SPIE Europe Remote Sensing
Urban Remote Sensing

The Effectiveness Of Morphology And Street Networks In Determining Models Of Urban Growth At Different Spatial Scales Analysis

Keywords
Remote sensing, G.I.S., Street network, urban morphology, spatial analysis

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The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

1. Objectives

The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

Classify, evaluate and compare different urban forms related to street networks and land characters, also considering the morphological typologies of urban settlements by moving from the spatial scale of a municipality to a wider territorial. The intent is to discover secure principals to find the most likely urban models of cities, taking topographical parameters into account.

•Understanding the dynamics and patterns of urban extend related with their interactions in heterogeneous landscapes.

•Determining the analogies between patterns of cities and their "physical" characters providing indicators of the aspect of settlement form and structure.

•Focusing on the development of a methodology to classify the geometric properties and intrinsic space of urban settlements based on their characteristics and fundamental forms.

An approach to analyze urban morphology through understand the relation between urban settlement and grid with land topology:

• Better understanding on what is possible to observe using urban remote sensing and how such information can be integrated to improve our theoretical knowledge about urban areas and their dynamics;

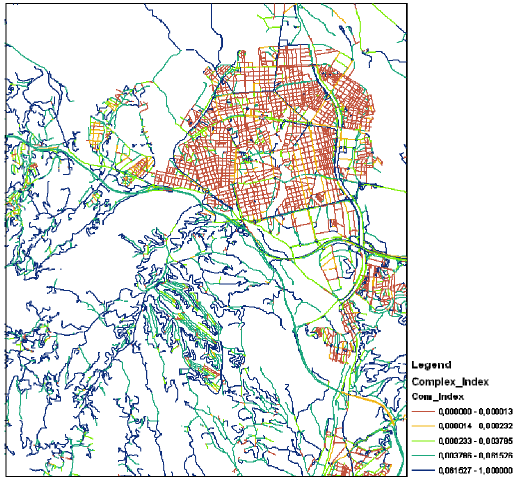
• Assess and verify the measurement of metropolitan urban growth from a strictly morphological perspective and classifying typologies using the cluster analysis.

1. Objectives

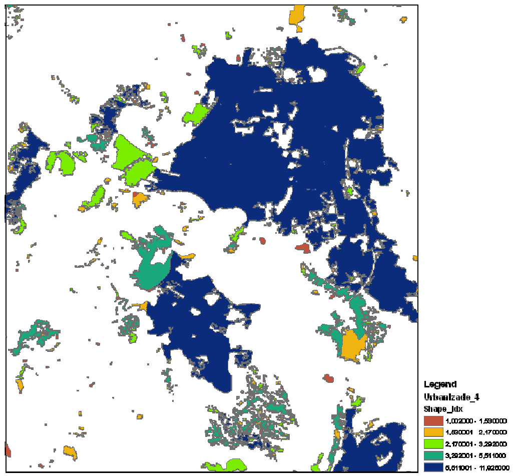
The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

•Define the interaction between morphology measures and grid integration revealing that the effect of morphologies on grid is strongest according to urban types.

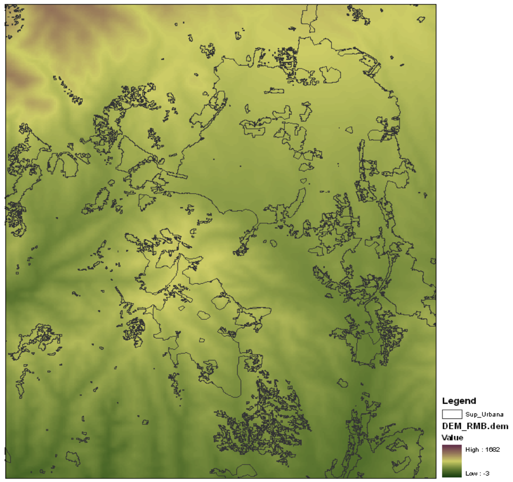
•Find the effect of geographical characters on the urban settlement defined by Form of urban shapes and the infrastructure system.



TeleAtlas street networks



Land occupation and morphology



Digital Elevation Model

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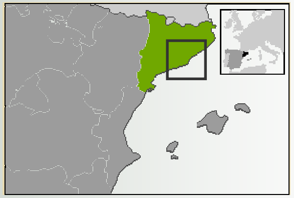
2. Data and study area

The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

The chosen area is Metropolitan Region of Barcelona (RMB), which is the regional capital of Catalonia, lying in the north-east of Spain (see Figure 1). The Metropolitan Region of Barcelona consists of 164 municipalities and the physical limit of the region extends to almost 3,239 km2 and has a current population of some 4.7 million inhabitants (Campaign, 1991)



Today the increasing availability of satellite images is becoming instrumental in geographical applications and offering a reliable tool for decision making in territorial management. For example the SPOT 5 satellite offers the possibility of producing images of large scale territorial areas (60 km by 60 km) with a resolution from 2.5m to 10m

This research carried out focusing upon the metropolitan region of Barcelona, with urban sites defined according to the contiguity of artificial and administrative boundaries. The TeleAtlas and land activity classification deriving from Spot Imagery form the basis of this study.

Remote sensing data sets used for the study with a supervised classification for the urban agglomeration, drawing upon 2004 images in order to maximize the number of distinguishable land cover classes for the study area. This methodology employed *maximum and minimum likelihood*, *binary encoding* and *parallel piped methods*, prior to *scattergram processes* and the merging of all the data, drawing upon a *subtraction process* to arrive at the final classified image.

A base-map from TeleAtlas was used, acquired on 2000

In order to obtain the territory slop, it was necessary to use DEM (Digital Elevation Model)

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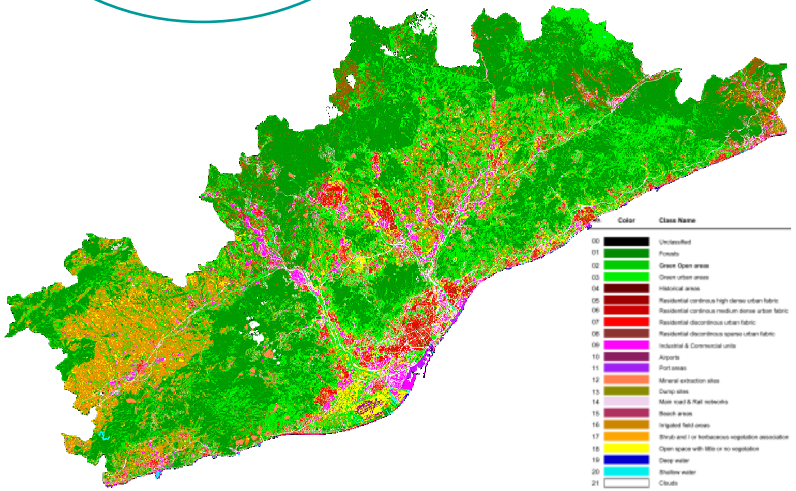
2. Data and study area

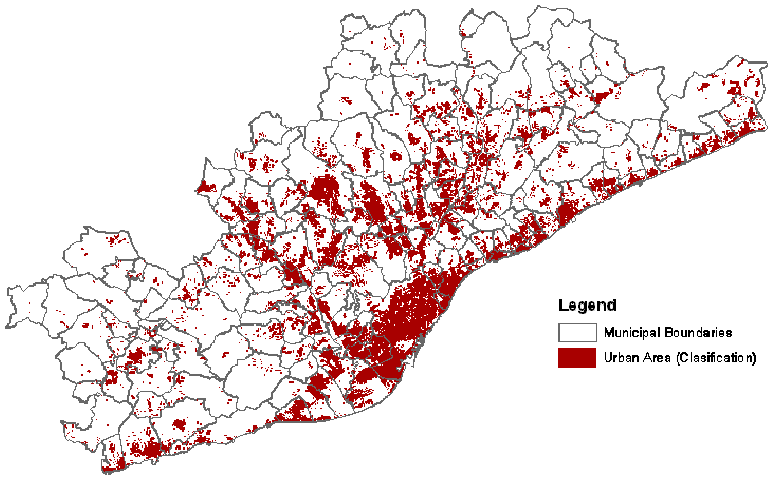
The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

The classification process led to the identification of some twenty (21) land cover categories for Barcelona.

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



The metropolitan region of Barcelona in the final result with 21 improved categories

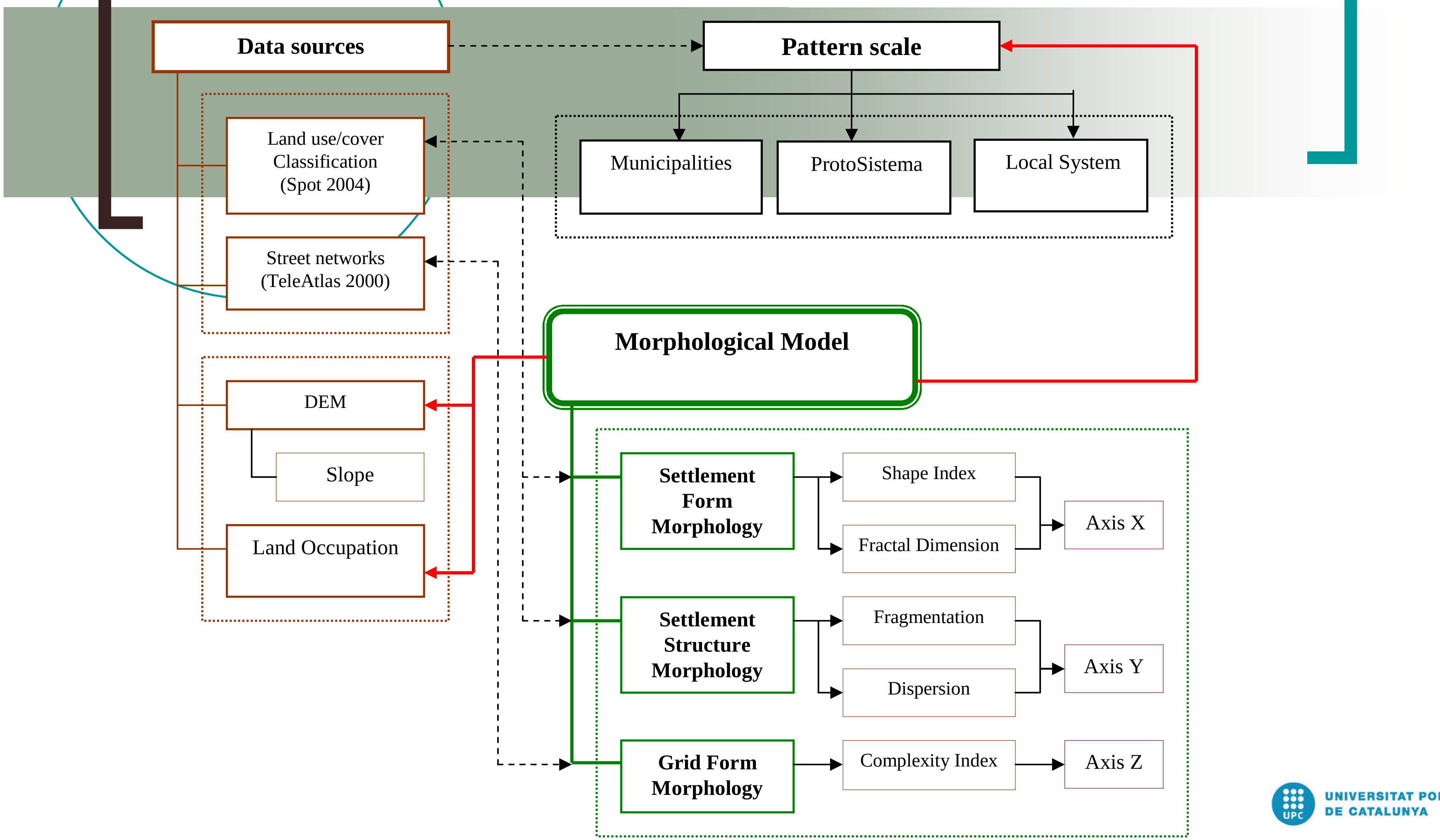


Artificial areas

Three steps: the first step deals with the quantification of characters (Pattern scale model), the second will identify the settlement behaviours with its location (Morphological model), and the third one will study the relation between models (Urban Model)

3. Methodology

The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis



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3.1. Pattern Scale Analysis

The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

Changing the scale changes the spatial patterns, which has implication for the understanding the complex urban system. Thus, urban analysis performed at a single scale is incomplete and insufficient for understanding spatial patterns (Barros Filho and Sobreira, 2007).

Three scales are presented, one using the **municipalities** as units of analysis, the second will focus over the ***Protosistemas*** unit, finally ***local System*** unites will define the largest scale in our research

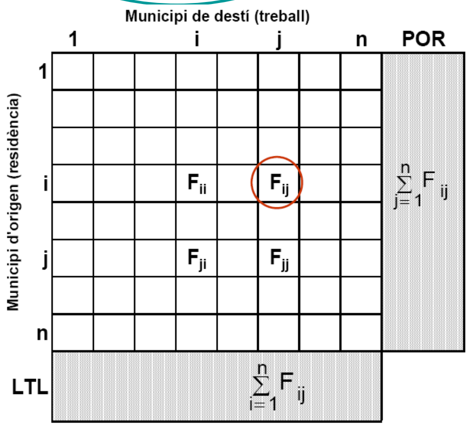
The *Protosistemas* unit allows delimiting supra-municipal Areas, joining municipalities in greater unites, "drawing" a territorial level organization based on strong interactions between nearby towns; the grouping of municipalities is made according their highest value for interaction (V.I.) as it shown in the equation:

$$\mathrm{VI}_{\mathrm{ij}} = \frac{F_{ij}^{2}}{POR_i.LTL_J} + \frac{F_{ji}^{2}}{POR_j.LTL_j}$$

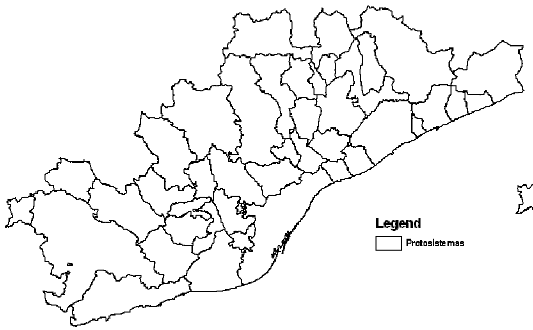
Where:
Fij: number of workers living in the town "i" and who go to work to the municipality "j", if i = j than Fij=RWi (Resident Workings), Workers who live and work in the same town.
PORi: resident working population of the municipality "i"
LTLi: jobs located in the municipality "i"

3.1. Pattern Scale Analysis

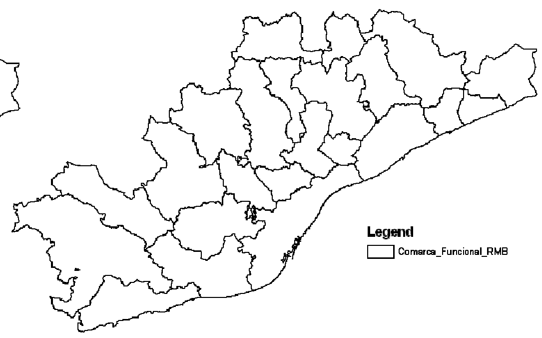
Looking for larger scale level, *Local Systems* are defined and made by add more restrictions on the *Protosistemas*, such as contiguity or size, demographic issues and even the evaluating of resident workers. These parameters allow to “Consolidating” the *Protosistemas* limits to define this new scale level. Since the classification systems affect the result of urban land use pattern analysis, result also shows the effect of spatial scale on urban land use pattern analysis if different classification system takes different characteristics in certain range of scale



Matrix bound by Labour Mobility and Functional systems for Metropolitan Region of Barcelona RMB



Protosistemas map



Local System map.

3.2. Morphological Model

The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

Urban morphology “implies ‘form,’ ‘land use,’ and ‘density,’ and has connotations with the shape, structure, pattern and organization of land use, and the system of relation between them” (Donnay, Barnsley, and Longley, 2001)

Three levels of conceptualization, these levels will help to obtain the morphological model which presents a relation between two pure morphology settlement calculations, made on urban area patches, and the morphology of street networks model, presenting them by three axis (X,Y,Z).

The first is the physical record or representation of **settlement urban form** itself by studying the following parameters: shape and fractal dimension indexes. The second is the **settlement structure** by observing the settlements behaviour through fragmentation and dispersion indexes and the third is to analysis **Street network form** which can be achieved with the data available by analyzing streets Complexity

To understand settlement form and structure a process was realized in four phases. In the first phase, will be related to settlement form morphology which look to calculate the **shape index** and **fractal dimension** refer to specific calculations. In the second phase will focus on settlement structure morphology which takes place to understand urban settlements from **fragmentation** and **dispersion**. All calculation results applied will applied over settlement dataset in municipal level and repeated over *Protosistemas* and *Local Systems*

Morphological analysis, which refers to the geometric characteristics of urban sites, illustrates its usefulness in determining the analogies between patterns of cities and their “physical” characters providing indicators of the aspect of settlement form and structure

3.2.1. Morphology of Settlement Form and Structure

The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

Shape Index, as quantitative indices to describe patterns of the settlements form (Gravelius)

Fractal Dimension, to “measure” urban patterns, aiming at finding “new” descriptions of the variety of urban morphologies, analysed following principles from fractal geometry

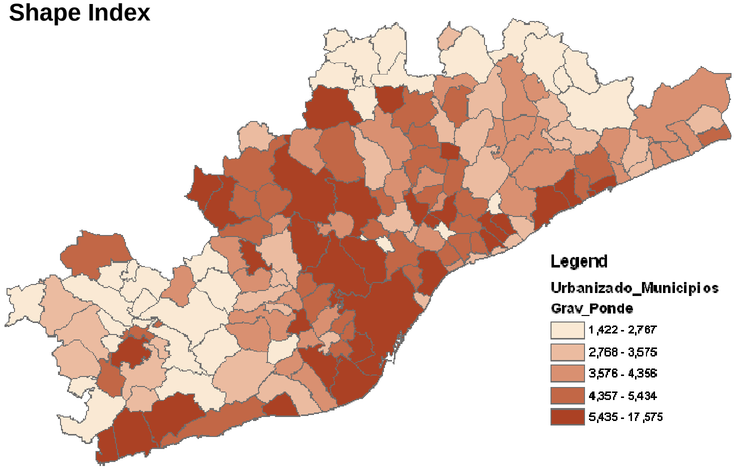
$$\mathrm{AWMSI} = \frac{\sum_{i=1}^{n} \left(\frac{p_i}{2\sqrt{\pi\, a_i}} \cdot a_i \right)}{\sum_{i=1}^{n} A}$$

Where:
pi = Perimeter of patch
ai = Area of patch
n = number of pathces

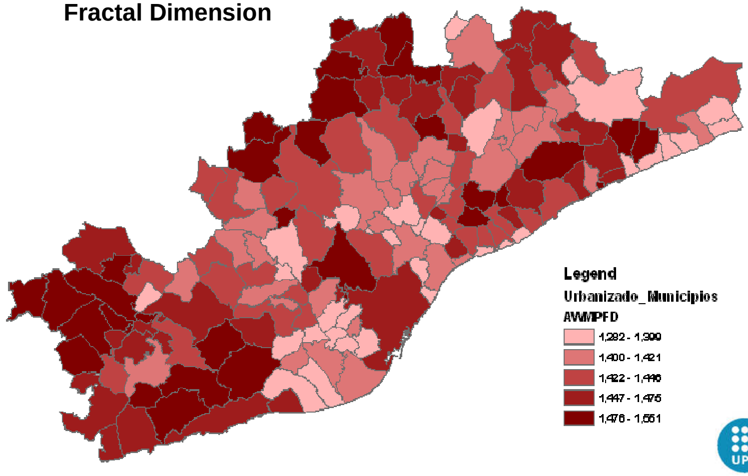
$$\mathrm{AWMPFD} = \frac{\sum_{i=1}^{n} \left[\frac{2\ln(0.25 \cdot p_i)}{\ln a_i} \cdot a_i \right]}{\sum_{i=1}^{n} A}$$

Where:
A = total Area of urban patches in the landscape

Shape Index



Fractal Dimension



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3.2.1. Morphology of Settlement Form and Structure

The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

Fragmentation, measures spatial atomization and holes in the city area (Shannon)

Dispersion, used to describe a representative measure of distance between the parts which compose the urban area (Standard Distance)

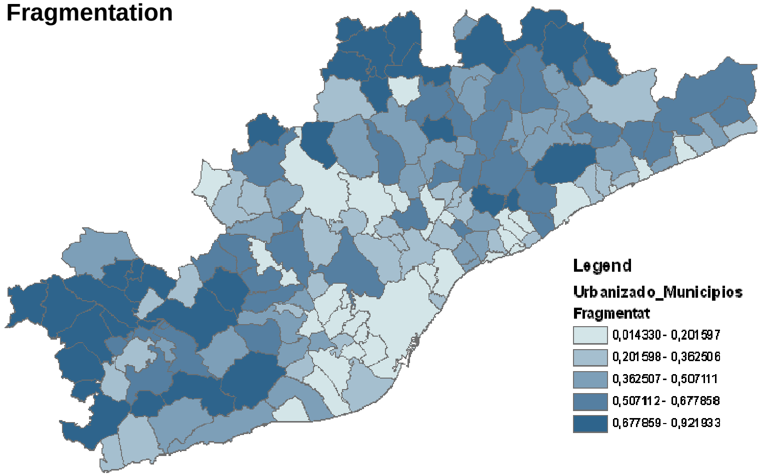
$$H = \frac{-1\sum_{i=1}^{n}\left[F_i\left(\mathrm{Ln}\,F_i\right)\right]}{\mathrm{Ln}\,n}$$

Where:
Fi = A*i* / Atot = Area of patch *i*, divided by the total area made sumarizing all the pathces in the landscape

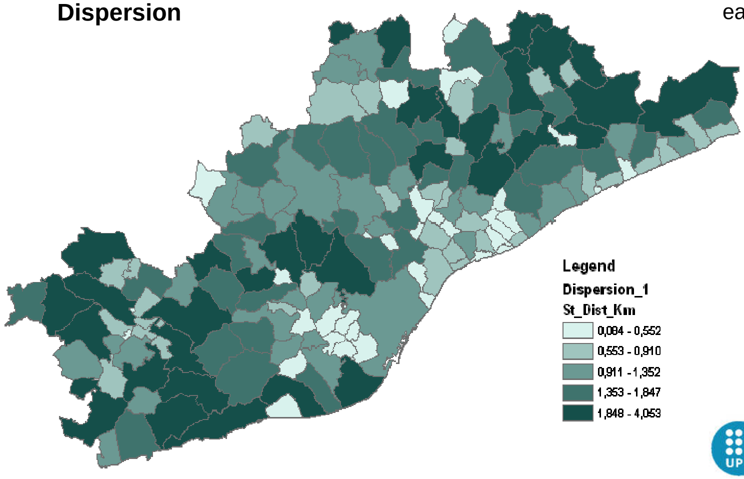
$$SD = \sqrt{\left(\frac{\sum_{i=1}^{n} x_i^2 \cdot a_i}{\sum_{i=1}^{n} A} - \overline{x_w^2}\right) + \left(\frac{\sum_{i=1}^{n} y_i^2 \cdot a_i}{\sum_{i=1}^{n} A} - \overline{y_w^2}\right)}$$

Where:
Xw, Yw = the coordinate position of polygons centroide system.
Xi , Yi = the coordinate position of each polygon centroid.

Fragmentation



Dispersion



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3.3. Grid Form Morphology

The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

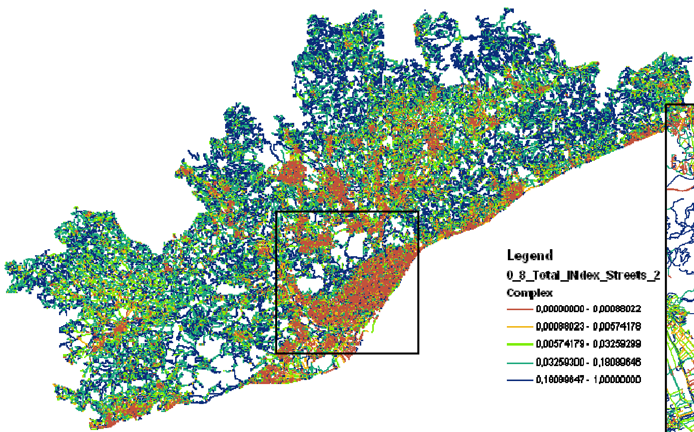
The main object to study the complexity of street networks is to identify their shape effectiveness in urban characteristic; for example, dens cities contains narrow and almost strait shape lines which gave high in complexity for less curves existed and in the otherwise curvy streets which could find outside dens cities show less in density and form its mean less in complexity

Grid Complexity

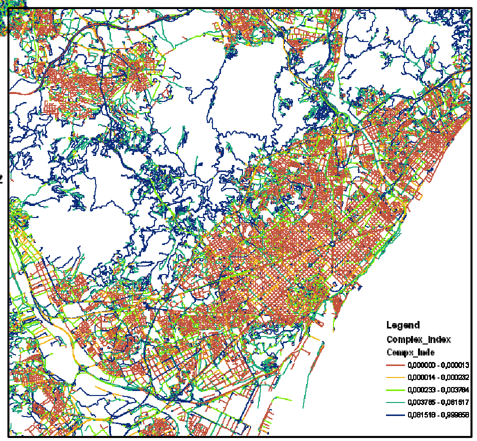
Street segmentation, length and start end point determination already done for each street line, by calculating a virtual line between start end points and compare the virtual distance with a real one the complexity must gave on a range between 0 to 1

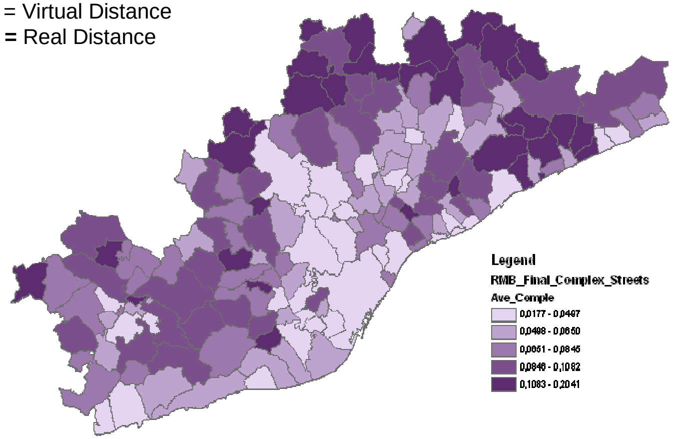
$$GCpxI = 1 - \frac{VD}{RD}$$

Where:
VD = Virtual Distance
RD = Real Distance



Grid Complexity vector dataset results





Thematic map of complexity street patterns results

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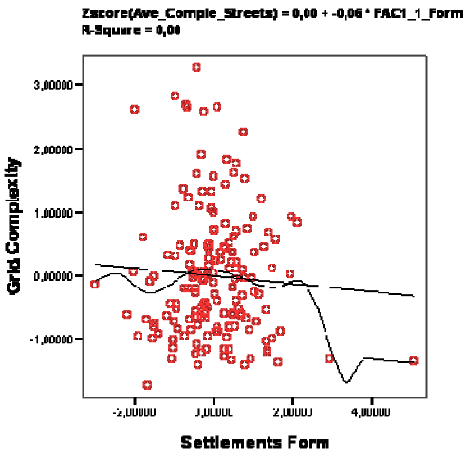
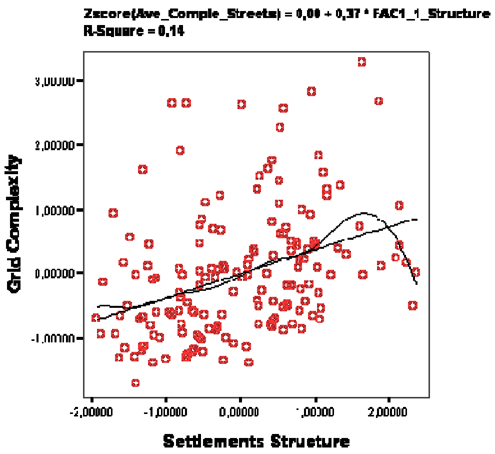
4. Describe Cluster Analysis by Interaction of Settlement Form and Structure with Urban Grid

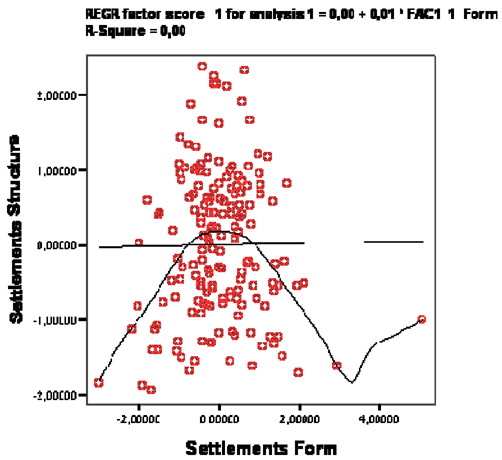
The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

From a methodological point of view, form and structure study captures significant properties of the urban settlements and discriminates the relation between both and street networks, but measures of form and structure morphologies, which are based on geometrical characteristics, show correlation with measures of street networks.

X axis illustrates joined relation between shape index and fractal dimension as away to understand the settlements form morphology, in the otherwise Y axis try to fin a relative relation between fragmentation and dispersion to describe settlements structure morphology and Z axis presents the grid complexity







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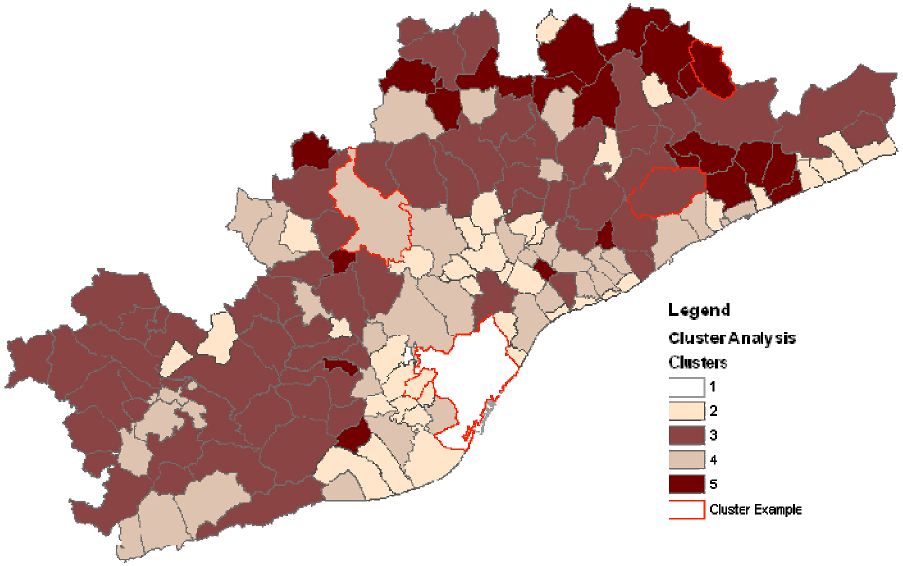
4. Describe Cluster Analysis by Interaction of Settlement Form and Structure with Urban Grid

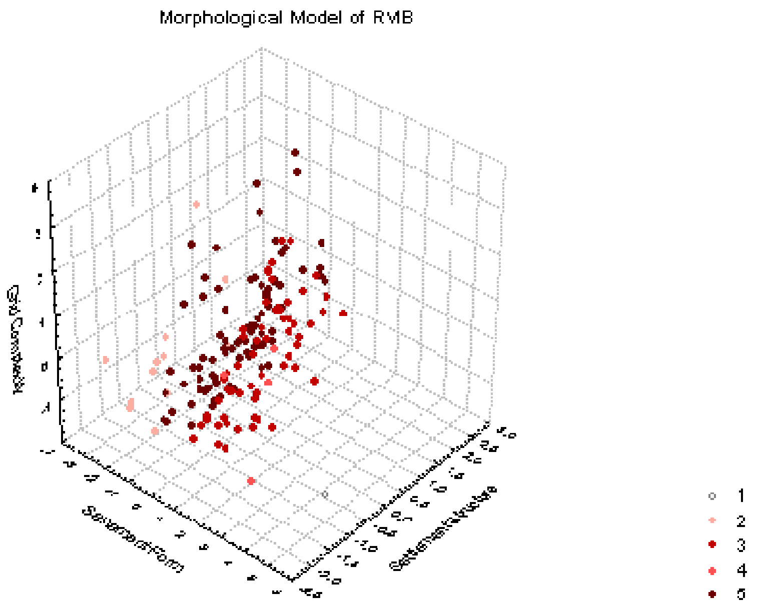
The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

The concept of the model is to present the relations in a unique model able to show previous morphological parameters and illustrated in three dimensional axes to indicate urban behaviours of growth.

The objective of the cluster analysis is to explore the relation between our three axes in different data source levels.

The district map coded for the results of the final cluster analysis with 5 scenarios shows which municipalities have similar morphological characters





The 3D model illustrates the relation between morphological form, structure and Grid Complexity

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4. Describe Cluster Analysis by Interaction of Settlement Form and Structure with Urban Grid

The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

Cluster analysis is a family of methods that seeks to explore the structure of a data set by defining the relationships between individual observations in the set and group each neighbourhood with other neighbourhoods that are most similar to it.

Random examples illustrate cluster result taken from the metropolitan region of Barcelona (see thematic map above).

These areas define clearly the topological behaviour of each cluster unit:

1 (Barcelona city) High compactness and complexity forms with low dispersion of varied street network types

2 High compactness and low complexity forms with zero fragmentation, road network structure contains two types: Orthogonal and Seprentine

3 High fragmentation without dispersion, street structure shows a predominantly serpentine type with high density

4 Middle compactness mixed with dispersion including high complexity shape, street structure shows a predominantly orthogonal merged with few seprentine types in the peripheral city part

5 Low compactness and complexity shape, high fragmentation and dispersion with serpentine street network structure but with low density

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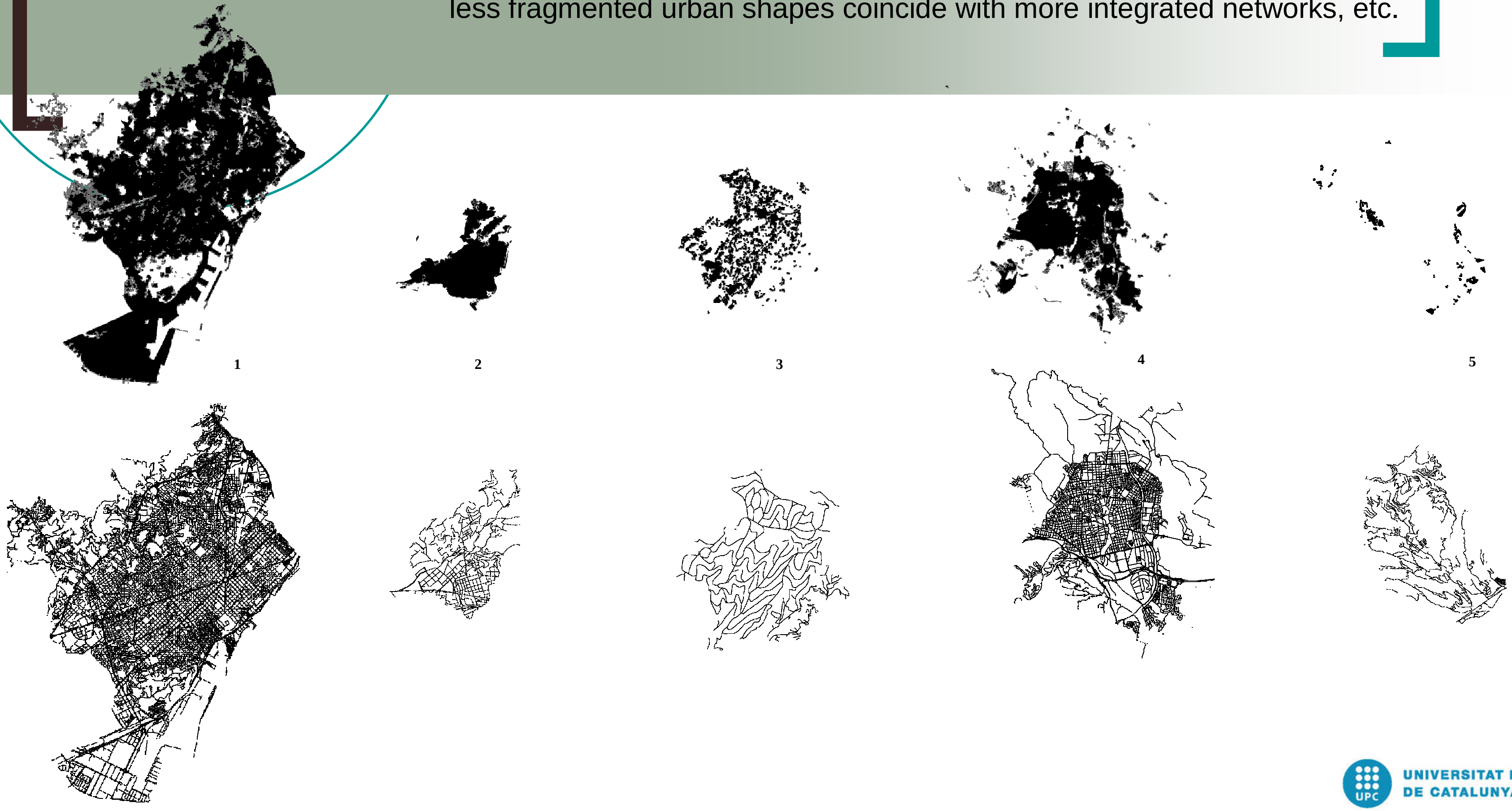
4. Describe Cluster Analysis by Interaction of Settlement Form and Structure with Urban Grid

The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

Strong and significant correlations between the measures indicate that the effect of settlement shape on street network is exerted according to the shape fragmentation or dispersion, where more convex and less fragmented urban shapes coincide with more integrated networks, etc.

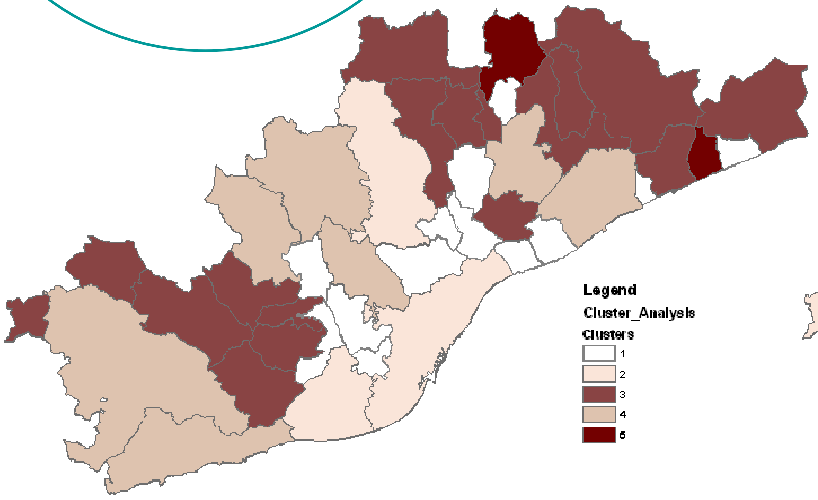


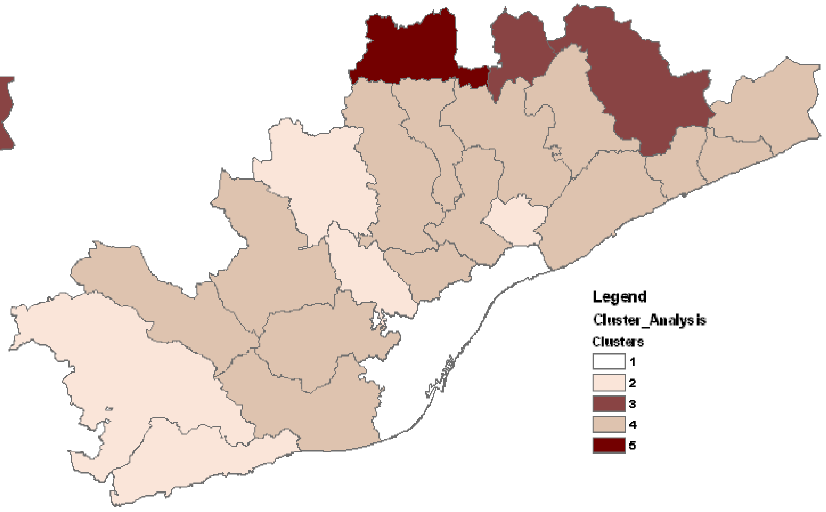
4. Describe Cluster Analysis by Interaction of Settlement Form and Structure with Urban Grid

The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

Cluster analysis applied over *Protosistemas* and *Local Systems* levels.

This finding is potentially significant to cluster behaviour in changing scale level. Cluster results here had the ability to explore the settlement behaviours but from pure morphological said. Observe last cluster results with reality such as land occupation and land slop gave by DEM we found it important to understand deeply our urban model behaviour relating to the territory.





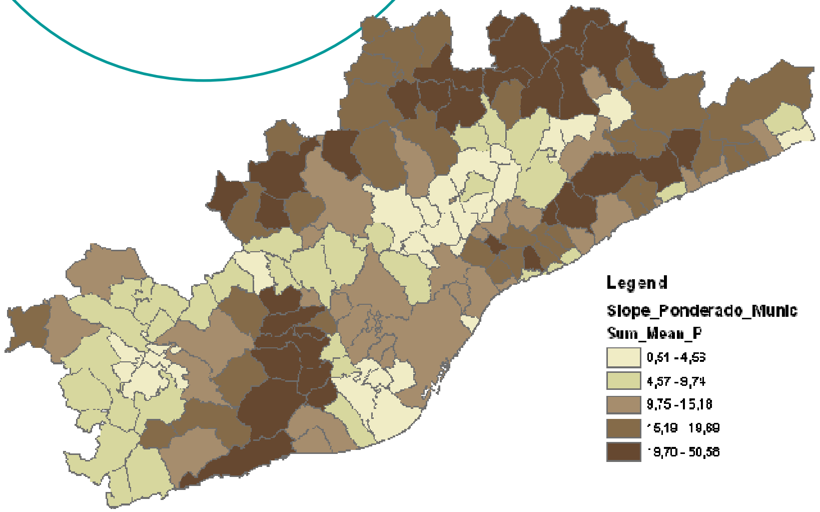
Cluster analysis results shown different characteristics of urban model over different scales.
(1) Protosistemas thematic cluster map.
(2) (2) Local Systems shown different scale of cluster analysis.

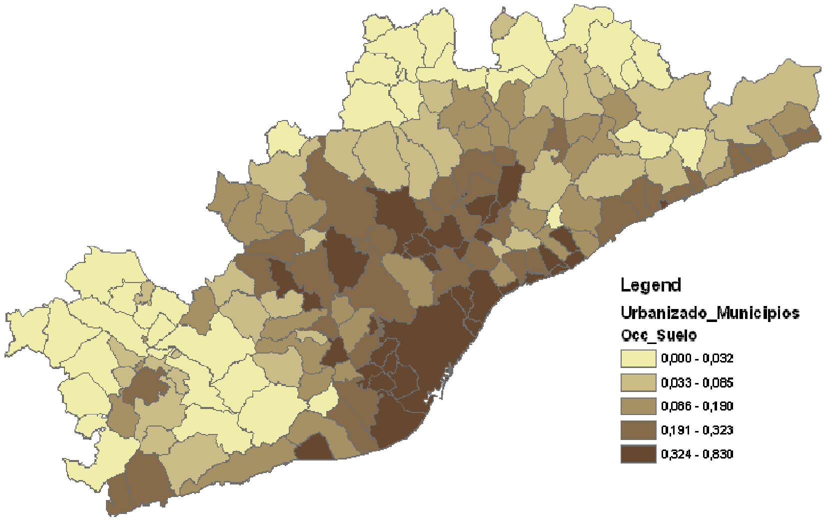
5. Correlation Between Cluster Analysis, Slope and Land Occupation in Describe Urban Model

The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

The thematic slope layer needed for this analysis can be easily created using a series of processes and produce from a Digital Elevation Model (DEM) associate to the altimetry, elaborated in ArcGIS.

Land occupation is a fundamental factor to define settlement units. The analysis shows that the majority of the land occupations occur in the lower slope levels and it's almost concentrate in the costal zones and in the northern west of Barcelona city.





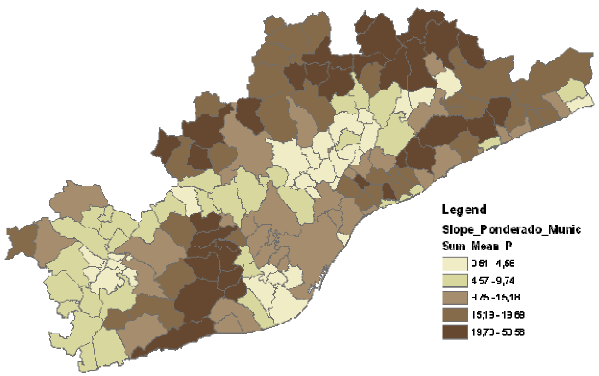
The following parameters Slope and land occupation were analysed. The figure illustrate municipal thematic maps. The maps represent the slope values (% of slope) and land occupation values (% of urbanized area on municipal area).

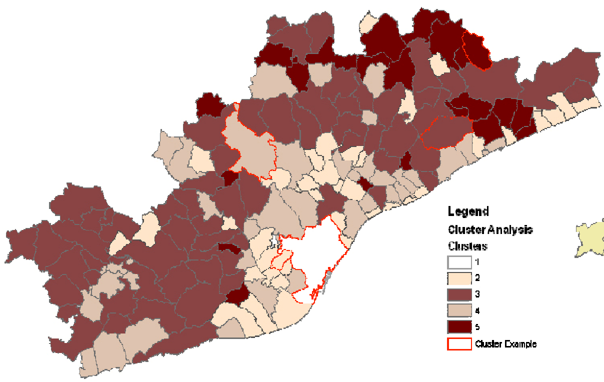
5. Correlation Between Cluster Analysis, Slope and Land Occupation in Describe Urban Model

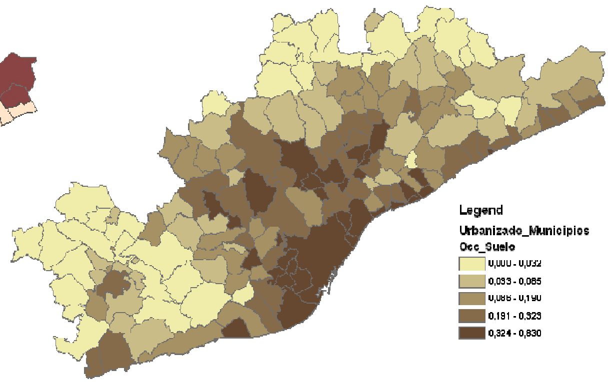
The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

Various parameters could add to the final description of urban model behaviour to be part of them in order to improve the capability to adopt different scales, occupation and territories.
Urban growth has quite good relation with above parameters as we know the continuity in land occupation produce high possibility of urban extend and the same for slop analysis which show like urban behaviour go for less extend in high slop areas and almost full occupation in the flat one.

This behaviour of previous indicators forces us to explore the relation with cluster analysis results, that is the morphological characters. Table 1 and 2 present that relation in *municipal* scale looking to repeat similar process over *Protosistemas* and *Local Systems* scales







The Digital Elevation Models framing of data on urban areas and the amount of land occupation allow to see the way in which it can be cross-referred to the data on urban model

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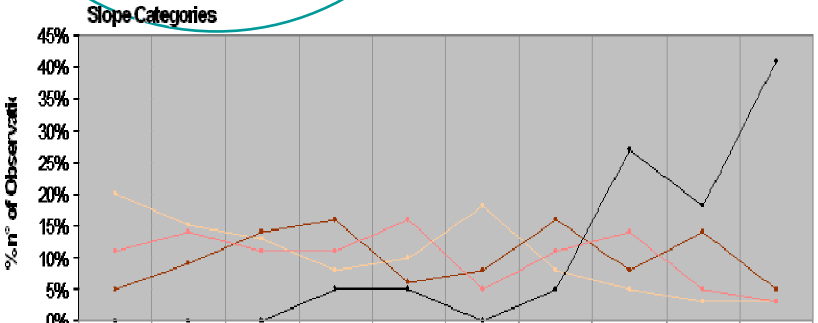
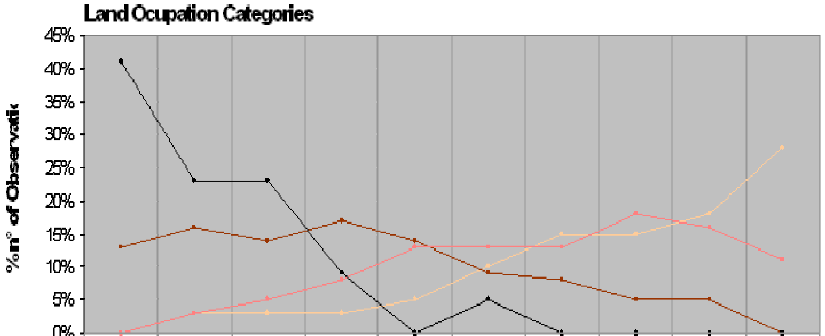
5. Correlation Between Cluster Analysis, Slope and Land Occupation in Describe Urban Model

The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

Clear correlation between terrain slope and land occupation parameters suggests other point of interest to understand their effectiveness on cluster analysis behaviour. Slope analysis is an important component of site selection analysis and allows an in-deep and more direct morphological analysis.



	Low	Low	Middle-Low	Middle-Low	Middle	Middle	Middle-High	Middle-High	High	High
Clus.2	20%	15%	13%	8%	10%	18%	8%	5%	3%	3%
Clus.3	5%	9%	14%	16%	6%	8%	16%	8%	14%	5%
Clus.4	11%	14%	11%	11%	16%	5%	11%	14%	5%	3%
Clus.5	0%	0%	0%	5%	5%	0%	5%	27%	18%	41%



	Low	Low	Middle-Low	Middle-Low	Middle	Middle	Middle-High	Middle-High	High	High
Clus.2	0%	3%	3%	3%	5%	10%	15%	15%	18%	28%
Clus.3	13%	16%	14%	17%	14%	9%	8%	5%	5%	0%
Clus.4	0%	3%	5%	8%	13%	13%	13%	18%	16%	11%
Clus.5	41%	23%	23%	9%	0%	5%	0%	0%	0%	0%

Immediate relation waiting cluster analysis compared with slope indicator (Right)
And correlation between cluster analysis and land occupation in municipal scale (Left)

6. Conclusions

The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

Remotely sensed data products have got unique advantage over conventional data gathering techniques in the study of urban morphology. The physical parameters like urban form, street pattern and urban structure as well as functional characteristic which can be derived from land use classification, area clearly visible on satellite data products.
Remote sensing data is capable of detecting and measuring a variety of elements relating to the morphology of cities, such as the amount, shape, density, textural form and spread of urban areas.

The present study has demonstrated a new method for Urban Model to identify measure and monitor various patterns of urban behavior in different scale levels in the metropolitan region and its environs, by integrating with remote sensing and GIS techniques.

The current method can be easily implemented within GIS to facilitate the measurement of urban growth.

When thinking about Urban Morphology it is important to remind that we use urban models to identify and compare patterns of settlements and to understand the relation between form and structure in them, and between morphology and topology.

The model already tested over the metropolitan region of Barcelona will be improved in its part concerning the scale analysis and tested over others geographical areas in Spain.

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The effectiveness of morphology and street networks in determining models of urban growth at different spatial scales analysis

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