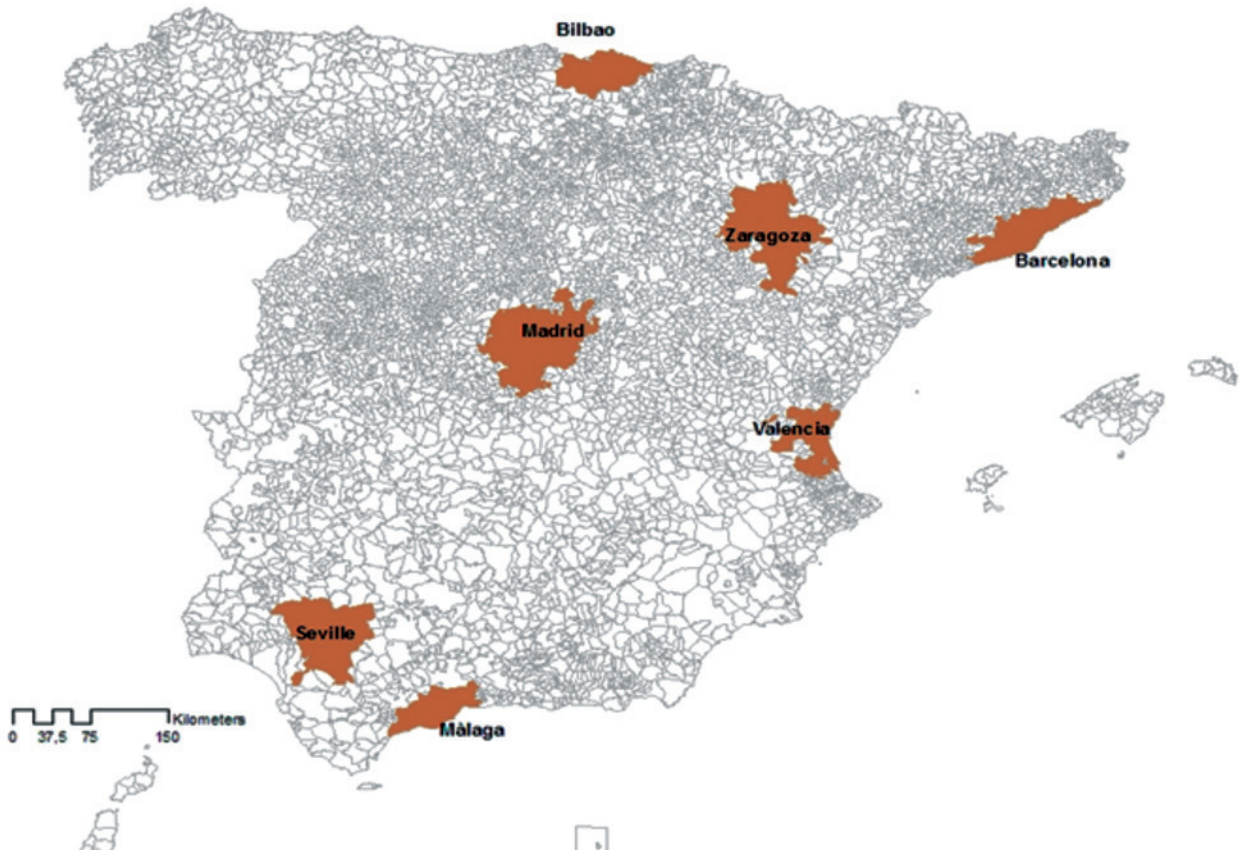
4. As a final step is calculated the General Functional Polycentricity Index P_{GF} through the average of specific rates of input and output flows weighted to the extent that are complementary, in the following way:

$$P_{GF=} \frac{\phi \cdot P_{SF-IC} \cdot P_{SF-OC}}{2} \quad (5)$$

Note that the indicator is constructed with flows between zones, excluding those who stay in them. This is consistent with the christallerian original concept of centrality and nodality. For Christaller (1933) the centrality of a place is given by the ability to attract flows (consumers of goods and services), while the nodality for its ability to meet domestic demand and thus is represented by those who live and consumed in the same area, although in practice nodality has been assimilated to the size of the nucleus. Then could be said that a multinuclear paradigmatic system would be the one where the size of the cores is similar (not dominated morphologically by none), while a paradigmatic in terms of polycentricity would be one with a diverse, bidirectional and dense network (no center monopolizes flows that receives or emits), Burger and Meijers (2012).
As seen from the mathematical formulation, the general functional polycentricity index takes values between 0 and 1. If is close to zero means that the system tends to functional monocentrism with an important center in terms of employment, and also that monopolizes the destination of labor flows from other areas. If the indicator approximates one means that the system tends towards functional polycentricity, as there is a more "democratic" or plural distribution of flows between areas, that is, there is no dominating areas as destinations, nor others left behind and therefore isolated.
Using labor flows, Hall and Pain (2006) have found that this indicator in practice goes from 0.02 to 0.19. In their study, based on the analysis of the interlinkage of FUR (Functional Urban Regions) comprising the eight European regional megacities1, Paris is the less interlinked, while the RhineRur and Randstad are the most interlinked and therefore with the highest rate of polycentricity, as common sense suggests.

Methodology, study area and data

The methodology of this work consists mainly of the following:
1) Detect functional subsystems and subcenters of the study area.
2) Delimitate metropolitan areas as the integration of functional subsystems.
3) Calculate the level of functional interlinking within each metropolitan area through functional polycentricity indicator of Green (2007) having separately as inner unity of analysis municipalities, subcenters and subsystems that comprise those areas.
For the detection of functional subsystems and the delimitation of metropolitan areas subject of this study, it's been used the municipal integration method based on the value of interaction proposed by Roca, Moix and Arellano (2012), since it is well suited to our interest because: 1) is based on the analysis of commuting flows by pairs of municipalities and is therefore consistent with the search for the boundaries of the local systems, 2) considers bidirectional center-periphery relations and hence is able to apprehend the complexity of contemporary mobility, 3) ignores the arbitrary thresholding of flows in absolute or relative terms as is common in most of the methods for detecting FUR (functional urban areas). This method allows to find urban subsystems within metropolitan areas that are self-contained by 50%, that is that at least half of employed people living in municipalities are actually working in a municipality of the same subsystem. The authors explain how, through the same interaction value calculated between subsystems, it is possible to find metropolitan areas, and for consistency in this work have been identified likewise the real cities of study.
The scope of the study is limited to the seven major metropolitan areas in Spain: Barcelona, Bilbao, Madrid, Malaga, Seville, Valencia and Zaragoza.



MA	Municipalities	Artificialized soil (km^2)	WP	Population	Global Density ($WP+Pop/km^2$)
Madrid	183	860	2.446.400	5.542.843	9.291
Barcelona	184	745	1.903.867	4.530.164	8.636
Valencia	104	308	686.247	1.792.375	8.046
Sevilla	52	237	447.849	1.381.531	7.719
Bilbao	123	112	445.666	1.231.367	15.024
Málaga	32	194	366.525	994.984	7.032
Zaragoza	88	127	301.860	724.335	8.066

MA: Metropolitan areas
WP: workplaces
Source: Corine Land Cover 2000 and Population Census 2001.

il. 1. Main metropolitan areas in Spain

The information sources used are:
1) In terms of demographics and travel-to-work the Population and Housing Census 2001.
2) In terms of data related to consumption and land use the Corine Land Cover 2000.
3) In terms of road network infrastructure the Tele Atlas in 2001 and the network of stations and halts the RENFE and other supra-regional rail services.
4) The optimal distance matrix between subsystems and municipalities calculated from the data of the previous point with the help of a specific transport SIG.
5) Digital Terrain Model with a resolution of 1 pixel = 80 * 80 meters from which has constructed topographic indicators.

Polynucleation and polycentricity in the Spanish urban system

As mentioned, the vast majority of studies on polycentrism in Spain have focused on the analysis of polynucleation. Whether analysis methods have been based on morphological criteria, such as the analysis of spatial patterns of employment density, or functional as the detection of nodes that are especially relevant in attracting flows, the common destiny of these studies has been the identification of the polynucleation level. In this work was carried out the analysis of the magnitude of functional

polycentricity for the seven major metropolitan areas in Spain. Firstly, the calculation was performed for each metropolitan area taking municipalities as the unit of analysis, in the second, the analysis was based on the subcenters identified in previous studies (Roca et al. 2009) and in the third part, the analysis was performed at the level of the subsystems that comprise each metropolitan area.

The functional polycentricity index estimated considering commuting flows between all the municipalities of the seven metropolitan areas is presented in the table below. It was found a high level of polycentricity in the metropolitan system of Bilbao, a medium level of polycentricity in Barcelona, Valencia and Madrid, and a lower level in systems Seville, Malaga and Zaragoza. The table also warns that urban systems with higher level of polycentricity among their municipalities are obviously those with less self-containment, that is, in these areas there are more flows or connections between the towns, and in turn, there are lower levels of functional polycentricity in systems with higher self-containment levels, as expected.

As a second step it was calculated the level of functional polycentricity between subcenters of the Metropolitan Areas, grouping the municipalities of the CEC (Continuous Economic Center)[2] as the primary subcenter or CBD (Central Business District). The lower table data reveals that in this case the greater polycentricity level are precisely those most polynuclear systems, so is the number of subcenters and their relative importance in terms of metropolitan employment concentration (Subcentrers Commuting (not CEC)). These are Barcelona, Valencia and Bilbao, followed distantly by, Seville, Madrid and Zaragoza. Malaga is a very special case, because having fewer cores, they concentrate a significant amount of economic activity, so that the metropolis would tend more towards the equipotential, since the presence of major tertiary centers such as Marbella and tertiary-industry as Torremolinos or Fuengirola compete with the central city.

However, polynucleation can also be analyzed from another reading based on the weight of CEC subsystem, as a macrocephalic urban system would have a large share of employment in its center, displacing the rest of the subcenters to a secondary role. In this line of thought, it is possible to rank urban systems in terms of the relative importance of their principal core, thus as a result, Zaragoza would be the most macrocephalic system, with a weight of 95.6% of sub-

Table 1. Functional polycentricity among municipalities of the Metropolitan Area

MA	Total Commuting	In-commuting	Self-containment	Municipalities	Pgf
Bilbao	430.056	227.460	47,1%	122	0,401
Barcelona	1.854.082	792.564	57,3%	184	0,346
Valencia	659.612	264.042	60,0%	103	0,318
Madrid	2.328.709	871.477	62,6%	183	0,306
Sevilla	427.498	120.237	71,9%	52	0,187
Málaga	340.105	67.267	80,2%	32	0,114
Zaragoza	283.788	39.473	86,1%	88	0,101

Pgf: general functional polycentricity
Source: INE, 2005.

Table 2. Functional polycentricity among Metropolitan Area Subcenters

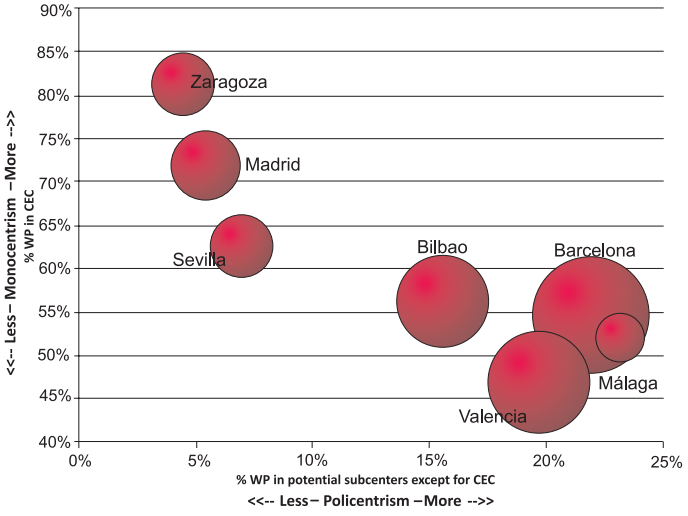
MA	Total Commuting	CEC Commuting	Subcenters Commuting (no CEC)	Subcenters	Pgf
Valencia	361.110	256.747	19,8%	18	0,068
Barcelona	1.218.005	889.210	21,9%	24	0,066
Bilbao	257.557	310.317	15,5%	15	0,042
Málaga	241.389	164.442	23,1%	5	0,022
Sevilla	229.197	202.710	6,9%	8	0,013
Madrid	1.480.448	1.376.415	5,5%	9	0,011
Zaragoza	250.943	239.905	4,4%	8	0,007

CEC: Continuous Economic Center
Pgf: general functional polycentricity
Source: INE, 2005.

centers commuting, followed by Madrid and Seville, in a second group would Bilbao, Barcelona, Malaga and Valencia that would be the center with less significance in relation to the whole metropolitan area.

If both forms of reading the urban structure are sorted in a Cartesian plane emerges the image of the figure below, where can be observed very clearly two families of metropolitan systems. The first one consists of Zaragoza, Madrid and Seville where the center tends to dominate at the expense of the number and specific weight of the subcrnters, and the second, consisting of Barcelona, Valencia, Bilbao and Malaga in which the opposite occurs: the center has a lesser importance, compared to a more abundant number of cores and their economic weight.

It is interesting to note how the size of the metropolitan system has little or no influence on the number of cores, as Madrid and Barcelona, which are very similar in terms of population and number of municipalities, are at opposite ends and so it is Malaga in relation to Zaragoza. Instead, the territorial matrix upon which rest the urban systems seems to have an influence on the polynucleation as is evident in the case of Barcelona and Bilbao



il. 2. Polynucleation level of urban systems in Spain
Note: The size of the spheres is representative of the number of cores / subcentres of the metropolitan system.

where the cores follow the valleys or distributed along watersheds.

The table below details the result of applying the Green indicator of functional polycentricity at the level of subsystems that comprise the metropolitan areas, leading to the third set of estimations of this work. As shown, Valencia and Barcelona stand out as the systems with the largest polycentricity of those studied. Bilbao is in an intermediate position, and Malaga is closer to urban systems group with the lowest level of polycentricity constituted, in this order, by Zaragoza, Madrid and Seville. Therefore, while Malaga has a multinuclear structure that moves toward equipotential in terms of the weight of the economic activity of its cores, is far from the cities where the subsystems denote the highest labor interlinking among them. Instead, we can say that Zaragoza, Seville and Madrid are less polycentric cities both in terms of their low level of polycentricity as polynucleation.

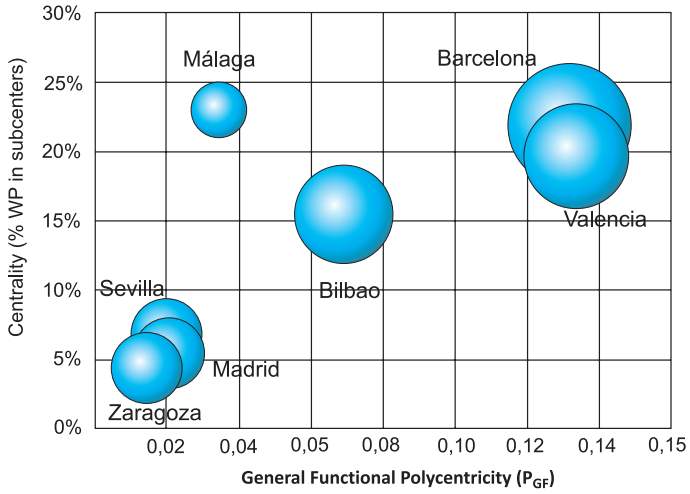
Meanwhile the correlation between the average of self-containment of the subsystems constituting each metropolitan area and the general polycentricity index ($r = -0.918$) confirms that the metropolis formed by self-sufficient systems are those in which there is less interaction within subsystem, as is apparent. This means that the greater the policentricity the higher the density or network opening (measured as the ratio between the flows and work places), more reliance exists, therefore, between the various subsystems that make up the metropolis.

If the above data are analyzed, unfolding the two constituent parts of the general polycentricity, it means, the specific polycentricity of input and output flows, one can see how the larger metropolitan areas tend to have greater polycentricity in their inflows regarding to out commuting. This correlation may be due to that larger cities have

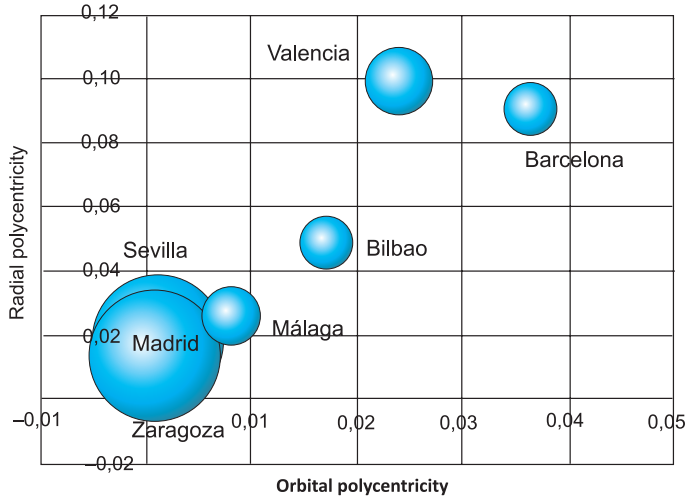
Table 3. Functional polycentricity between the subsystems of the Metropolitan Area

MA	Subsystems	Self-containment	Subcenters Commuting (no CEC)	psf (in-commuting)	psf (out-commuting)	Pgf
Valencia	18	75,3%	19,8%	0,13	0,13	0,13
Barcelona	24	77,5%	21,9%	0,14	0,13	0,13
Bilbao	15	86,9%	15,5%	0,07	0,07	0,07
Málaga	5	89,4%	23,1%	0,03	0,04	0,03
Sevilla	8	94,9%	6,9%	0,02	0,02	0,02
Madrid	9	93,6%	5,5%	0,03	0,02	0,02
Zaragoza	8	96,5%	4,4%	0,01	0,02	0,01

Psf: specific index of Polycentricity
Pgf: general functional polycentricity
Source: INE, 2005.



il. 3. Polynucleation vs. Polycentricity
Note: The size of the spheres is representative of the number of cores / subcentres of the metropolitan system.



The bigger the sphere, the bigger the radial polycentricity than the orbital

	P_{GF}	$P_{GF\,orbital}$	$P_{GF\,radial}$	$P_{GF\,radial/\,orbital}$
Madrid	0,02	0,00	0,02	11,0
Barcelona	0,13	0,04	0,09	2,5
Valencia	0,13	0,02	0,10	4,2
Sevilla	0,02	0,00	0,02	16,4
Bilbao	0,07	0,02	0,05	2,8
Zaragoza	0,01	0,00	0,01	16,6
Málaga	0,03	0,01	0,03	3,4

Source: own elaboration

il. 4. Radial and orbital polycentricity

Barcelona	1,285
Valencia	1,169
Bilbao	0,313
Málaga	0,092
Sevilla	–0,693
Madrid	–0,923
Zaragoza	–1,242

il. 5. Polycentrism in Spanish metropolises
Note: Units are factorial scores, the more positive they are, the greater the level of polycentrism (polynucleation and polycentricity).

bigger subsystems capable of hoard inflows in a more democratic way in relation to emissions of workers.

So, is there a relationship between the polynucleation and polycentricity? The simple statistical conjunction suggests that there is, since the correlation between the number of subcenters and general polycentricity is $r = 0.918$, and the correlation between the relative weight of the subcenters in terms of economic activity and general polycentricity is $r = 0.717$. As seen in the chart below the correlation is not perfect, since, as was said before, Malaga has a higher polynucleation level than the level of polycentricity, while, according to the trend line, Seville, Madrid and Zaragoza has a higher the level of polycentricity than their level of polynucleation. This same finding was highlighted by Hall and Pain (2006) in his POLYNET project in which the Greater London, markedly monocentric system, was found to have a higher level of polycentricity in relation to their level of polynucleation.

If we repeat the analysis splitting radial (the interactions of subcenters with the centre) and orbital relations (the interaction between subcenters not considering the relation with the centre), it emerges the image of Figure 4. In such an image it is evident that most of the functioning in urban areas in Spain is radial, it supports the idea that cities highly rely on the monocentric paradigm. Nonetheless, some areas, such as Barcelona, Bilbao and Valencia depict some evidence of orbital polycentricity. Such a finding is important on discussing quality of life of housing environments since orbital polycentricity rely on the existence of connections and public transport connecting the subcentres without passing thorough the center of the city. This reality contrast with the fact that most of the infraestructures are designed to connect peripheries and centres and not subcentres with subcentres.

Finally, in an attempt to bring together the topography (polynucleation) and topology (functionality) of the network in a more general indicator of polycentrism, it has been carried out a factor analysis with the various dimensions of polynucleation (ie number of subcenters, % of WP in subcenters, % WP in the CEC) and polyfunctionality. The result of it is a principal component (able to synthesize the 78% of the information) whose factorial scores are significant of the level of Polycentrism in metropolitan systems. The table below reflects the results of this analysis where are three clear paradigms: polycentric cities (Barcelona and Valencia), moderately polycentric (Bilbao and Málaga) and less polycentric (Seville, Madrid and Zaragoza).

It could be said that a desirable urban environment is characterized by plurality and diversity reflected in the coexistence of different land uses to ensure the development of daily living, it means that its people have the ability and liberty to carry out any activity they choose from a wide range of options. A simplification of human life we can see depicted in the two main activities: the one that performs within their house and in their workplace. In terms of urban structure, the confluence of these two activities in the same environment is knows as self-containment in the sense that the resident does not have to move out of it to perform one of the two activities, which in metropolitan, that involves an enlarged scale beyond the city limits, it is understood that the purpose can be achieved within the development of polycentrism.

But, according to the theoretical framework of this paper, which of the components of polycentrism are we talking about? What is more favorable on residential environments in terms of quality of life and in seeking for that house of tomorrow? Certainly, a polycentric metropolitan area in morphological terms, characterized by the existence of prominent, robust and self-contained nuclei, with greater diversity of land uses, leads to a reduction in mobility through the minimization of long-distance travel and as a consequence to a reduction in time and cost used in such movements. In this way the individual, in this case the worker will have more time for leisure or for performing any other activity that allows to develop as he/she wish. This side of polycentrism can advocate for the existence of transport systems environmentally cleaner that ultimately favor the quality of life and environmental sustainability of urban places.

On the other hand, the higher level of polycentrism in functional terms, namely polycentricity, is indicative of a greater number of journeys from residence to work since at the regional scale stands for coexistence and complementarity in their different centers, prominent and vigorous, and also self-contained relative to their hinterland. This network cities cooperation therefore requires more efficient transport systems for both radial and orbital displacements between centers that constitute the network. A greater polycentricity implies that a greater number of journeys are supported by the complementary and therefore the specialization of economic activities in the nuclei, so that firms would benefit from agglomeration economies leading to less congested residential environments more apt to reproductive activities, which undoubtedly can be desirable in terms of sustainability, economically speaking, of the house of tomorrow.

So, the idea of polycentrism, far from being a finished concept, represents the search for an improvement in sustainability of residential environment and in that sense this work, without wanting to impose a preconceived and static idea of optimal level of polycentrism, seeks to point out that greater polynucleation and greater interconnectivity may result in improving the quality of life of large-scale metropolitan systems. Bearing in mind that the quality premise involves a number of attributes and elements as a result of a collective agreement between economic beings, finding the right balance between both sides of the coin can be considered indeed a significant task of the urban planner.

Conclusions

The significance of the concept of polycentrism has to be understood as a process and not a finished definition. In this article we try to provide elements that nourish the debate, in the sense of supporting a definition certainly based on both morphological and functional criteria. In this context we are not wrong in saying that a polycentric urban system should be one structured in several (poly) centers, which interact both with their immediate surroundings (forming subsystems) and between them (establishing relations of complementarity). Not enough, therefore, that there are many cores but also necessary that there is an obvious connection between them.

The empirical program undertaken suggests, for the seven major Spanish cities, that there is a strong relationship between polynucleation (defined as the number of sub-centers and their relative weight) and polycentricity (understood as the level of functional interlinking among subsystems structured by subcenters). However, this correlation is not perfect and the case of Malaga is paradigmatic, as long as its functional interlinking level is lower than suggests its high level of multicentric equipotentiality in the morphological way.

Basically, functional analyzes have shown that almost every metropolitan area has a strong monocentric component, being the policentrism an emerged stadium at most of them, derived from the integration of former originally independent cores, than the appearance of new ones as polycentrism in North America. However, in some areas like in Bilbao, and especially in Barcelona, evidence strongly suggests of functional polycentric relationships between subcenters that would justify the creation or enhancement of road /rail systems promoting complementary relationships historically created. Improving in this way the quality of life in such housing and working environments.

Is the polyfunctionality, namely, functional polycentrism, something desirable? The answer depends on what is being analyzed. In the case of labor mobility, as studied here, the level of functional interlinking is positive, as it enables territorial complementarity by the flow of human capital that benefits companies, and provides more job opportunities for people; but could also be harmful to the extent that mobility has an environmental and social cost when travel time is detrimental to reproductive activities. Improving the transport systems connecting subcenters promoting sustainable systems may help to overcome the negative aspects of excess-mobility.

ENDNOTES:

[1] South East England, Paris Region, Central Belgium, Randstad, RhineRuhr, Rhine-Main, Northern Switzerland EMR and Greater Dublin.

[2] The CEC were defined as the group of functionally integrated municipalities via the interaction value, to the central municipality, and also with a workplace density above 700 LTL/km2, criteria latter resumed GEMACA methodology, which defines central economic agglomeration from contiguous municipalities which in addition to having the density of economic activity mentioned, have an overall mass of 20,000 workplaces. It is important to mention that in the seven urban systems, CEC consist in all neighboring municipalities which are considered as urbanized municipalities whose urban fabric are less than 200 meters apart. In the case of the Metropolitan Area of Malaga, Seville and Zaragoza, the CEC is defined only by the municipality of the city center (Marmolejo, et al. 2011).\

BIBLIOGRAPHY:

[1] Berry B.J.L., *Cities as systems within systems of cities, Papers of the Regional Science Association*, no. 13, 1964, p. 146–163.

[2] Boix R., *Caracterización de redes de ciudades mediante el análisis de cuatro estructuras urbanas simuladas. Encuentro de Economía Aplicada*, Oviedo, junio de 2002.

[3] Boix R., Trullen J., *Polycentrism and urban structure: a critic review from the perspective of the research agenda. ACE: Architecture*, City and Environment, vol. 6, 2012, 18.

[4] Burger M., Meijers E., *Form follows function? Linking morphological and functional polycentricity*. Urban Studies, no. 49, 5, 2012, p. 1127–1149.

[5] Camagni R., *From city hierarchy to city network: reflections about an emerging paradigm,* J.R. Cuadrado-Roura, P. Nijkamp, P. Salva (eds.), *Moving frontiers economic restructuring*, regional development and emerging networks, Aldershot, Avebury, 1994.

[6] Chorley R.J., Haggett, P. (eds.), *Models in geography,* London: Methuen, 1967.

[7] Christaller W., *Die Zentralen Orte in Süddeutschland*, Jena: Gustav Fischer, 1933.

[8] Craig S.G., Ng P.T., *Using Quantile Smoothing Splines to Identify Employment Subcenters in a Multicentric Urban Area*, Journal of Urban Economics, 2001, 49, pp. 100–120.

[9] Dematteis G., *Contro-urbanizzazione e strutture urbane reticolari, en Bianchi G e Magnani I (a cura di): Sviluppo multiregionale: teorie, metodi, problemi: 121–132*, Franco Angeli, Milano, 1985.

[10] Gallo M.T., Garrido R., *Una aproximación a la estructura urbana policéntrica en la Comunidad de Madrid*, ACE: Architecture, City and Environment, A o 6, no. 18, 2012, p. 69–100.
Giuliano G., Small K.A., *Subcenters in Los Angeles Region. Regional Science and Urban Economics*, no. 21, 1991, p. 163–182.

[11] Goei de B., Burger M., Oort, F. van, Kitson M., *Functional polycentrism and urban network development in the greater south east UK: evidence from commuting patterns*, Regional Studies, no. 44, 2010, p. 1149–1170.

[12] Gordon P., Richardson H.W., *Beyond Polycentricity: The Dispersed Metropolis, Los Angeles, 1970–1990*, Journal of the American Planning Association, no. 62:3, 1996, p. 289–295.

[13] Gordon P., Richardson H.W., Giuliano G., *Travel trends in non-CBD activity centers*, Washington, DC: Report Ca-11-0032, Urban Mass Transit Administration, US Department of Transportation, 1989.

[14] Green N., *Functional Polycentricity: A Formal Definition in Terms of Social Network Analysis*, Urban Studies, Vol. 44, No. 11, 2007, p. 2077–2103.

[15] Green N., *General functional polycentricity: a definition*, Discussion Paper, Institute of Community Studies/The Young Foundation/ Polynet programmes, 2004.

[16] Green N., *Towards a definition of polycentricity in terms of network theory, and the visualisation of polycentricity using a GIS*, Paper given at CUPUM 05: Computers in Urban Planning and Urban Management, London, 2005.

[17] Haggett P., *Locational Analysis in Human Geography*, London: Edward Arnold, 1965.
Hall P., Pain K., *The Polycentric Metropolis. Learning from mega-city regions in Europe*, Earthscan, Abingdon, 2006.

[18] Limtanakool N., Schwanen T., Dijst M., *Developments in the Dutch Urban System on the Basis of Flows*, Regional Studies, 43:2, 2009, p. 179–196.

[19] Limtanakool N., Schwanen T., Dijst M., *A theoretical framework and methodology for characterising national urban systems on the basis of flows of people: evidence for France and Germany*, Urban Studies, 2007, no. 44, p. 2123–2145.

[20] Marmolejo, C., Masip, J. y Aguirre, C., *Policentrismo en el sistema urbano espa ol: un análisis para 7 áreas metropolitanas*, CyTET, 2013, no. 174: XX–XX.

[21] Marmolejo C., Chica E., Masip J., *Hacia un sistema de metrópolis espanolas policéntricas?: evolución de la influencia de los subcentros en la distribución de la población*, ACE: architecture, city and environment, 2012, no. 18, p. 163–190.

[22] Masip J., Roca J., *An lisi retrospectiu del sistema metropolit de Barcelona i la seva influ ncia en l'estructura urbana*, ACE: architecture, city and environment, no. 18, 2012, p. 101–138.

[23] McDonald J.F., McMillen D.P., *Employment subcenters and land values in a polycentric urban area: the case of Barcelona*, Environment and Planning A, no. 22, 1990, p. 1561–1574.

[24] Mcdonald J., Prather P., *Suburban employment centres: The case of Chicago*, Urban Studies, no. 31, 1994, p. 201–218.

[25] McDonald J.F., *The Identification of Urban Employment Subcenters*, Journal of Urban Economics, no. 21, 1987, p. 242–258.

[26] McMillen D., *Non-Parametric Employment Subcenter Identification*, Journal of Urban Economics, no. 50, 2001, p. 448–473.

[27] McMillen D., McDonald J.F., *A Nonparametric Analysis of Employment Density in a Polycentric City,* Journal of Regional Science, no. 37, 1997, p. 591–612.

[28] Meijers E., *Measuring Polycentricity and its Promises*, European Planning Studies, no. 16:9, 2008, p. 1313–1323.

[29] Pred A., *City-systems in advanced economies: past growth, present processes, and future development options,* Hutchinson, London, 1977.

[30] Roca J., Moix M., *The interaction value: its scope and limits as an instrument for delimiting urban systems*, Regional Studies, 2005, no. 39, p. 359–375.

[31] Roca J., Arellano B., Moix M., *Estructura urbana, policentrismo y "sprawl": los ejemplos de Madrid y Barcelona*, Ciudad y Territorio: Estudios Territoriales, no. 168, 2011, p. 299–321.

[32] Roca J., Moix M., Arellano B., *El sistema urbano en Espa a*, Scripta Nova. Revista Electrónica de Geografía y Ciencias Sociales, vol. XVI, no. 395, 2012.

[33] Roca J., Marmolejo C., Moix M., *Urban Structure and Polycentrism: Towards a redefinition of the sub-centre concept*, Urban Studies, no. 46, 13, 2009, p. 2840–2868.

[34] Schwanen T., Dijst M.J., *Travel-time ratios for visits to the workplace: the relationship between commuting time and work duration*, Transportation Research Part A, no. 36, 2002, p. 573–592.

[35] Tinkler K.J., *An introduction to graph theoretical methods in geography*, London: Institute of British Geographers Catmog, 1977.

[36] Trullen J., Boix R., *Policentrismo y redes de ciudades en la Región Metropolitana de Barcelona*, Ponencia presentada al III Encuentro de Economía Aplicada, Valencia, junio de 2000.

[37] Tsai Y.H., *Quantifying Urban Form: Compactness versus "sprawl"*, Urban Studies, no. 42, 2005, p. 141–161.

[38] Vi uela A., Fernandez E., Rubiera F., *Una aproximación input-output al análisis de los procesos centrípetos y centrífugos en Madrid y Barcelona*, ACE: Architecture, City and Environment, ao 6, no. 18, 2012, p. 139–162.