Thresholding Urban Connectivity by Local Connected Fractal Dimensions and Lacunarity Analyses

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Abstract

The embodiment of fractal characteristics in the urban context relates to the mechanisms involved in the bio-functional evolution process and to the urban context's morphological characterization using fractal analysis. The failure of generalized fractal dimension to discriminate between active and non-active urban connections demands a precise method to estimate the local urban Connectivity. The focus of this research is on thresholding urban interactions, by multivariate discriminant function analysis based on Local Connected Fractal Dimensions and Lacunarity analyses. This invaluable local dimension analysis forms the core for estimating localized morphologic changes of different urban interactions levels, as a base for evolving fitness urban network by Genetic Algorithms.

The city's growth is guided by needs in local distribution and in communication among its parts (Courtat, Gloaguen, & Douady, 2011). These needs justify the complexity dimension investigations at localized level. According to Salingaros understanding the intricate connectivity of the living urban fabric it is necessary to undo the damage happened by erasing the fractal properties of the traditional city (A. Salingaros, 2005). This paper aims to thresholded Urban Connectivity Dimensions (U.C.D) using Fractal and Lacunarity logarithms by "FracLac" plugin in "ImageJ" software. The research chooses six cities (London, Paris, Rome, Milan, Aleppo and Cosenza) which represent diverse patterns in terms of U.C.D. Unfortunately, the *generalized box fractal dimension* (D) fails to differentiate successfully the morphological characterization found in different urban context. D is an overall or an average measure, and most of non-active and fragmented urban context show locally high-dimensional areas caused by nonfilling of the urban gaps together with locally low-dimensional areas caused by increased filling. The research has further investigated this problem using the concept of local connected fractal dimension.

Methods

The implemented methodology was applied to all case studies and involved two phases: maps digitization and fractal analysis.

Maps Digitization

The cities maps were elaborated by "Autocad" software and digitized as binary images in a computer with square pixels using "Xnconvert" software. The maps had a resolution of 1 pixel (1 pixel = 2 m), and consisted of 430 * 302 pixels.

Fractal Analysis

The computer program measured the total number of pixels local connected in a box of increasing size € centered at a point *x*, *y* (Richard F. Voss, 1993). In this context, "local connected fractal dimension" relates to all the pixels within the largest box used for the analysis that belong to the cluster connected to the pixel on which the box is centered. This method was applied to all the pixels belonging to the urban context in the case studies. The scaling relation is found by the linear regression of the logarithm of the mass (pixels) in a box of size € on the logarithm of €. The relationship is expressed as: **α = log [M (€)] / log (€).** (1) Where M (€) is the number of local connected pixels (eight-neighborhood connection) in a box of side size €. The procedure is as follows: For every pixel that "belongs" to both urban connections and contexts in the cities (Gabriel Landini, 1995):
1. Call the current pixel *P*.

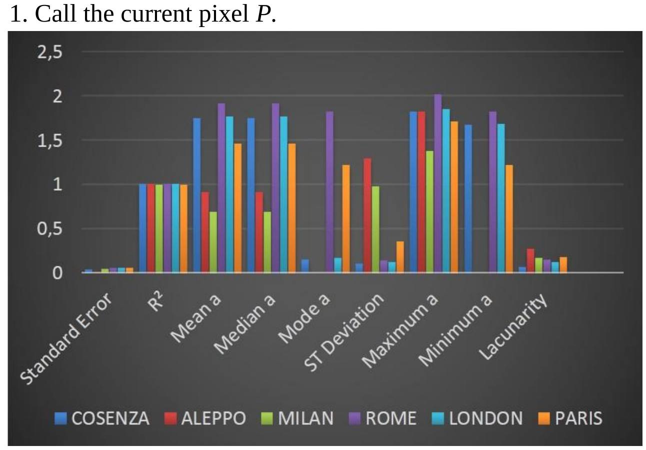

Figure 1: Summary of the parameters from local connected fractal dimension and Lacunarity analyses for the case studies.

2. Find all the pixels connected to *P* within a 430 pixel-side window centered at *P* (this is the "local connected set" *S)*.
3. Count the number of pixels M (€) of *S*, in boxes of increasing side size € (1 ≤ € ≤ 430) centered at P.
4. Calculate the local connected fractal dimension of *S* relative to *P* using equation 1 by linear regression of ***log(M(€)) versus log(€).***

Results

The methods were achieved by various analytical fractal dimension. Then the parameters from local connected fractal dimension and Lacunarity analyses were calculated and shown in Figure 1, which shows the mean values of the mean, median, mode, minimum, and maximum α and λ in the case studies, as well as the Standard Error and R2 (Coefficient Factor).

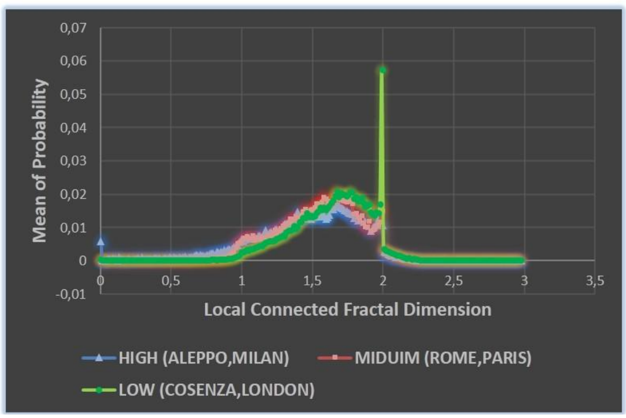

Figure 2: Mean distribution of the α value for the urban connectivity levels (high, medium and low).

Where none of the variables individually allowed a useful discrimination between the two groups. The mean distribution probability in the high, medium and low connectivity levels groups are shown in Figures 2. Note that the urban fragmented cases have a higher probability of high-dimensional features (near α ~ 1.7 to 2.00 region) with large peak at 2 that corresponds to the areas devoid of urban interactions and connections (open spaces).

Multivariate Linear Discriminant Function Analysis

The mean values of the mean, mode α, and Lacunarity, were used in a multivariate linear discriminate function analysis implemented by "SPSS" software, to investigate any association that could lead to a classifier or univariate design (Huberty & Olejnik, 2006). Discriminate analysis successfully reclassified 6 of the 6 (100%) urban connections and contexts correctly in the original groups. This successfully of classification mean, mode α and Lacunarity emphasize their role as the main parameters controlling morphogenesis of urban connections. Producing a dimensional map is used due to interrelate every local connected fractal dimension with a single pixel figure 3. Which shows how the changes in structure and behavior of the urban interactions depend on the difference between the local connected fractal dimension and Lacunarity values (Bilotta & Pantano, 2006).

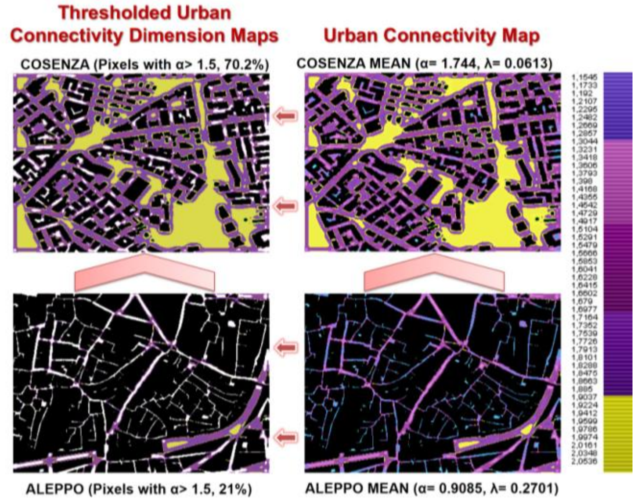

Figure 3: Urban connectivity in Cosenza and Aleppo cities and a thresholded version of the dimensional map showing only pixels with α>1.5.

The urban connectivity dimensional map represents a significant tool for evaluating and measuring the urban connectivity dimensions, which forms a real presenting of fractal criterion testing the cities geometry's as one condition for their success and a crucial guidance for the urban network's optimization process.

Conclusion

This morphological approach have been used to produce an objective method for assessment urban connectivity by a dimensional mapping, which was very successful for isolating areas with low connectivity dimension of high and medium ones. As well as helps to respond to the challenge for the contemporary city of how to superimpose competing connective networks in an optimal manner (Salingaros, 2004), by thresholding one of the essential characteristics in the cities "Network Interactions". Evolving an urban interactions adopting the new U.C.D threshold using genetic algorithms technique is under investigation.

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