Urban Texture and Space Configuration   Ref 003

Analysing Recife's Urban Fragments

Luiz Amorim
Universidade Federal de Pernambuco, Departamento de Arquitetura e Urbanismo, Recife, Brazil
amorim@ufpe.br

Mauro Normando Barros Filho
Universidade Federal de Pernambuco, Programa Pós-Graduação em Desenvolvimento Urbano, Recife, Brazil
mbarrosfilho@gmail.com

Débora Cruz
Universidade Federal de Pernambuco, Programa Pós-Graduação em Desenvolvimento Urbano, Recife, Brazil
debora_cruz@hotmail.com

Keywords
urban texture; texture analysis; socio-spatial patterns; space syntax; public-private interface; lacunarity

Abstract
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. 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.

1. 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. 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 (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. 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 and Sobreira 2005), proving 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 and 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.

2. 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 (Barros Filho and Sobreira 2005).

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).

2.1 Lacunarity analysis

The concept of lacunarity was 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 and 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 et al. 1984). It permits to distinguish spatial patterns through the analysis of their gap distribution in different scales (Plotnick et al.

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.

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

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 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 Chaudhuri (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 x 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 x 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):

$$n_{r}(i, j) = v - u + 1 \qquad (2)$$

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 x W image window, the mass will be:

$$M_{r} = \sum_{i,j} n_{r}(i, j) \qquad (3)$$

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 equation 2 is replaced by in equation 3 to obtain the lacunarity in the W x W window. The lacunarity value is assigned to the central pixel of the window, as the W x W window slides throughout the whole image.

2.2. Socio-spatial patterns

Measurements based on lacunarity have been used on remote sensing due to their ability on distinguishing different image textures (Henebry and Kux 1995). They have also been very useful on the accuracy of segmentation methods (Du and Yeo 2002), and on image classification of urban features (Myint et al, 2006). Moreover, these measurements have shown the ability to distinguish morphological patterns between slum and non-slum, as well as among slums with different parceling types, densities, and urbanization levels (Barros Filho and Sobreira 2005).

Experiments conducted with IKONOS (Barros Filho and Sobreira 2005), QuickBird (Barros Filho and Sobreira 2007; Barros Filho and Amorim 2008), and CBERS-2 (Barros Filho 2007) images from Brazilian cities have shown that it is possible to distinguish morphological patterns from urban areas with different inhabitability conditions.

The experiments showed that high spatial resolution satellite images from urban areas with better inhabitability conditions have high lacunarity values than those with worse conditions. These differences, however, tend to decrease as the scales become finer. As the spatial resolution of the images decreases, an opposite relation between lacunarity and inhabitability can be found. For example, CBERS-2 images from urban areas with better inhabitability conditions have lower lacunarity values than those from poor areas. This is because small gaps, very common in slums, cannot be detected in low spatial resolution images (Barros Filho 2007).

Such findings showed that there is a strong correlation between social and morphological patterns. The spatial scale is a determinant factor on the comprehension of socio-spatial inequalities in the city. A single scale analysis of the intra-urban structure leads to a partial and uncompleted understanding of its socio-spatial patterns. An appropriate analysis requires a comparison among spatial data at different scales (Barros Filho 2006).

2.3. Public-private interface map

The robustness of these findings led us to question if this socio-spatial distinctiveness within cities is also captured by other forms of urban representation, notably those adequate to image texture analysis. In other words, if traditional urban thematic maps (land use, income, interface maps, for example), as well as, relevant space dimension descriptions, such as linear (Hillier and Hanson 1984) and visual graph analysis (Turner 2001), are able to carry embedded in their inner structure the same inequalities satellite images are able to reveal.

Public-private interface map is recurrently used within the field of space syntax as a tool to represent the relationship between the continuous open space and the enclosed fragmented private domains. Also referred to as constitution map, it is a powerful instrument to evaluate the degree of potential interaction between these urban spheres and its consequences to socio-spatial phenomena, such as urban safety, social surveillance, movement, etc. Its relevance is evident in studies such those developed by Holanda (2002) on the relationship between constituted and non-constituted open spaces, their sizes, uses and social strata.

In fact, it is known that some urban activities are highly dependent on an intense public-private interface. Retail activities, for example, are more successful if, first, are located close to busy lines of pedestrian and vehicular movement, and, second, if they are easily accessible and seen by the individuals that move about along those lines. Other uses, as residential one, tend to retain its privacy by reducing and controlling the public-private interface, notably in neighborhoods with historical of social conflicts or of strong social inequalities.

The interface map, combined with land use and movement pattern maps, is an important instrument to the understanding of urban dynamics, particularly, of socio-spatial distinctiveness. In self-generated settlements, for example, social cohesion is reinforced by blurring the public-private domains, whereas in modern suburbs, distinction is acquired by isolation. It would be of relevance to investigate if these differences are revealed in the spatial distribution of public-private interfaces in different urban districts, both socially and morphologically speaking. Furthermore, if the emergent patterns are, somehow, correlated to those already observed in satellite images.

3. The urban fragments and methodological procedures

The investigation looked at 4 urban fragments of Recife, Brazil, selected according to their distinct morphological and land use properties, as well as social and economical variables. The urban fragments were select from a Quickbird satellite image of Recife, with 0,70 meters space resolution, taken in 2001. The image is a R1G2B3 composition with 8 bits, georeferenced to UTM projection, Fuse 25, South America Datum 1969. Each fragment has 712 x 712 pixels, which corresponds to 500 x 500 meters. Figure 1 shows the urban fragments, side by side, and Table 1 presents the UTM coordinates of each selected fragments. The public-private interface map was generated from an official georeferenced map of Recife reviewed in 2000, therefore compatible with the analyzed image.

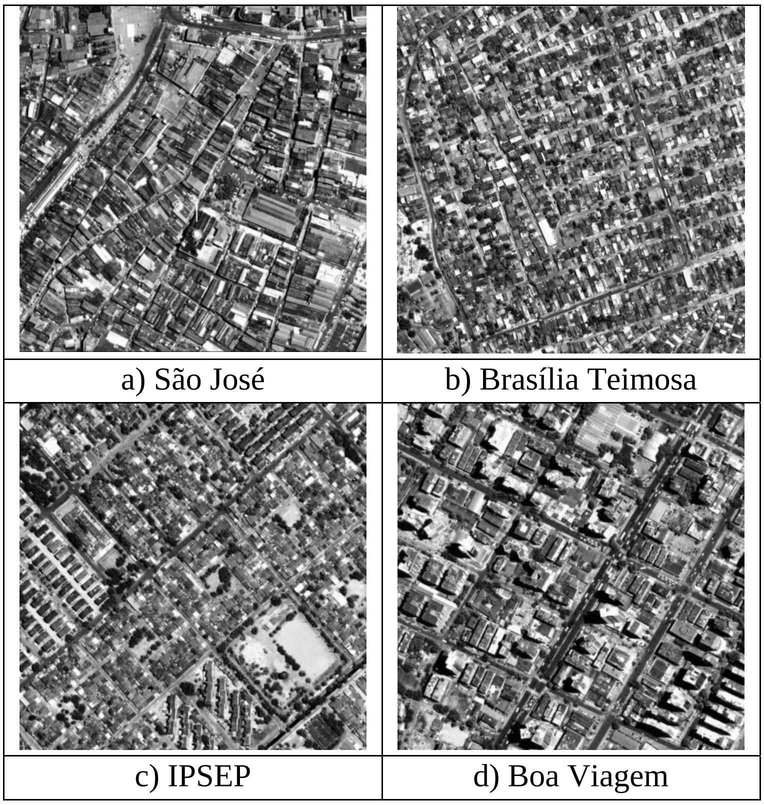


Figure 1

Urban fragments of Recife: 8 bits image, 712 x 712 pixels.

Fragment	**Lower left coordinate**	**Upper right coordinate**
Boa Viagem	290750, 9102000	291250, 9102500
Brasília Teimosa	292500, 9105600	293000, 9106100
IPSEP	288.250, 9102250	288750, 9102750
São José	292750, 9107500	293250, 9108000

Table 1

References of the selected fragments

3.1 The urban fragments

São José is part of Recife's historical centre, first occupied during the XVII century, but assumed its characteristics during the XVIII century, according to Portuguese urban tradition. The area can be described as a deformed grid (Hillier and Hanson 1984), composed of large irregular blocks and narrow and winding streets, interrupted by squares and patios (Loureiro and Amorim 2000). In the 1970's the area was significantly modified by a modernizing plan aiming at better connecting the historical centre to the spread out urban tissue. Historical documents inform that São José was essentially a residential neighborhood until the first quarter of the 20th Century, when a strong retail economy of regional impact slowly expelled the local residents. The resilient ones are of the lower income ranks.

Boa Viagem neighborhood is the denser district of Recife. Its origin is associated to an 18th Century fishermen village, but became an important suburb in the first quarter of the 20th Century as a weekend and holiday resort of the local bourgeoisie. In the 1950's, modern building flats started to substitute the weekend houses announcing the process of urban speculation and densification that would take place in the following decades. The urban tissue is fairly regular, with block forms varying according to their proximity to the sea front.

The IPSEP (Instituto de Previdência dos Servidores do Estado de Pernambuco) district is a housing estate financed by the former State of Pernambuco employees social security company. It was originally designed by the architect Florismundo Lins and his colleagues, in the 1950's, according to CIAM recommendations, and it went through successive design and construction periods. After fifty years, substantial alterations were introduced by its inhabitants, both at the urban (public open spaces privatization) and housing (houses and flats upgrading and extensions) levels, reproduce-ing a fairly common Brazilian phenomenon (Rigatti 2000; Amorim and Loureiro 2001). Nowadays, IPSEP is a consolidated middle-class neighborhood.

Brasília Teimosa is one of many self-generated settlements part of the large urban palimpsest that characterizes Recife's metropolitan region. The neighborhood combines typical dense and deformed grid from the original occupation with fairly regular urban tissue, which resulted from an official housing program, characterized by wide and narrow urban blocks. In fact, block sizes, both in the self-generated and planned areas, and grid configuration turn navigation within the area difficult. In general, plot sizes and buildings are small, and the absence of strict urban regulation allows inhabitants to maximize plot occupation, either by extending the houses or by introducing new independent units for rent or activities – retail, restaurants, etc.

3.2 Methodological procedures

The methodological procedures of this study involved two main steps. The first step consisted on the preparation of the maps and images of the 4 fragments described above. In the elaboration of the constitution maps, firstly, the research team did a field survey, registering all the public-private interfaces from each fragment on the official georeferenced map of the city. Then, the CAD files of the constitution maps were converted to binary images. Finally, an image processing technique was applied to dilate the public-private interface dots of the maps 5, 10, 15, and 20 times of their original sizes. In the elaboration of the satellite images, firstly, the fragments were extracted from the original image, considering the same UTM coordinates of the constitution maps. Then, the fragment images were enhanced through a histogram equalization process in order to increase the contrast of the pixel tones. Finally, the enhanced RGB images were converted to grayscale ones.

The second step consisted on the application of the lacunarity based texture analysis on the images treated in the first step. Firstly, the following parameters were used to all images: (i) the image background was setup to black; and (ii) it was considered 9 box sizes: 2x2; 4x4; 8x8; 16x16; 32x32; 64x64; 128x128; 256x256; and 510x510 pixels, which represent, respectively, squares which sides have: 1.40; 2.80; 5.60; 11.20; 22.40; 44.80; 89.60; 179.20; and 358.40 meters. Thus, at each iteration the box side duplicates its previous size. Then, due to the different characteristics of the satellite images and constitution map images, the Differential Box Counting algorithm was applied on the former, whereas the Sliding-Box algorithm was applied on the latter. Finally, the lacunarity values of each image were plotted against each box size, and a curve was generated, thus showing the lacunarity behavior of the image along the selected spatial scales. In order to have a single measure that offer a more direct comparison among the images, in some parts of the study, it was also considered the mean of lacunarity (Lm) values in all box sizes.

4. Data results

4.1 Satellite image

The image results are related to the spatial arrangement of the tones of pixels in the four images (see Figure1). The more concentrated the pixels with a same tone in an image, the higher its lacunarity. The more spread out the grayscale values in an image, the lower its lacunarity. The images of Brasília Teimosa and Boa Viagem are more homogeneous than IPSEP and São José. Despite their homogeneity, the size of the morphological elements present in Brasília Teimosa and São José are quite different. Even though the images are at the same scale, it seems as they are seen though different scales: Boa Viagem at a finer scale than Brasília Teimosa.

In general, Boa Viagem presents large building, plots, squares and roads. Such elements can be seen as large surfaces covered by a particular built material, which are represented as clusters of pixels with similar colors or tones at specific parts of the image. These clusters interfere on the image texture, increasing its lacunarity. This is more evident when the image is observed at larger box sizes. On the other hand, Brasília Teimosa has, in general, small buildings and narrow alleys. As a consequence, cluster of pixels with similar colors are smaller and more dispersed in the image, and its lacunarity is lower than Boa Viagem.

IPSEP and São José have a mix of large and small morphological elements. For example, the soccer field in the lower right corner of IPSEP image, as well as the large square in the upper right corner of São José image, contributes to increase their lacunarity, particularly when they are observed at larger box sizes. However, the building blocks in the surrounding of the soccer field and square are relatively small, decreasing their lacunarity when they are observed at smaller box sizes.

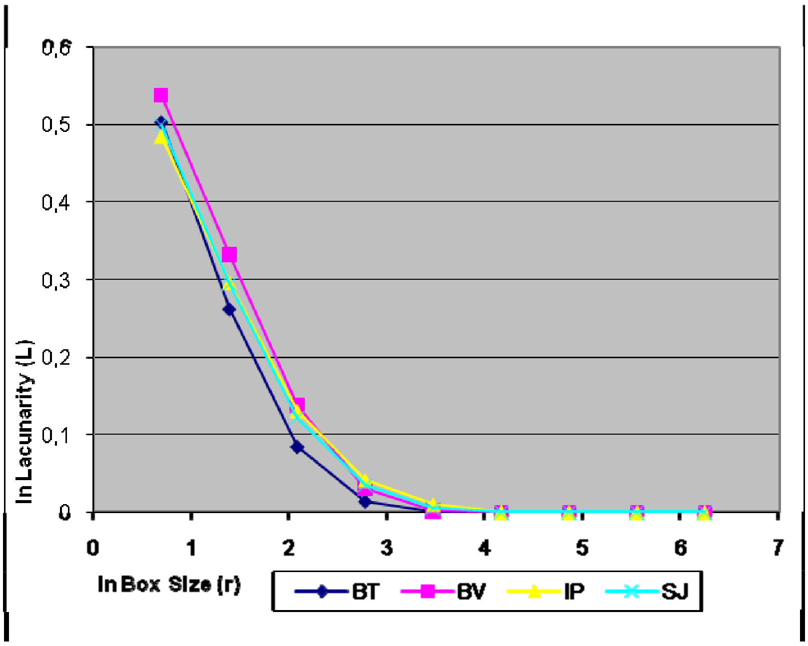


Figure 2

Satellite image lacunarity:P : BT – Brasília Teimosa; BV – Boa Viagem; IP – IPSEP; SJ – São José.

Due to the heterogeneous morphology of São José and IPSEP, their lacunarity values are lower than Boa Viagem, but higher than Brasília Teimosa, being located in between these image values in almost all box sizes. Moreover, the lacunarity curves of São José and Ipsep have a very similar behavior, being very difficult to distinguish both images. In a previous paper (Barros Filho and Amorim 2008), subfragments of these images were analyzed, revealing that the mean lacunarity values of São José's subfragments is a bit higher than those of IPSEP.

4.2 Public-private interface maps

In the analysis of the spatial distribution of public-private interface dots in an image, the concept of 'gap' could be related to the separated distance between pairs of dots. The greater the diversity of distances are, the more irregular the gap distribution and the higher the lacunarity would be. However, it is important to note that lacunarity values are not necessary related to dot's density, but to their spatial distribution in an image. Therefore, two images with the same dot's density, for example, may have different lacunarity.

Moreover, one should not confuse gap irregularity with urban grid irregularity. Gap irregularity is related to the presence of small and large gaps in an image. Many informal urban areas, for example, are comprised of tortuous alleys and irregular blocks that generate a diversity of open spaces or gaps with different sizes. However, there is not a great contrast between small and large gaps. On the other hand, some formal urban areas have large open spaces such as vacant plots and big squares that increase the diversity of gap sizes.

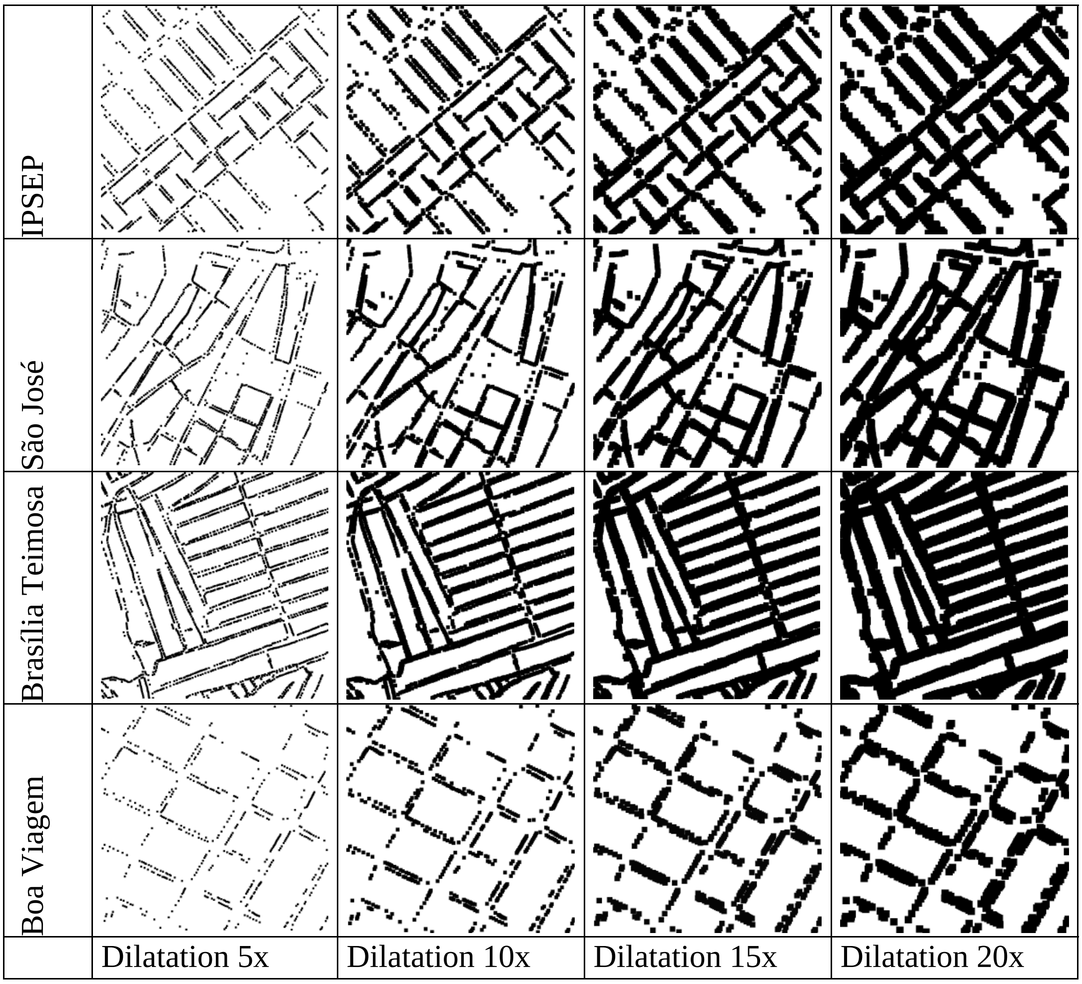
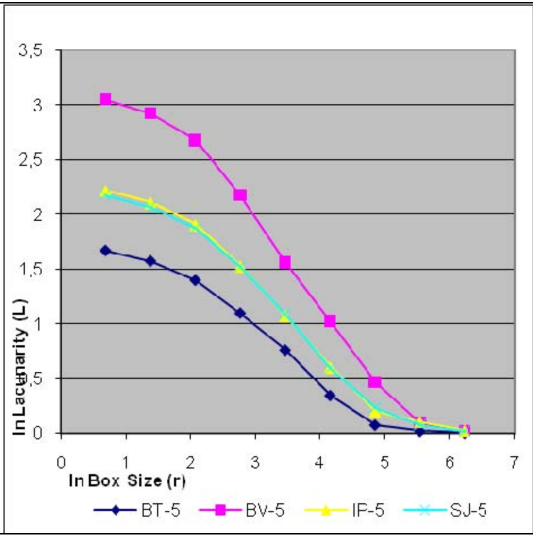


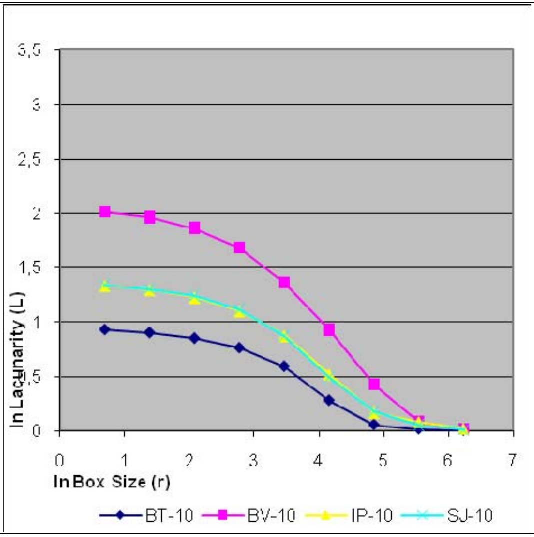
Figure 3
Public-private interface maps

Interface maps are, to a certain extent, a-dimensional, ie, the constitutions describe topological connections between private and public domains that are generally represented as dots. Seen as images, these dots are pixels. Texture analysis, as seen before, identifies spatial patterns through the analysis of pixels gap distribution in different scales, therefore, the pixels size have direct interference in the final results. For this reason, due to the small dimension of the dots in the original vector file, it was necessary to increase their size in order to have a better visualization of their spatial arrangement in the image, as well as of the gaps in between them. A dilatation technique was applied to increase 5, 10, 15 and 20 times each dot size. This technique emphasizes the importance in considering several sizes or scales in the analysis of a spatial pattern (see Figure 3).

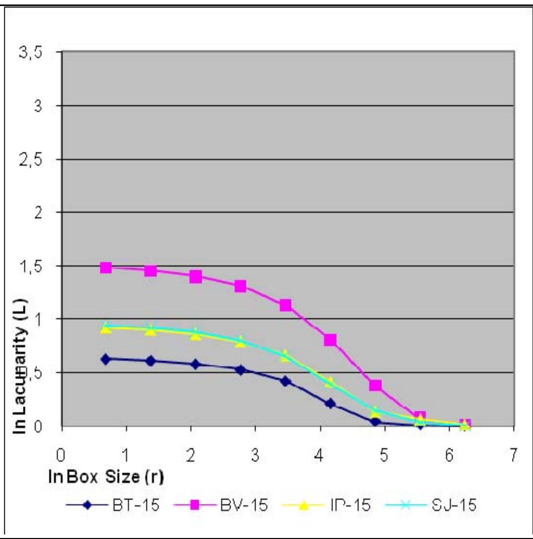
In fact, the dilatation level and the distance between pairs of dots can considerably change the lacunarity results (see Figure 4). On one hand, if the original dots are very close to each other, as the dot size increases, they would be easily overlaid. On the other hand, if the dots are sparser, as their size increases, they would not be overlaid, unless in larger sizes, or a very small part would be overlaid. This means that the gaps between the dots will be more efficiently fulfilled in the latter than in the former. Thus, the spatial arrangement of the dots reflects on the lacunarity results.



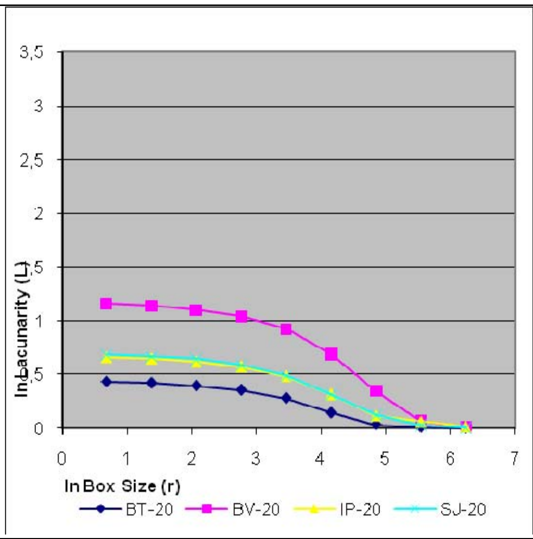
Dilatation 5x



Dilatation 10x



Dilatation 15x



Dilatation 20x

Figure 4

Lacunarity values: BT – Brasília Teimosa; BV – Boa Viagem; IP – IPSEP; SJ – São José.

In Boa Viagem, the dots located on a particular road are closer to each other than those located in different building blocks. As the building blocks and plots in Boa Viagem are bigger than those in Brasília Teimosa, there is a greater diversity of distances (gaps) among the dots in the former than in the latter.

Despite São José and IPSEP have very different morphological patterns, their lacunarity curves are very similar. This means that the gap distribution is quite similar in both images. Their roads are not as large as Boa Viagem, but also not as narrow as Brasília Teimosa. The same is true regarding their building blocks and plots sizes. These factors have a great influence on their lacunarity values, putting these images in an intermediate position in relation to Boa Viagem and Brasília Teimosa.

In the end, the constitution results showed a similar behavior with the satellite image results regarding to the Lm value of each fragment, as seen at Figure 5. In fact, the rank order of Lm value for both images is the same: BV>SJ>IP>BT. With these results in mind, we are able to start to draw general laws that may govern the emergence of texture patterns on interface maps.

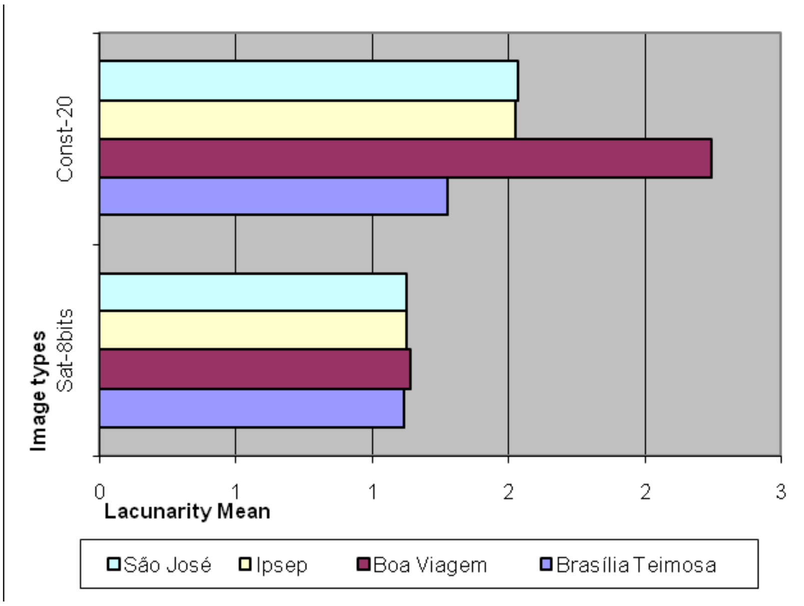


Figure 5
Mean lacunarity: interface maps and satellite images.

Firstly, it seems that the smaller and parceled the blocks and narrower the streets are, therefore, the more compact the settlement is, the higher the probability of finding low Lm values. As a consequence of this first assumption, the larger and less parceled the urban blocks and wider the streets are, the higher the probability of reaching to high lacunarity levels. It is important to highlight that the presence of public open spaces, such as squares and parks, as well as natural resources, such as beaches, rivers and lakes, will interfere in the results (Barros Filho and Sobreira 2007).

Secondly, we have to bear in mind that the form of the urban grid plays an important role, as the form of the blocks and the distribution of parcels may favor the distribution of constitution on one side of the block, increasing the void between them.

Thirdly, Lm values will alter according to the land use. The probability is that the more diverse and more spatially related activity, the higher the number of constitutions.

In sum, compact and highly parceled settlements densely occupied by spatially dependent activities –the ones that depend on intense interface with the public space -, will tend to present low levels of Lm, whereas disperse and non-parceled settlements occupied by transpatial activities – those that are weakly dependent on the public space, will tend to present high levels of Lm.

4.3. Brasília Teimosa: a further investigation

As seen, urban form, size and land use are determinant elements in our equation. However, we may pose a question: which are the relevant elements that contribute most to generate high Lm values? To answer that, a further step is necessary. For the sake of the argument, let us establish that the urban grid is rarely altered and if we keep the urban parcels momentarily unaltered, we will be able to measure the contribution of each variable by observing the effects on lacunarity values by altering the number of constitutions.

Let us take Brasília Teimosa and simulate a situation in which each plot is single constituted (SC) and compare it to the present situation (PS), characterized by an impressive urban dynamics expressed by a diversity of activities, particularly those dependent on intense relationship with the public open spaces. The single-constituted-plot map was drawn and analyzed according to the same criteria previously used. Figure 6 shows, for a better visual comparison, the process of dilatation of both maps, and figure 7 shows the lacunarity distribution graphs.

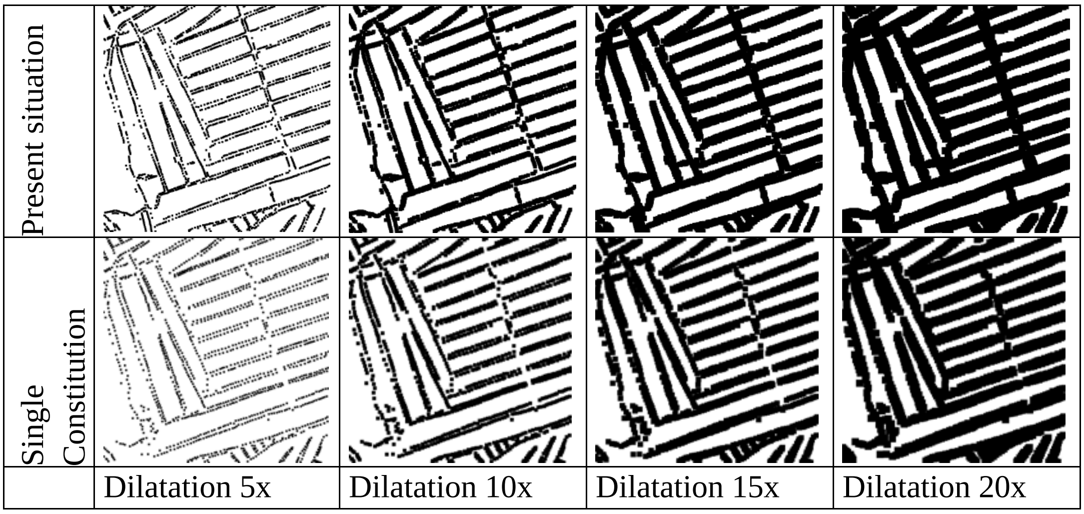


Figure 6

Brasília Teimosa's interface maps.

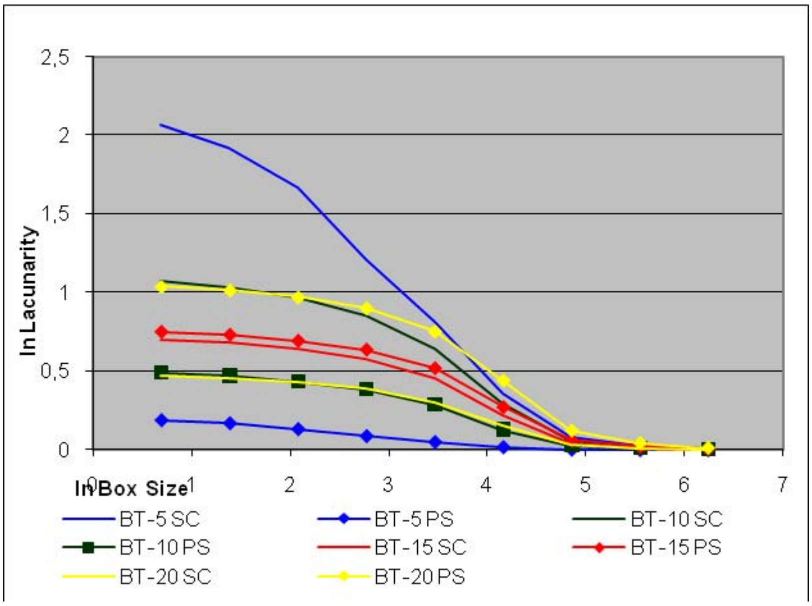


Figure 7

Brasília Teimosa's Lacunarity values for single constituted (SC) and present situation (PS) maps: BT – Brasília Teimosa; BV – Boa Viagem; IP – IPSEP; SJ – São José.

As expected, these results suggest that when the dilatation level is low (such as the images which were dilated 5 times), the lacunarity values of the single constituted plot map is higher than those of the present situation map. This is because the dots in the former are more separated to each other than those in the latter. However, as the dilatation level increases, the difference between both maps decreases and the lacunarity values of the present situation map surpass those of the single constituted plot map when the dilatation level reaches 20 times its original size. This is because the dots of the single constituted plot map fill the gaps more efficiently than those of the present situation map, whereas the dots of the present situation maps overlap more frequently, leaving more gaps in the image, which in turn increase their lacunarity values.

A closer look at the land use maps of Brasília Teimosa and Boa Viagem may help to better understand the constitutions' spatial distribution and the obtained lacunarity values (see Figure8). The fragments of both neighborhoods are predominantly occupied by housing, but mixed use buildings, those that are occupied by housing and retail activities are almost inexistent in Boa Viagem (only 3 buildings), but it is the second predominant occupation type in Brasília Teimosa. This is because low income population depends on their own resources to make a living and it is quite common that retail and service activities are offered to the community straight from inhabitants' own houses. In Boa Viagem, on the contrary, is found large retail companies, such as supermarkets, occupying a single urban block. Furthermore, retail and mixed use units are, as expected, located at the most integrated lines, both, at Boa Viagem and Brasília Teimosa.

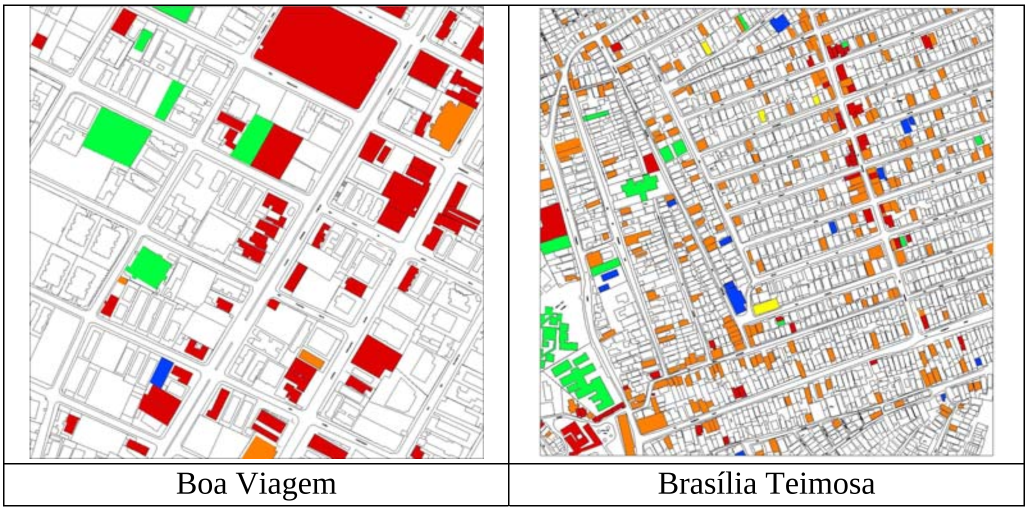


Figure 8
Land use maps: a) residential – white; b) retail – crimson; c) retail/residential – orange; d) educational – Green; e) religious – blue; f) yellow – institutional.

Therefore, on one hand, the block sizes combined with large retail and housing occupation in Boa Viagem, both with low public-private interface contributes to the resulting high lacunarity levels. On the other hand, small plot size combined with mixed use buildings contributes to the low lacunarity values found in Brasília Teimosa.

5 Conclusions and further studies

The case study confirmed that it is possible to distinguish morphological patterns from urban areas with different habitability conditions, as previous studies have are already demonstrated (Barros Filho and Sobreira 2005, 2007; Barros Filho 2007). This is clearly evident when Boa Viagem and Brasília Teimosa lacunarity values are compared. More relevant, however, are the results of the constitution map texture analysis, which revealed distinct patterns according to different social and urban dynamics conditions. These patterns are determined, as detailed above, by 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. It should be noted, however, that there are still great challenges to be considered on the next steps of this research.

Firstly, it is important to say that satellite images and interface maps were generated from different cartographic techniques, and they represent two different kinds of spatial objects. The former represent tangible objects such as buildings, roads, and trees, whereas the latter are comprised of non-tangible dots, i.e., objects that do not have material existence neither can be touched, but simply intend to symbolize the private-public interface.

Secondly, grayscale satellite images have 8 bits, whereas binary interface maps have only 1 bit. If one converts all images to the same number of bits, it would be easier to compare their lacunarity results. However, the interface map can only be represented as a binary image because it has only two informations: the dots (foreground pixels) and the gaps in between them (background pixels). So, it would be wiser to convert all images to binary. However, binary satellite images may not represent the real textures of the original images. Some valuable information about the spatial arrangement of the image tones may be lost when a grayscale image with 8 bits is converted to a binary one with only 1 bit. A comparative analysis between grayscale and binary Quickbird images from urban areas with different inhabitability condition has shown that grayscale images permit a better differentiation of such areas than binary ones (Barros Filho and Sobreira 2008).

Finally, it should also be considered the temporal gap between the satellite images and the interface maps. The former were acquired in October 2001, whereas the dots of the latter were acquired from a field survey in November 2007, using a reference map from 1997, reviewed in 2000. As a consequence, the public-private interfaces naturally changed during this time interval, particularly in Brasília Teimosa which has been subjected to faster urban dynamics.

Besides the challenges described above, the ongoing research is now dedicated to further investtigate the preliminary results of the texture analysis of Visual Graph Analysis maps (Turner 2001) and their possible correlation with satellite image and interface map analysis, described here. The preliminary findings show that grayscale visual integration maps present a distinct texture pattern when compared to satellite ones. These results, however, require a thorough investigation on the established analytical procedures. Tests are being performed to evaluate the effects of grid size, area of the fragment and its boundary to the lacunarity values. The grayscale of both images – satellite and Visual Graph Analysis map – must also be evaluated.

Acknowledgements

The authors would like to thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)and the Fundação de Amparo à Ciência e Tecnologia do Estado de Pernambuco (FACEPE) for supporting this investigation, and to Carolina Brasileiro, Júlia Gouveia and Maria Tereza Mendonça for their collaboration on data collection.

References

Allain, C., and M. Cloitre. 1991. Characterizing lacunarity of random and deterministic fractal sets. *Physics Review A* 44: 3552-58.

Amorim, Luiz, and Claudia Loureiro. 2001. Converted flats? Converted houses? A study of the transformation of Brazilian housing estates. Paper presented at the third international space syntax symposium, May 7-11, in Atlanta, USA.

Barros Filho, Mauro, and Fabiano Sobreira. 2005. Analysing spatial patterns in slums: a multiscale approach. Centre for Advanced Spatial Analysis. University College London. http://www.casa.ucl.ac.uk/working_papers/paper87.pdf.

Barros Filho, Mauro. 2006. As mútiplas escalas da diversidade intra-urbana. PhD diss., Federal University of Pernambuco, Brazil.
Barros Filho, Mauro, and Fabiano Sobreira. 2007. Urban textures: a multi-scale analysis of sociospatial patterns. Paper presented at the X Computer in Urban Planning and Urban Management, June 11–13, in Foz do Iguaçu, Brazil.
Barros Filho, Mauro. 2007. A morfologia da habitabilidade intra-urbana: o uso de imagem CBERS-2 na análise de padrões morfológicos no Recife. Paper presented at the XIII Brazilian Symposium of Remote Sensing, April 21–26, in Florianópolis, Brazil.
Barros Filho, Mauro, and Luiz Amorim. 2008. Texturas urbanas e diferenciações morfológicas. Paper presented at the II Brazilian Symposium of Geodesic Sciences and Geoinformation Technologies, September 8–11, in Recife, Brazil.
Barros Filho, Mauro, and Fabiano Sobreira. 2008. Accuracy of lacunarity algorithms in texture classification of high spatial resolution images from urban areas. *The International Archives of the Photogrammetry, Remote Sensing, and Spatial Information Sciences* 37: 417-22.
Dong, P. 2000. Test of a new lacunarity estimation method for image texture analysis. *International Journal of Remote Sensing* 2: 3369-73.
Du, Gan, and Tat Soon Yeo. 2002. A novel lacunarity estimation method applied to SAR image segmentation. *IEES Transitions on Geoscience and Remote Sensing* 40: 2687-91.
Gefen, Yeval, Amnon Aharony, and Benoit Mandelbrot. 1984. Phase transitions on fractals: III infinitely ramified lattices. *Journal of Physics* A 17: 1277-89.
Henebry, G., and H. Kux. 1995. Lacunarity as a texture measure for SAR imagery. *International Journal of Remote Sensing* 16: 565-71.
Hillier, Bill, and Julienne Hanson. 1984. *The Social logic of space*. Cambridge: Cambridge University Press.
Holanda, Frederico de. 2002. *O Espaço de exceção*. Brasília: Editora Universidade de Brasília.
Karperien, A. 2007. User's guide for FracLac v.2.5. School of Community Health. Faculty of Science. Charles Sturt University. http://rsb.info.nih.gov/ij/plugins/fraclac/FLHelp/Introduction.htm.
Loureiro, Claudia, and Luiz Amorim. 2000. O mascate, o juiz, o bispo e os outros: sôbre a gênese morfológica do Recife. *Revista brasileira de estudos urbanos e regionais* 3: 19-38.
Mandelbrot, Benoit. 1992. *The fractal geometry of nature*. New York: Freeman.
Mesev, Victor. 2003. Remotely sensed cities: an introduction. In *Remotely sensed cities*, ed. Victor Mesev, 1-13. London: Taylor & Francis.
Myint, Soe, and Nina Lam. 2005. A study of lacunarity based texture analysis approaches to improve urban image classification. Computer, Environment and Urban Systems 21: 501-23.
Myint, Soe, et al. 2006. Urban textural analysis from remote sensor data: lacunarity measurements based on the differential box counting method. *Geographical Analysis* 38: 371-90.
Plotnick, Roy, Robert Gardner, William Hargrove, Karen Prestegaard, and Martin Perlmutter. 1996. Lacunarity analysis: a general technique for the analysis of spatial patterns. *Physical Review* 55: 5461-68.
Rigatti, Décio. 2000. Order and Structure, Design and use in Housing Estates. *Urban Design International* 5: 161-176.
Sarkar, N., and B. Chaudhur. 1992. An efficient approach to estimate fractal dimension of texture images. *Pattern Recognition* 25: 1035-41.
Steadman, Philip. 1983. *Architectural morphology*. Cambridge: Cambridge University Press.
Sobreira, Fabiano and Marcelo Gomes. 2001. Urban Fragmentation: Spatial scaling laws in squatter settlements. Paper presented at the third international space syntax symposium, May 7-11, in Atlanta, USA.
Turner, Alasdair. 2001. "Depthmap": A program to perform visibility graph analysis. Paper presented at the third international space syntax symposium, May 7-11, in Atlanta, USA