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An automatic classification of urban texture: form and compactness of morphological homogeneous structures in Barcelona

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ABSTRACT

This paper investigates the morphology of the city of Barcelona; the main objective is to identify and automatically classify morphological homogeneous categories and determine the level of compactness of urban texture. The classification consists of several steps. A first analysis was performed to identify different morphological types in the built-up area and typify urban patterns by using geometrical and relational characteristics such as shape of buildings and spatial interaction between them in terms of distance. This was followed by an automatic classification of urban structures with homogeneous characters. Finally, the morphological compactness was determined, calculated as “equilibrium” between size and distances of buildings. In order to make the automatic classification, we calibrated a set of indices, capable to describe specific formal and functional characters. Using GIS and statistical analysis, such as factor and cluster analysis, we categorized several homogeneous structures.

This classification process was based on geometric characteristics, assuming that, in general, different functions require different forms. By aggregating subjects of similar behaviour we could identify to which kind of urban configuration an area possibly belongs. The outcome of this study can support urban planning and management in identifying target areas concerning socio-economic interventions within urbanized territories.

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1. INTRODUCTION

Cities can be classified according to their urban morphology. Depending on the spatial configuration of built-up and empty spaces, blocks and streets (or squares) we can distinguish compact or fragmented cities as well as continuous or discontinuous. Anas et al (1998), in their review of the contributions to an understanding of urban spatial structure, pointed to the diversity of the nature and dynamics of urban morphology. The principle behind these studies is that a city, as a self-organism, has a unique identity that is preserved through the years, despite the passage of time and the spatial and functional transformations that occur (Rabie,1991); (Frenkel 2004). The configuration of the physical elements, with their own functional dynamics, produces different “drawings” in the cities. By disaggregating the urban texture into different components, it is possible to study the topological, geometrical and dimensional relationships between the elements. In recent years, research on urban morphology has investigated the way in which cities are created, renewed, and extended in space. Studies have constructed random models to describe town growth (for example, Batty, 1998; Batty and Longley, 1994; Benguigui et al, 2001; Longley and Mesev, 1997); (Frenkel 2004).

The paper is structured in the following way. First we will briefly describe the relevance of this work, the objectives, and the main characteristics of urban morphology. This is followed by the methodology and a description of the typologies of urban texture in Barcelona. Then comes a description of results of the morphological analysis produced by the proposed methodology and we will conclude the paper with a discussion of the major findings.

2. EFFECTIVENESS OF THE RESEARCH AND OBJECTIVE

The increasing amount and detail of digital spatial data is a useful resource for automatic interpretation of urban phenomena such as urban morphology. Knowledge on urban morphology can be a useful resource in urban planning and management, for example in socio-economic targeting, or also for sustainable issues.

The main research objective is to design a methodology for automatic classification of urban texture which produces homogeneous areas with respect to the shape of buildings, and their spatial configuration and arrangement in space. This also involves the selection and

calibration of a set of indices which are suitable to describe certain geometric and relational characteristics of urban structures and which can be used in the subsequent automatic classification of urban structures. By evaluating characters such as the density of the city and the efficiency of urban forms we also attempt to identify what variables have a higher impact on the estimation of urban compactness.

The experiment will be performed for the municipality of Barcelona, in Spain, using the footprint data of built-up area and constituting around twenty thousand objects in a shape file format. Figure 1 shows a planimetric map of the built-up area items of the city.

Figure.1 Planimetric map and section of Barcelona: case study



3. URBAN MORPHOLOGY

The morphological identification and the “quantification” of building groups is based on geometric characteristics of the objects, assuming that, in general, different functions require different forms of buildings.

The assumption is that different urban structures generate different economic and social dynamics, and that in such complex framework of the urban areas, all these factors interact and affect each other.

It is also important to underline that buildings with similar properties will be close to each other or even form groups in feature space (Steiniger et al. 2007)

Morphology studies suggest parameters to measure the urban configuration that might serve as tools in the hands of urban designers to assist the functioning of intra-urban systems. Geometrical and topological indicators are used in investigating relationships between the urban pattern and other systems that affect urban morphology. Steiniger et al. (2007) argue that we can define to what type of urban structure a neighbourhood possibly belongs to by measuring the character of the buildings in a neighbourhood, based on similarity and proximity.

The new generation of models tries to recapture, based on past trends, the evolution of the formation of the city's shape and its geometrical pattern. Understanding the urban system and its components can be supported by a quantitative analysis of the relative share of the various land uses (Frenkel 2004).

4. METHODOLOGY

The methodology consists of three parts. A first analysis concerns the identification of different groups of building typologies and the analysis of patterns of urban structure based on geometric characteristics such as the shape of the buildings and the spatial interaction between them in terms of distances. We identified seven different kind of urban fabric, based on basic concepts of urban planning theory which are presented in section 5.

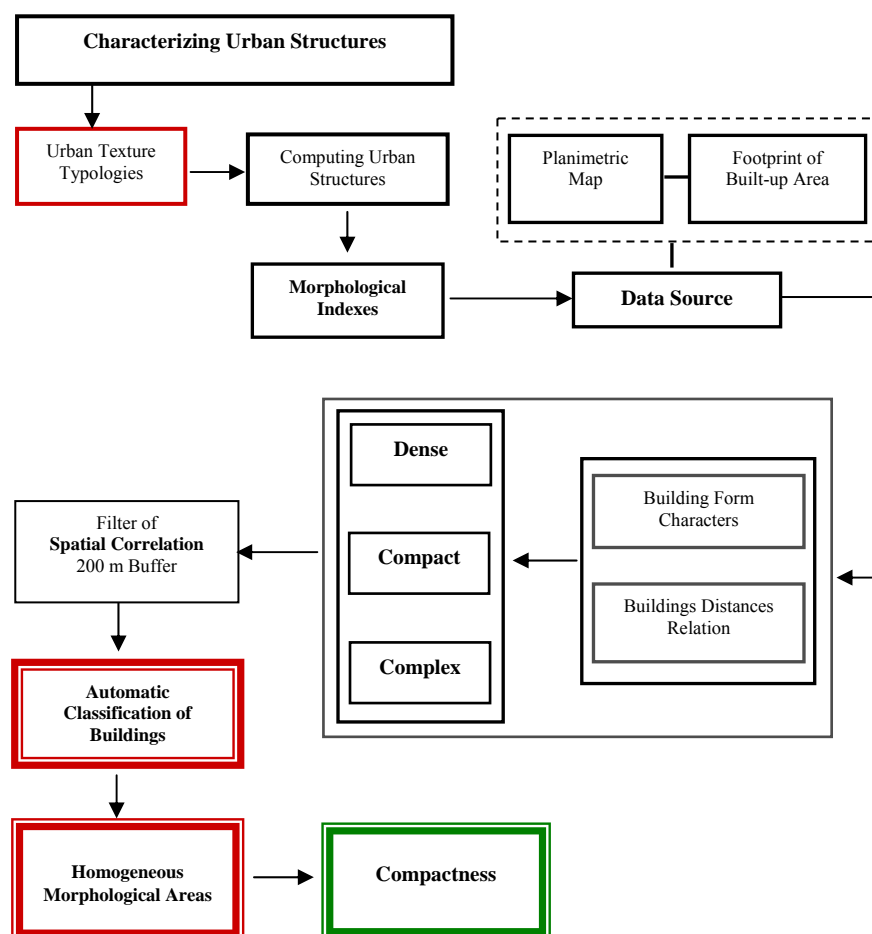
The second analysis is to identify similarities in the morphological configuration of structures, in order to automatically classify urban textures. Based on the fact that buildings have particular geometric features, and that the zoning of a city may cause that nearby

buildings are similar (although exceptions occur), we concentrate on the application of indicators that measure shape and the distances between buildings.

The automatic classification into homogeneous morphological is done by statistical analysis, factorial and cluster, and the application of a filter of spatial correlation⁴ in a 200 meters buffer around each building.

The final part concerns the evaluation of the level of compactness of homogeneous areas from the morphological point of view. Figure 2 shows a conceptual map of the applied methodology.

Figure.2 A conceptual map of the methodology



⁴ The filter of spatial correlation consists in making a buffer around each building and calculates the average value of a specific index, for the objects intersected by the buffer. It provides a new value which takes into account the major trend of nearby objects.

5. URBAN FABRICS TYPOLOGIES

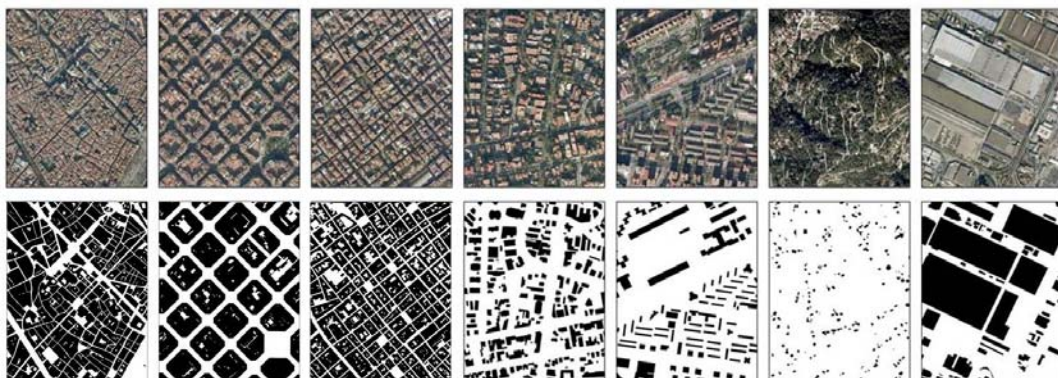
It has been widely asserted that the morphology of urban areas is a result of the interactions of urban function and urban form. This has led to a number of studies to postulate, either explicitly or implicitly, that a shaping exists between the physical form (land cover) of the urban fabric and its corresponding function and activity (land use) (Barr et al. 2004). As stated in the introduction, studies of urban morphology investigate the urban pattern and the structure of urban land uses from design perspectives.

The metropolis of today is a palimpsest, characterized by the continuous overlapping of different architectural languages, the multiplicity of spatial forms, construction techniques and functions (Secchi 2001). The city is the sum of smaller building blocks, which could be delineated depending on their characteristics strictly correlated to the planning process and resulting from the stratification of different epochs. Within the city of Barcelona we defined seven classes of homogenous structures, also related to different historical periods, and named these typologies of urban texture as follow:

- *Old Town*
- *Enlargement*
- *XX Century city*
- *Fragmented City*
- *City of Seventies*
- *Suburb*
- *Industrial, Commercial, and Special Buildings*

In order to better understand the characteristics of the typologies, we will first describe briefly the substance of the structures which are illustrated in figure 3.

Figure.3 Examples of typologies of urban fabrics in Barcelona



In Barcelona, the *Old Town*, mostly identified like the historical centre, originates from the gothic period. It presents a continuous and highly dense urban system. The fabric is very compact and the boundaries are well defined and form a closed circle.

The layout of the *Enlargement*, built around the end of the XIX century, in Barcelona commonly known as “*Eixample*”, is a regular grid. It is composed of large grains and a regular roads pattern, often oriented differently than the adjacent neighbourhoods.

The organization of this structure does not show special hierarchies and the public space is represented by main roads, extensive and orthogonal, motivated mainly for reasons of functionality (Mattogno 2007).

The *XX Century City*, together with the Enlargement and the Old Town, defines the limits of the consolidated city. This type of structure consists of big blocks, bordered by buildings with continuous fronts, alternating with a small discontinuous tissue which provides the common spaces. The density is now decreasing, due to the less number of floors, but the design is still clear due to the road network which testifies that the open space represents a clear choice of planning.

In the *Fragmented City* land occupation is considerable lower than in the first three types. It has more open space, almost leading to a switch in the order of things: it seems like now the empty space is organizing the position of the buildings, while the hierarchies of roads are slowly disappearing, together with the importance of the public space.

The *City of Seventies* (Mattogno 2007), marks the transition from the modern city to the contemporary city. Lines and blocks are juxtaposed in an inconsistent manner, passing from dense building structure to a progressive loss of density as we move away from the main road infrastructure. It is almost impossible to detect any presence of public spaces, except for the dominant space represented by the road, which however does not lead to any recognizable urban design; in fact the urban morphology is only characterized by the shapes of wide open spaces, high buildings and big infrastructures. The clear route of the highway, in most cases to a higher level, highlights the status of suburbs and produces considerable impacts of physical and visual barriers (Mattogno 2007).

In contrast to the contemporary residential structures characterized by intensive blocks of buildings, the *Suburb* is a structure of houses for one or two families, fragmented into small lots, with own gardens, completely dispersed and located at the periphery of the city. Any identifiable configuration of facilities and types of occupation of the territory is disappeared and the great value of the open space has lost all morphological and structural features, being deprived of their intrinsic meaning (Mattogno 2007).

The *Industrial, Commercial, and Special Buildings area*, represents groups with plenty variety of forms, even if the blocks are mainly industrial. It is because an industrial area is often constituted by objects with ample variety of characteristics in terms of dimensions, form and distances, and it is common across a city to find buildings with “special” characters such as highly isolated, or with big dimensions.

6. MORPHOLOGICAL INDICES FOR URBAN FABRICS

We identified nine indices, useful to quantify the morphology of the city, based on several features, calculated depending on formal and relational characters of the buildings. The nine indices were selected on the basis of a statistical and also qualitative analysis of the originally 15 variables found in the literature and the concepts explained. The other 6 indices were removed from the analysis because of too little explanatory contribution or redundancy. Table 1 shows the indices.

Table.1 Indices of urban morphology

| Form / Building | Relation / System |
|---|--|
| Building Area $AREA = a_i$ | Buildings Proximity $PROX = \frac{\sum_i^n a_i}{\sum_i^n d_{ij}^2} \cdot n$ |
| Core Area Index $CAI = \frac{a_i^c}{a_i} (100)$ | |
| Area to Perimeter Ratio $AP = \frac{a_i}{p_i}$ | Buildings to Buffer Area $BHAD = \frac{\sum_i^n a_i^{Int}}{a_{i\text{ Buff}}}$ |
| Shape Index I $SSPI = \frac{\sqrt{Area/\pi}}{\text{Longest Axis}}$ | |
| Shape Index II $SHPI = \frac{p_i}{2\sqrt{\pi a_i}}$ | Buildings to Convex Hull Area $CHAD = \frac{\sum_i^n a_i^{Int}}{a_{i\text{ Hull}}}$ |
| # Corners of the building CORN | |

The core area index (CAI), like implemented in fragstats (McGarigal et al. 2002), is the ratio between the core area of the building, with an inside offset of 10 meters, and the area of the building. We also computed the ratio between area and perimeter of each object in order to reach a value of building efficiency (AP).

Shape index I is the Schumm's longest axis to area ratio (MacEachren 1985), while shape index II is the index of Gravelius or coefficient of compactness, which compares the profile of any polygon with the profile of the circumference, intended as the maximum compact form.

The proximity (PROX) is calculated like the ratio between the sum of areas of the buildings in a buffer of 200 meters around a building and the sum of the squares of the distances, toward the central object, of all building in the buffer. The result is multiplied for the number of buildings in the buffer. BHAD is computed as follow: 1) Buffering of buildings and selection of all buildings intersected by buffer. 2) Calculation of intersection regions (Buffer, Buildings). 3) Calculation of area of intersection to area of buffer ratio (Steiniger et al. 2007). CHAD is computed as follow: 1) Buffering of buildings and selection of all buildings intersected by the buffer. 2) Calculation of convex hull around these buildings. 3) Calculation of area of buildings to area of convex hull ratio (Steiniger et al. 2007).

In order to identify similarities in the morphological configuration of structures automatically classify urban textures, we also aimed to set synthetic indices by using our basic indicators. By applying a factorial analysis and using principal component analysis with the varimax rotation method we obtained three synthetic indexes which are explaining our model at more than 83% (table 2).

Table.2 Components and total variance of the model explained through the factorial analysis

| Component | Total Variance Explained | | | | | | | | |
|-----------|--------------------------|---------------|--------------|-------------------------------------|---------------|--------------|-----------------------------------|---------------|--------------|
| | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 4,333 | 48,147 | 48,147 | 4,333 | 48,147 | 48,147 | 2,856 | 31,729 | 31,729 |
| 2 | 1,648 | 18,313 | 66,460 | 1,648 | 18,313 | 66,460 | 2,793 | 31,034 | 62,763 |
| 3 | 1,530 | 17,004 | 83,464 | 1,530 | 17,004 | 83,464 | 1,863 | 20,701 | 83,464 |

Extraction Method: Principal Component Analysis.

The extracted indices refer to three characteristics which could summarize the degree of compactness of urban forms. In fact by interpreting the components we identified some of the main characteristics of compactness commonly used in morphology studies; these are

density of the urban texture, the formal *efficiency* of buildings and *complexity* of the shape. The latter two are indicators of form. Efficiency, in fact, is referring to the effectiveness of form, taking into account the dimension of buildings but related to the level of squareness of the building. Complexity, instead, is evaluating how convoluted the outline is, with more details. Table 3 shows the loadings of the indices on the three components, which we can assign the following meanings: Dense, Efficient, and Complex. Figure 4 explains the position of every basic index in the 3-dimensional space of the three principal components.

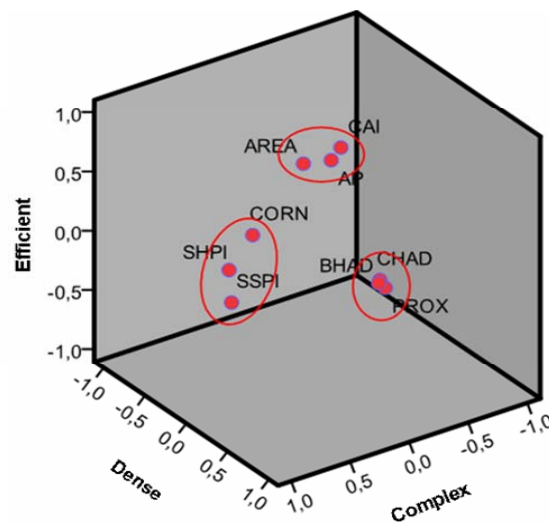
Table.3 The result of the factorial analysis and the interpretation of components

| Rotated Component Matrix ^a | | | |
|---------------------------------------|-----------|-----------|---------|
| | Component | | |
| | 1 | 2 | 3 |
| | Dense | Efficient | Complex |
| AREA | ,150 | ,868 | ,223 |
| CAI | ,170 | ,913 | -,080 |
| AP | ,278 | ,909 | ,077 |
| CHAD | ,932 | ,223 | ,122 |
| BHAD | ,945 | ,208 | ,142 |
| PROX | ,947 | ,152 | ,088 |
| SHPI | ,199 | ,213 | ,887 |
| SSPI | ,004 | -,206 | ,729 |
| CORN | ,165 | ,418 | ,663 |

Extraction Method: Principal Component Analysis

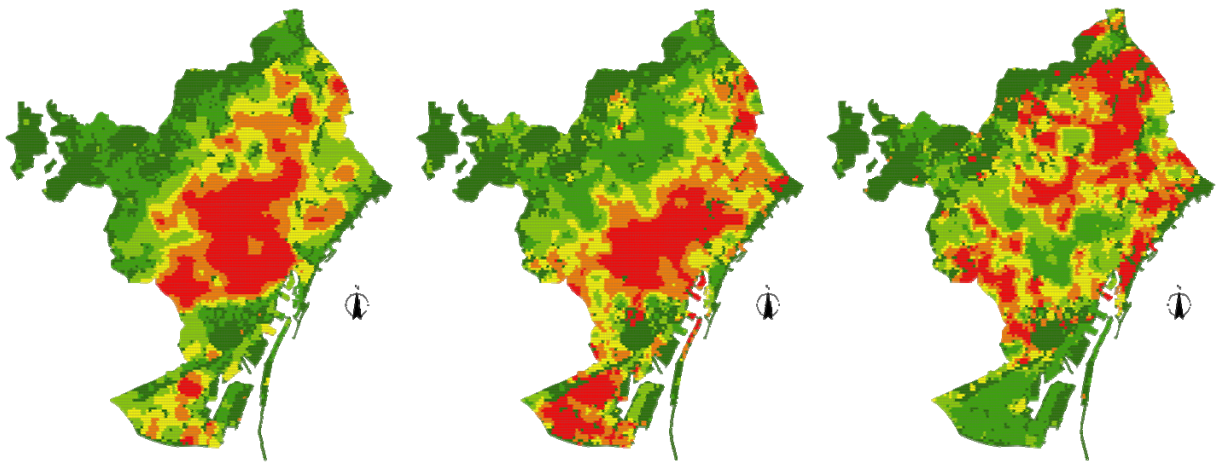
a. Rotation converged in 4 iterations.

Figure.4 The three dimensions of the model in a 3D representation



Considering that the concept of zoning in urban planning produces homogeneous contiguous blocks, a filter of spatial correlation has been applied to the three synthetic indices. Specifically, in order to implement the filter procedure, a buffer of 200m has been applied to every building, followed by calculating the mean and the standard deviation of the synthetic indices for the objects in that buffer. The result after applying the filter, provides our final indices (Dense*, Efficient* and Complex*), as shown in the figure 5, and the standard deviation of first synthetic indices as additional indicator for classifying urban structures.

Figure.5 The spatial behaviour of the Dense*, Efficient*, and Complex*



If we intend the compactness like high levels of density and efficiency, but also of the complexity of buildings forms, it could be effectively hypothesize the relation between urban structures and compactness, also related to distances, by observing the image upon.

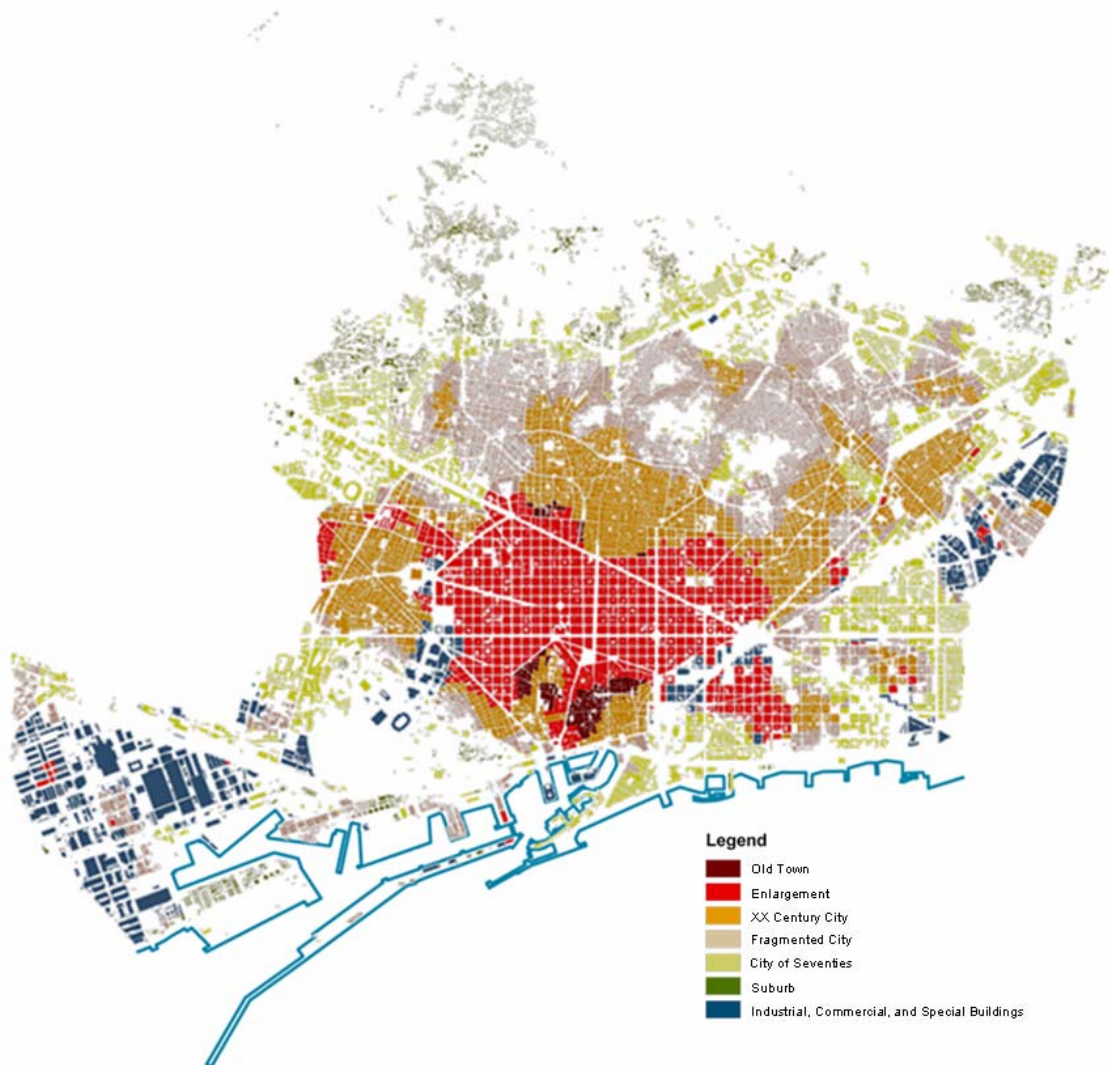
In order to determine the distance of the buffer, we have taken into account several studies in which the measure most commonly accepted and proved to be useful in the analysis of urban dynamics is that of the 200 meters. Varying this parameter should have an influence on the classification result, which can be concluded from the work of Le Gléau et al. (1997) and Boffet (2001). When classifying the buildings it is very likely that a building will have the same structure type as buildings in the neighbourhood owing to the underlying zoning structure. Maximum distance values given by Le Gléau et al. (1997) vary between 50 m (e.g. Scotland) and 200 m (e.g. France). The results show that a maximum of classification accuracy and certainty is reached for a 200 m buffer radius. Improvements can still be reached if the dataset has been characterised with density indices based on a 200 m buffer radius (Steiniger et al. 2007).

7. AUTOMATIC CLASSIFICATION OF URBAN FABRICS

In this section we demonstrate the suitability of the cluster analysis for identifying, automatically, similar morphological structures across a city.

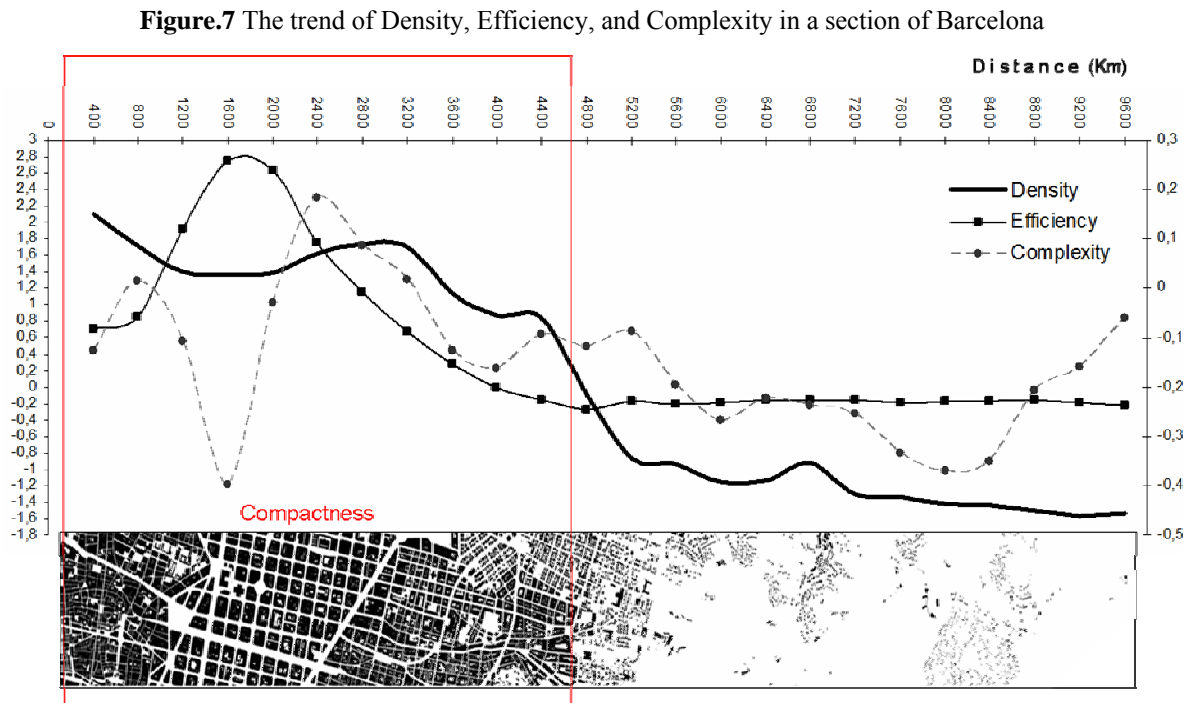
The cluster analysis was applied to the morphological components Dense*, Efficient*, and Complex* as well as their standard deviation, calculated for every building. We have chosen representative samples ('training sites') for each of the seven urban typologies, qualitatively defined in section 4. For each sample, we calculated the mean value of the morphological components and their standard deviation. The resulting values were used as cluster centres for the seven categories defined by the typology. Additionally the analysis was made without iterations, in order to "lock" the value of cluster centres. The outcome is illustrated in the figure 6.

Figure.6 Result of Cluster analysis for seven urban typologies



We propose to include spatial characteristics in the identification process for city clusters such as quantitative data on the size, composition, and intensification of the built-up area, as well as geometrical measures indicating the configuration and morphology of the urban pattern (Frenkel 2004), however in some groups the homogeneity may disappear. For example in the case of industrial areas, the variability of dimensions and isolation could be quite sensitive. It means that, the values of standard deviation can make our model working better, mostly using together the average and the standard deviation.

Figure 7 it is an example of the behaviour of the indices, across a section of Barcelona, in relation with the distance from the centre of the city towards the periphery, while the red zone can be assumed like the most compact urban textures, based on our indicators.



8. CONCLUSIONS

The aim of this work was to propose a methodology to investigate the complexity of the actual city, ie its urban morphology, considering that a city is not only design, economic movement or migration of people, but rather an outcome of their interaction. A proper definition of urban structures, such as inner the city area or industrial sites, could support on one hand map reading and on the other hand initial decision making processes in planning (Steiniger et al. 2007)

The goal of the experiment was to systematically investigate the complexity of urban morphology by applying automatic classification of different typologies, which follow the dynamics of the urban ambits, making it possible to assign standardized values to different structures. It is really important, for example, to be able to calculate values of density or compactness in the cities, and to evaluate whether it is a compact model or a dispersal model.

The methodology proposed, could also be implemented using high resolution remote sensing imagery of urban areas, to automatically identify typologies of urban texture with the corresponding values of compactness. This could be useful in cities in developing countries to identify different types of settlements with differing demands in the provision of basic services.

This result gives the possibility to assign values of compactness to those neighbourhoods which we defined in the section 4, based on theoretical background, in order to standardize the definition of urban homogeneous areas from the morphological point of view.

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