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THE RELATION BETWEEN LAND OCCUPATION, DENSITY AND SPATIAL FRAGMENTATION, (SPAIN, 1956-2006)

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SUMMARY

The European political discourse has denounced the increase in land consumption in Spain, resulting from contemporary processes of urban development. The occupation of land deriving from demographic dynamics generates different patterns of urban growth, defining spatial structures with different degrees of fragmentation of urbanised areas. This study analyses the spatial relation of urban growth in Spain over the period 1956-2006 in three dimensions; land occupation, population density and the fragmentation of artificialised urban areas.

The methodology consists of the construction of a number of specific indicators of land occupation (%), population density (net and gross), and fragmentation (Shannon's *evenness*), in order to apply a relational statistical analysis (change over time and change between variables), as well as examine the likely future performance of these three indicators

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The results indicate that in general in the areas studied the decrease in the net density and the rates of expansion of artificialised land have been greater than the rate of population growth. However the spatial fragmentation has reduced over the period under review.

Finally it needs to be highlighted that the descriptive analysis identified landscapes of special performance (outside the overall tendency), which cannot be detected under the integrated 'relational' focus. Although the results do not indicate the value of one method with respect to the other, it can be confirmed that that the integrated focus is more complete in its conception and its capacity to explain complex phenomenon, than the partial vision offered by the indicators.

1. INTRODUCTION

The urban transformation undergone in Spain over the last 50 years is unquestionable, where the social and economic transformations led to clearly visible changes in the settlement pattern and land cover. Urban development has been the support of industry and services, and has enabled the development of tourism and property development to take place. From the residential perspective, despite the great tensions that have occurred resulting from migration, the urban residential market has allowed for access to housing for the vast majority of the population, at least as it relates to basic housing requirements. The massive urban development of land has placed Spain in the ranking of housing production per capita in Europe, well above the needs arising from new household formation. Many factors have influenced this growth of Spanish cities, where urban lifestyles have changed dramatically as well as that of the very structure of the cities.

Against this background, the paper describes a study on land use dynamics in Spain, concentrating on the spatial relationship between three dimensions of urban growth: the

rate of land occupation, population density and the fragmentation of the urban fabric. By definition an urban indicator allows for an estimation to be made of phenomena insofar as providing a synthetic aggregate of information about an event, beyond its own capacity of representation³. Therefore, by analysing a set of indicators the paper seeks to explain the trend of the urban dynamics produced in Spain during the period studied.

The integrated analysis of these indicators provides for a reflection on social and environmental aspects, such as land consumption and the uncontrolled fragmentation of urban development throughout the territory, presupposing the dispersion of built form and infrastructure, generating an increase in energy and water consumption, the loss of urban quality and public space in the cases in which little consideration is given to the relationship between real demand for house construction and urban growth.

The spatial extent of the study area corresponds to the areas examined in the context of a research project "20 urban landscapes" carried out by the Centre of Land Policy and Valuations (CPSV) of the Technical University of Catalonia (UPC) for the Spanish Ministry of Housing. From the databases resulting from this research, the study was developed in two main parts: the first to calculate the indicators to be applied to the database; and in the second the analysis and interpretation of the results. In addition to being a relational study of the three indicators and transversal across the cases examined, the analysis was developed through a temporal evolution, in order to account for a significant change in time and to permit the detection of the existence of peculiarities at the municipal level, as well as making a comparison between the municipalities.

³ Salvador Rueda. Modelos e Indicadores para ciudades más sostenibles

2. DATA AND STUDY AREA

The study area comprised 18 urban landscapes in Spain, which include some 120 municipalities, with a total area of 10,686 km², and with a total population of 13,702,113 inhabitants. In 2006 1,747 km² of such land was developed for urban purposes⁴.

In terms of the timescale, data was drawn upon relating to land occupation for 1956, 1990, 2000 and 2006, from the previously mentioned "20 urban landscapes" research project, through the application of different methodological processes. In some cases this comparison reduced the technical reliability and for this reason the time-scale was divided into two stages of analysis:

- A short-term period (1990-2000)⁵ drew upon data of land classification processed by the CORINE Land Cover⁶ project. The classes used in the analysis of urban land for this period were those described in the fourth level of CORINE's artificial land classification, with the population data deriving from the Spanish National Statistics Institute (INE) for 1990 and 2000.
- A longer term period (1956-2006)⁷ used the classification data elaborated by the CPSV, through the photo interpretation and manual digitizing of aerial photography images produced by the United States in 1956 (USA 7/B/56), and of SPOT 5 satellite images and updated images of Google Earth for 2006. The population data for 2006 was estimated through the application of a behavioural pattern at the municipal level to the figures deriving from the 2001 Census of Population.

⁴ Source: INE (2000)

⁵ At the urban scale, a ten-year period can be significant, in as much as 10 years are sufficient for an urban development project to be planned, carried out and fully completed.

⁶ CORINE Land Cover project is a joint initiative of the European Environment Agency and the European Commission which has affected 26 countries and includes the acquisition of land cover data at a European level, through Landsat 7ETM + satellite images, photo interpretation and the classification of that land.

⁷ This time may see significant structural and permanent changes in an urban setting at a local level.

1. METHODOLOGY

The methodology consisted of two processes: firstly indicators were applied for quantitative analysis in the four temporal stages, and secondly a statistical analysis of the results was carried out.

1.1 Indicators

For the quantitative study, three indicators were used: one of *land occupation*, calculated as the proportion of urbanized land with respect to the total area of the municipality under review; one for *population density*⁸ (inhabitants/Km²); and finally a *fragmentation* index. The use of such indicators allowed for obtaining descriptive synthetic measures of the spatial distributions of a specific phenomenon in a specific geographical area, to provide comparative analysis between spatial models. In this case the objective was to measure the complexity of urban areas considering patterns of discontinuity in the urban fabric, and the relationship between the polygons that comprised the morphological configuration of the urban areas, together with the evaluation of growth of the urban areas and the rate of population present. This type of analysis of evolutionary models can facilitate the identification of structures characterized by spontaneous settlements, for example, or by types of growth that diverge from the more "typical" Mediterranean compact and medium density city.

Land Occupation

With regard to the size of the artificial surface defined by each urban area, the land consumption O_s [1] was calculated as the proportion of urbanised land⁹ ($S_{up.Urb.}$) and

⁸ The density index might be net or gross, depending upon whether it refers to inhabitants within the administrative limits of a territorial unit, or within the part of that unit developed for urban purposes (artificialised).

⁹ CORINE Land Cover and CPSV database

the municipal area according to the spatial administrative boundaries¹⁰ ($S_{up, Ter}$). A ratio between m^2 and m^2 then expressed as a percentage of urban land over free surface.

$$O_s = \frac{S_{up, Urb}}{S_{up, Ter}} * 100 \quad [1]$$

Population Density

To calculate the spatial distribution of the population in urban landscapes, i.e. to evaluate the weight of all persons over specific spatial area, two population density indicators were used: *gross* [2] and *net* [3].

Population density - Gross

$$D_G = \frac{P_{ob}}{S_{up, Ter}} \quad [2]$$

Population density - Net

$$D_N = \frac{P_{ob}}{S_{up, Urb}} \quad [3]$$

The two indicators place in perspective the number of people with an area – in the first case within the administrative boundaries of the territorial unit and in the second case within the part of that territorial unit which has undergone urban development. In both cases the density is static and not dynamic, meaning that it is considering only the resident population and not the flows of people who move between urban areas, whether it be for employment or other reasons. The "dynamism" of residents was however assessed over time, taking into account the four temporal stages, from 1956 until 2006.

¹⁰ Tele-Atlas 2004

Fragmentation

The analysis of fragmentation measures the degree of breakdown in more parts of an urban structure. It is based on the concept of *entropy*¹¹ provided by a measure of segmentation depending on the number of polygons and their weights, with respect to the surface. This index refers to an entire category of descriptive indicators that measure the variability of specific characteristics such as heterogeneity, dispersion or concentration, fragmentation, etc. The study on the fragmentation of urban growth, measured in particular the number of polygons that made up an urban area, weighted by their own dimensions, providing a value that evaluated the relationship between the parts of a system in which discontinuities were generated in the spatial distribution. The formula used to calculate the entropy was that of Shannon¹² [4], which proportions values between 0 and 1.

$$SE = \frac{-1 \sum_{i=1}^n [F_i (\text{Ln } F_i)]}{\text{Ln } n} \quad [4]$$

where:

F_i = the proportion of urban landscape occupied by the patch "i", over the total area of the urban landscape¹³

n = number of patches in the landscape

1.2 Analysis of the probability of exchange

This part of the paper proposes a methodology of analysis over the variation in time and space, of patterns of land occupation based on the various indicators. For the detection

¹¹ Entropy is a concept in physics which measure the degree of disorder of a system.

¹² The entropy index introduced by Shannon in 1948 is a measure of homogeneity on logarithmic scale. The Shannon index is a popular measure used to calculate diversity and is frequently used in the field of ecology. Shannon proposed two formulas: one to calculate diversity (*Shannon Diversity*); and the other to calculate the uniformity or homogeneity (*Shannon Evenness*). The second formula takes into consideration the number of parts that constitute a whole, so in a case in which there is a high quantity of zones that form a structure, this variable is more significant. The formula of Shannon Evenness has been drawn upon in this study.

¹³ F_i = area of patch "i" divided by the total area.

of behavioural patterns in the urban growth, all the municipalities between which direct relations existed were worked with, rather than those municipalities comprising the urban landscapes. The specific test was applied to the urban landscapes of six spatial areas: Alicante, Barcelona, Madrid, Murcia, Bilbao, and Valencia, owing to the fact that the remaining ones were constituted by a single municipality and did not provide a statistically useful analysis. The methodology was built on the following techniques:

Simple temporal correlation analysis

This analysis was applied separately for each indicator and time period. Firstly the scatter plot of the values in different years was graphed, and the *Pearson* linear correlation coefficient was calculated. The scatter diagram enables the visualization of the relationship between variables, which can show whether or not a relational pattern between the values (direct-inverse, linear-non-linear, etc.) exists. Furthermore, the correlation coefficient assesses the strength of the relational pattern detected in the scatter diagram, with the exception that it only evaluates the degree of linearity in the relation, with a value between -1 and 1.

Analysis of multiple cross-sectional correlations

This analysis was applied for each year examined, and consisted in the calculation of the *Pearson* linear correlation coefficient between the explanatory variables of the pattern of urban growth. This will detect dependence or independence between the indicators.

2. RESULTS

The initial results derived from the application of the four indicators based upon the 120 municipalities of the overall sample. Table 1 indicates the mean and median values (for the municipalities), obtained for each indicator. The median was calculated, given that in general the statistical distributions obtained are not symmetrical.

Table 1 Descriptive statistics for variable and by year

Indicator	Year	1956	1960	2000	2006	Year annual (%) 1956-06
Overall Gross (hab./km ²)	Arithmetic	1.320	2.583	2.977	3.003	2.8
	Mediana	401	1.216	1.700	1.447	5.2
Overall Net (hab./km ²)	Arithmetic	11.610	9.095	7.712	7.077	-0.8
	Mediana	0.725	0.375	0.902	0.048	-1.1
Percentage of occupation (%)	Arithmetic	10	24	29	34	4.8
	Mediana	5	17	21	25	9.2
Fragmentation	Arithmetic	0.45	0.42	0.41	0.36	-0.4
	Mediana	0.46	0.46	0.43	0.37	-0.4

Source: Own elaboration

The last column of Table 1 shows the annual growth rate (in percentage and with reference to the 1956 value) in the period 1956 to 2006. As shown, the municipal gross density grew at an annual rate of between 2.8 and 5%, lower than the increase in the percentage of land occupation, which grew at an annual rate of between 4.8 and 9.2%. This situation contributed to the reduction in the net density to an annual rate of between -0.8 and -1.1%, so that the expansion of artificialised land was greater than the population growth. Moreover, the fragmentation of the territory decreased during the study period, but at a lower annual rate (-0.4%).

Interpreting the results all at once, one can detect a phenomenon of a greater increase in artificialised land than the population, with the pattern of fragmentation of the territory being maintained relatively.

2.1 Results of the analysis of the temporal evolution of urban models

Considering all the municipalities, there was a high correlation between the values in both the long (0.772) and the short term (0.978). The positive sign indicates that the percentage of land occupation remained relatively constant over time.

Gross Density

Considering all the municipalities, a high correlation in both the long (0.853) and the short term (0.995) can be seen. As with the land occupation, the gross density remained relatively constant over the period under review.

Net Density

Taking all the municipalities into consideration, a high correlation was obtained in the short term (0.963), but in the long term the correlation decreased significantly (0.469), i.e. in the long-term the values become independent and there is greater variability. In general, it appears that the net density changed over long time periods, but due to very small changes over short time intervals. .

Fragmentation

Considering all the municipalities a high correlation between 1990 and 2000 was obtained (0.752), while over the 50 years the correlation decreased significantly (0.286), i.e. the values become independent over a long period.

2.2 Results of cross-sectional analysis of relation

The cross-sectional analysis dealt with analysing the statistical relationship between different variables, but for a certain period of time. In this case the question was to determine how they relate to the values of density, land occupation and fragmentation of the territory, as measures for all the municipalities and the urban landscapes, for the four temporal stages (Table 2). What follows is a detailed analysis for each combination of the indicators.

Table 2. Cross-sectional correlations, all municipalities

Grande lliçons	Ocupación		Fragmentación	
Dens. Bruta	1956	,889	1956	,787
	1990	,808	1990	-,316
	2000	,817	2000	-,452
	2006	,790	2006	-,581
Dens. Neta	1956	,157	1956	-,201
	1990	,511	1990	,267
	2000	,559	2000	-,397
	2006	,577	2006	-,574
Ocupación			1956	-,212
			1990	-,300
			2000	-,408
			2006	-,609

Source: Own elaboration

Gross Density v / s Percentage Occupancy

This relationship provided a very high positive correlation, which over the years decreased, with the value for 2006 still being highly significant. This means that a high value of gross density corresponds to a high value in the percentage of land occupation. As this relationship derives in part through the construction of a spurious relationship (because of the way of calculating the variables, since both are divided by the surface

area of the municipality), what can be deduced is the high ratio between the total population and artificialised area of the municipality, which was maintained over time.

The relative decrease observed in the correlation could lead to the hypothesis of the loss of intensity of the relationship between the total population and the artificialised land, i.e., these variables becoming independent. But it is noteworthy that this is a trend, the actual value of which is not shown. At the level of the urban landscapes what is apparent is that they all maintained this behaviour referring to high values which decreased towards 2006. Murcia's urban landscape is that which presented a lower scale of the correlation value (diminishing from 0.6963 in 1956 to reach 0.509 in 2006).

Net Density vs. Percentage Occupancy

This relationship provided a relatively high and significant positive correlation (about 0.5). This value was significant only after 1990, having an increasing behaviour by the year 2006, meaning that the ratio of "the greater the net density, the greater the percentage of land occupation" had become more intense over time. At the level of the individual landscapes, the situation was different. Thus the landscapes of Barcelona, Bilbao and Valencia had a response similar to all municipalities, with the correlations of Barcelona being the largest (ranging from 0.74 in 1956 to 0.671 in 2006). On the other hand the urban landscapes of Madrid, Alicante and Murcia had no significant correlations in this relationship, so there is independence between the net density and the percentage of land occupation.

Gross Density vs. net-Fragmentation

In 2006 these relationships indicated a high and negative correlation, which over the years had been increasing in absolute values. During the early years this relation was

low, but the sign remained negative. In the current situation it can be deduced that a high density value corresponds to a low value of fragmentation. This is consistent with previous results on the percentage of land occupancy.

The urban landscape analysis shows that Alicante, Murcia and Valencia indicated the same behaviour as all of the municipalities, i.e. a growing relationship, but significant only after 2000. The urban landscapes of Barcelona, Madrid and Bilbao had significant values as of 1990, with these correlations being greater than those of all the municipalities (between 0.6 and 0.7). Later in these urban landscapes and after 1990, there was a significant negative relationship between the densities and the fragmentation of the territory, i.e., less fragmentation at higher densities.

Occupation v/s Fragmentation

In 2006 this relationship provided a high and negative correlation, which over the years has been increasing in absolute value. During the earlier years, this relation was low, albeit maintaining the negative sign. From the most recent situation it can be inferred that a high value of the occupancy percentage corresponds to a low value of fragmentation, especially in more consolidated urban structures.

The analysis for urban landscapes shows that Alicante and Barcelona had the same behaviour as all of the municipalities. Bilbao and Madrid showed the same behaviour, but the values in recent years were higher (in absolute values), reaching correlations of -0.71 and -0.8 respectively for 2006.

3. CONCLUSIONS

Beyond the criticism that may arise concerning the construction of databases and perhaps on the choice of indicators or the municipalities, which may be unrepresentative because of the relatively low number compared to the total possible cases, the intention of the paper was to understand the dynamics of land occupation in Spain, noting the spatial relationship between three dimensions of urban growth: the rate of land occupation; the population density; and the fragmentation of the urban fabric.

Additionally, it has been innovative in the application an analytical approach which integrates the aforementioned dimensions statistically, with the advantages and disadvantages that this signifies, of the very statistics. This methodological approach and the prediction of phenomena of urban development seeks to be relatively "standardised" and "viable", to enable its application to other territorial areas and to incorporate other types of variables. The advantage of this integrated approach of analysis rests upon the definition of a flexible instrument, which with numerical data supports the theoretical analysis that technical planners and geographers often provide in relation to the processes of growth, past and present, which are affecting urban territories.

It has been found, although with a restricted limited number of indicators, that it has been possible to generate a database of information capable of delineating patterns of urban settlements across the territory and somehow define the trends in the sample studied through a model with three dimensions of variables, applied over four temporary stages.

In the first place, it needs to be highlighted that the analysis of the evolution over time for the urban landscapes does not differ from that diagnosed in the analysis of all the municipalities as a whole, reflecting a certain similarity in the dynamics of growth throughout the Spanish territory. Moreover, it is relevant that in general, in the short

term (1990-2000) the behaviour of the study variables is fairly constant, i.e. the situation in 2000 is closely related to what happened in 1990. Moreover, over the long-term (1956-2006) dependences and independences can be observed, as a function of the variable analysed. In this respect it can be said that although the pattern of development over time of each of the indicators shows a similar trend, the very evolution of the variables is different.

While the relational analysis identified non-linear dynamics of the relationships between variables, exponential trends were observed in the scatter plots for the relationship between density/fragmentation and land occupation/fragmentation. One of the characteristics of the exponential relationship is the inertia and reactivity (initial or final) in the behaviour of the variables¹⁴. An example of this is the situation of the dependence between land occupation and net density, indicating different velocities between population growth and the growth of urban development or artificialised land. Similarly, the fragmentation shows the inverse relationship of greater land occupation and density, and less fragmentation.

On the other hand, the descriptive analysis identified urban landscapes with particular behaviour, in contrast to the trends observed elsewhere. While Cadiz and Oviedo stand out as urban landscapes that have growth dynamics more in keeping with the trend, Bilbao and Vigo by contrast are urban landscapes with the greatest difference in their growth. However, in the integrated analysis of three relational indicators, other municipalities (Barcelona and Bilbao) maintained tendencies close to those of the sample set, in contrast to Madrid, Alicante and Murcia which indicated behaviour diverging from this.

Finally, this study shows that although in the analysis of time trends tendencies have been observed very similar to the dynamics of growth of each of the samples studied, it has only been through the relational analysis between the indicators that it has been

¹⁴ For inertia it must be understood that a variable modifies its value significantly, while the other is practically invariant. For reactivity the situation is opposite; i.e. one variable changes its value marginally, and the other varies considerably.

possible to identify the particularities existing in each of the urban landscapes. It has been proved that the expansion of artificialised land in Spain, has been generally higher than the growth in population, meaning that the net density has been reduced over time, thus demonstrating that the increase has not been the product of a real demand and much less as a result of correct planning. This dynamic has increased the rate of the outward growth of urban land. In addition it shows how the model of land occupation has been changing, from a denser model, as a product of the direct relation between the growth of both land and population, to a model of less dense land occupation.

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