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Urban texture and space configuration: An essay on integrating socio-spatial analytical techniques

Luiz Manuel do Eirado Amorim [a,*], Mauro Normando Macedo Barros Filho [b], Débora Cruz [a]

[a] Universidade Federal de Pernambuco, Departamento de Arquitetura e Urbanismo, Programa de Pós-Graduação em Desenvolvimento Urbano, Laboratório de Estudos Avançados em Arquitetura, Avenida dos Reitores, s/n, Cidade Universitária, Recife, PE, Brazil

[b] Universidade Federal de Campina Grande, Departamento de Engenharia Civil, Programa de Pós-Graduação em Engenharia Civil e Ambiental, Rua Aprígio Veloso, 882, Bairro Universitário, Campina Grande, PB, Brazil

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ABSTRACT

This paper integrates two distinct approaches to the analysis of urban phenomena – image texture analysis and space syntax –, aiming at a better description and understanding of complex intraurban socio-spatial patterns. On the one hand, satellite image texture analysis distinguished morphological patterns from urban areas with different inhabitability conditions, as previous studies have are already demonstrated. On the other hand, the constitution map texture analysis revealed distinct patterns according to different social and urban dynamics, according to urban form, size and land use, in such way that compact, highly parceled and constituted patterns tend to present low levels of mean lacunarity, whereas disperse, non-parceled and poorly constituted ones tend to present high levels of mean lacunarity. Such findings show that the texture analysis combining satellite images and interface maps is a very promising research for understanding the relationship between morphological and social patterns, and deserves future investigations.

Introduction

Cities are complex systems composed of non-linear and multiple scale iterations of spatial and physical heterogeneous components. Despite complex, these systems are self-organized and generate socio-spatial patterns as a result of human activities. The urban form is among the most stable of these patterns that not only structure those human activities, but also set limits to future reconfigurations. It can be described by size (scale), geometrical and topological properties; represented by vector and matrix datasets; and associated to distinct attributes. Recent computing processes, as well as the extended interest on the subject, allowed the emergence of distinct analytical procedures within the context of independent disciplines, with their theoretical and methodological foundations.

This paper reports the first stage of an ongoing research which main interest is to integrate two distinct approaches to the analysis of urban phenomena – image texture analysis and space syntax –, aiming at a better description and understanding of complex intra-urban socio-spatial patterns. As it is known, the core of space syntax theory and method is to link a precise built environment analysis to the human behavior (Hillier & Hanson, 1984). In fact, space syntax has been extensively used to comprehend socio-spatial relational patterns in urban and building's context, both historical and contemporary, and also as a decision making design tool, both to reproduce cultural patterns and to favor or to constrain, in probabilistic terms, behavior.

The very nature of space syntax is, therefore, the interaction with a variety of fields of study, bridging morphological, behavior and cultural investigations. This study aims at expanding the space syntax analytical, quantitative and descriptive toolbox by integrating the traditional set of syntactic built environment mapping, such as the public–private interface map, as originally proposed by Kruger (Kruger, 1979;Steadman, 1983), and the visual graph analysis diagrams (Turner, 2001), to the multi-scaling texture analysis, a description of the spatial variability of pixel tones in a digital image (Amorim & Barros Filho, 2009; Amorim, Barros Filho, & Cruz, 2009; Barros Filho & Amorim, 2008). It is of particular interest, the analysis of pixel tones gap distribution in different scales, measured by the lacunarity value, a complementary measure of the fractal dimension. Previous studies based on lacunarity measures revealed distinct morphological patterns in satellite images of slum and non-slum areas (Barros Filho & Sobreira, 2005), proving

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[*] Corresponding author. Tel.: +55 8121268311; fax: +55 8121268772.
E-mail addresses: amorim@ufpe.br (L.M.E. Amorim), mbarrosfilho@gmail.com (M.N.M. Barros Filho), debora_cruz@hotmail.com (D. Cruz).

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to be a powerful tool to identify and quantify distinct socio-spatial patterns, as intended by space syntax investigators.

The introduction of fractal analysis of syntactic dimensions was pioneered by Sobreira and Gomes (2001) in a study of the fragmented structures of enclosed and the open spaces, the latter represented as convex maps, found in spontaneous settlements in Northeast Brazil. They found a robust statistical distribution as a function of convex sizes in "settlements submitted to very rigid boundary conditions, [according to] a kind of packing process" (Sobreira & Gomes, 2001).

Our interest is to extend this pioneering study by applying and comparing lacunarity based texture analysis to describe the spatial arrangement of surfaces and built materials on high resolution satellite images and the spatial distribution of public–private interface points on constitution maps. Both approaches involve the analysis of the spatial distribution of pixels with similar gray levels. Therefore, the novelty of this paper consists on devising a new methodology that combines both approaches to improve spatial analysis, particularly with regards to the characterization (and differentiation) of urban morphological patterns.

Texture analysis, space configuration and socio-spatial patterns

Texture is a description of the spatial variability of pixel tones in a digital image, and it may improve image classification of urban areas. Texture analysis of digital images aims at recognizing and distinguishing spatial arrangements of gray levels values, based on methods which measure the spatial variability of pixel tones in an image. The higher the variability, the less homogeneous or uniform the image texture will be (Petrou & Sevilla, 2006).

A texture pattern is scale dependent. It may vary significantly according to the size and spatial resolution of a digital image. A very small image may contain parts of a pattern, and it may not be able to characterize the whole pattern, whereas a large image may be composed of more than one single pattern and could not be able to properly describe it as well. In the same way, a pixel in a low spatial resolution image may represent an integrated sign of many patterns smaller than the pixel size. As the spatial resolution increases the image pixels could become smaller than the analyzed pattern, generating spectral noises that degraded image classification (Mesev, 2003).

Lacunarity analysis

The concept of lacunarity was introduced by Mandelbrot (1982) to describe and quantify the deviation of fractal objects of their translational invariance. It was later established and developed from the scientific need to analyze multi-scaling texture patterns in nature (mainly in medical and biological research), as a possibility to associate spatial patterns to several related diagnosis. Regarding texture analysis of urban space registered by satellite images, lacunarity is a powerful analytical tool as it is a multi-scalar measure, that is to say, it permits an analysis of density, packing or dispersion through scales. In the end, it is a measure of spatial heterogeneity, directly related to scale, density, emptiness and variance. It can also indicate the level of permeability in a geometrical structure (Barros Filho & Sobreira, 2005).

Lacunarity can be defined as a complementary measure of fractal dimension or the deviation of a geometric structure from its translational invariance (Gefen, Aharony, & Mandelbrot, 1984). It permits to distinguish spatial patterns through the analysis of their gap distribution in different scales (Plotnick, Gardner, Hargrove, Prestegaard, & Perlmutter, 1996). Gaps in an image can be understood as pixels with a specific value (e.g. foreground pixels in binary images) or a certain interval of values (in grayscale images). The higher the lacunarity of a spatial pattern, the higher will be the variability of its gaps in an image, and the more heterogeneous will be its texture.

There are many algorithms to calculate lacunarity of an image. Among them, two algorithms have been commonly used: Gliding-Box and Differential Box-Counting.

The Gliding-Box algorithm was proposed by Allain and Cloitre (1991). According to this algorithm a box of size r slides over an image. The number of Gliding-Box with radius r and mass M is defined as $n(M,r)$. The probability distribution $Q(M,r)$ is obtained by dividing $n(M,r)$ by the total number of boxes. Lacunarity at scale r is defined as the mean-square deviation of the variation of mass distribution probability $Q(M,r)$ divided by its square mean.

$$L(r) = \frac{\sum_M M^2 Q(M,r)}{\left[\sum_M M Q(M,r)\right]^2} \tag{1}$$

where $L(r)$ = lacunarity at box size r; M = mass or pixels of interest; $Q(M,r)$ = probability of M in box size r.

The Gliding-Box algorithm when applied to binary images (images with only 1 bit) counts only the foreground pixels. This is because each pixel in a binary image can only have one of two possible values (either background or foreground). Whereas in grayscale images, one pixel can have many values, in an 8 bits image, for instance, each pixel can have 2^8 values. In this case it measures the average intensity of pixels per box which is the difference between the maximum and minimum intensity values at each box of size r (Karperien, 2007).

The Differential Box-Counting (DBC) algorithm was proposed by Dong (2000) based on the Gliding-Box algorithm described before, and the Differential Box-Counting algorithm proposed by Sarkar and Chaudhur (1992) to fractal dimension estimation. According to this algorithm, a Gliding-Box of size r is placed at the upper corner of an image window of size $W \times W$. The window size W should be an odd number to allow the computed value to be assigned to a central pixel, and $r < W$. Depending on the pixel values within the $r \times r$ Gliding-Box, a column with more than one cube may be necessary to cover the maximum pixel value by stacking cube boxes on the top of each other. If the minimum and maximum pixel values within a given column fall in cubic box u and v, respectively. Then, the relative height of the column will be (Myint et al., 2006):

$$n_r(i,j) = v - u + 1 \tag{2}$$

where $n_r(i,j)$ = relative height of column at i and j; v = cubic box with maximum pixel value; u = cubic box with minimum pixel value.

When the Gliding-Box slides over the $W \times W$ image window, the mass will be:

$$M_r = \sum_{i,j} n_r(i,j) \tag{3}$$

where M_r = mass of the grayscale image; $n_r(i,j)$ = relative height of column at i and j.

Then, the mass M in Eq. (2) is replaced by M_r in Eq. (3) to obtain the lacunarity in the $W \times W$ window. The lacunarity value is assigned to the central pixel of the window, as the $W \times W$ window slides throughout the whole image.

Socio-spatial patterns

Measurements based on lacunarity have been used on remote sensing due to their ability on distinguishing different image textures (Henebry & Kux, 1995). They have also been very useful on the accuracy of segmentation methods (Du & Yeo, 2002), and on image classification of urban features (Myint & Lam, 2005). Moreover, these measurements have shown the ability to