FAVELAS VIA SATELLITE
Spatial Analysis of Slums

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ABSTRACT

According to the Global Report on Human Settlements (United Nations, 2003), almost 1 billion people (32% of world population) live in squatter settlements or slums. Recently, the perspective over those settlements has changed, from harmful tumours which would spread around sickly and unhealthy cities, to a new perspective that interpret them as social expressions of a more complex urban dynamics. However, considering a report from UNCHS - United Nations Center for Human Settlements, in relation to illegal and disordered urbanisation issue, some of the main challenges faced by cities are related to mapping and registering geographic information and social data spatial analysis. In this context, we present, in this paper, preliminary results from the research Favelas Via Satellite. It is a study that aims to interpret city from the perspective of urban texture, using for this purpose, high resolution remote sensing images. We have developed analytic experiments of "urban tissue" samples, trying to identify texture patterns which could (or not) represent distinct levels of urban poverty associated to spatial patterns. Such analysis are based on some Complex Theory concepts and tools, as Fractal Dimension and Lacunarity. Preliminary results seems to suggest that the urban tissue is Fractal by nature, and from the distinct texture patterns it is possible to relate social pattern to spatial configuration, making possible the development of methodologies and computational tools which could generate, via satellite, alternative and complementary mapping and classifications for urban poverty.

1 INTRODUCTION

This paper sinthetises preliminary results from the research Urban Dynamics, originally developed by the authors within the Group for Studies on Technology and Sustainability Applied to Architecture and Planning, from the Faculty of Human Sciences – ESUDA, Recife, Brazil. This document is divided into three sections: Contexts, Concepts and Analysis.

In Contexts, one presents a global view of issues that are somehow related to the main purpose of the research, discussing possible relations between urban poverty and its interpretation from the point of view of urban morphology. At the second part, Concepts, some theories and analytical tools are presented, with the purpose to develop a morphological analysis that allow a preliminary comparison between geometric complexity and spatial data interpretation, obtained from satellite images: Complexity, Fractal Dimension, Lacunarity. Spatial analysis is the focus of the third and last section, which includes a brief description of the softwares applied that were used (FracLac and ImageJ), the analytical process applied in each experiment, image selection and preliminary results.

2 CONTEXTS

Urban spaces, because their complexity, need to be object of multiple and complementary analysis, in order to permit a basic level of comprehension of their dynamics, including a diversity of perspectives, as the social, economic, political, and cultural ones. This research intends to contribute towards a spatial perspective to urban spaces and their complexity. In this context, complexity is approached through analysis of images which can be then confronted to statistic datas and social-economical and cultural information. The city is so observed as a collection of spatial patterns and textures, which integrate a rich and diversified mosaic, that actually hide within itself an apparent aleatoriety, a sign of a non-linear order.

To understand the city from the point of view of form and space, one needs initially to synthesize the complex relations that exist on urban environment, through the carefull election of relevant elements to the chosen approach, highlighting only what is essential under the morphologic perspective. This synthesis exercise is not a simple one and frequently it is misunderstood as analytical reductivism. It is needed, therefore, to understand Urban Morphology (here defined as method and concept related to urban study through the perspective of form and space) not as an exclusive analytical method, but as a complementary tool among a wide variety of possible urban environment analytical tools .

Through this approach, where form and space describe aspects of urban environment, the main issue is to observe patterns that would morphologically characterise the object or system. When forms are planned or they are expression of a classic geometry, mathematically linear, so pattern analysis seems to be a straight and obvious analytical exercise. But, what should one do when form and space apparently do not offer signs of logic or linear order? How would one study spatIal patterns that seems to be an expression of the complete absense of pattern? (figure 1). At the same time, there is an intriguing issue: would the reincidence of that apparent disorder, observed in urban structures, mainly in non-regular areas, be a deep sign of a hidden order? (SOBREIRA, 2002).

All these focus on irregularity and diversity is somehow related to a relatively new concept of Urban Planning (Latin American's governments approach since the beginning of the 1980's), based on the preservation of the morphological structure of the slums and, at the same time, their improvement or upgrading, in terms of basic infrastructure, facilities and urban services. But despite those efforts to acknowledge diversity, slums with different inhabitability patterns are still being considered similar. As a result, only a few number of slums (or areas within them) are being treated by local authorities, while other areas, where sometimes are more problematic and need much more attention, are still not being considered as a priority (BARROS FILHO, 2000). Thus, the understanding of different morphological patterns among slums seems to be an way to improve the manegement and planning of such settlements.

Figure 1: Aerial view of squatter settlement in Caracas, Venezuela.

3 CONCEPTS

3.1 Fractals: Geometry and Complexity

Questions about complexity and apparent disorder of form did not appear in discussions and observations of cities. Spatial pattern analysis of objects and systems that seemed to be logical but that could not be explained by traditional tools and theories from usual mathematics and Classic Geometry started to get scientific respect through Benoit Mandelbrot (1983), and his classic book, The Geometry of Nature, through which the author presents his ideas of what would be known, in the near future, as The Fractal Geometry. In other words, the geometry of the universe that, by nature, is non-linear.

The idea of logic in Fractals is related to observing an object through successive scales. A circle, a square or a triangle (classic examples of Euclidean Geometry) keep their properties, independently of scale of observation. These are objects that can be described according to a linear geometry, that is non-fractionary, as new details will not be noticed as one observe the object closer. But, if one observes a seacoast map, as an example, one will find that the closer the view, more details will be noticed, more roughness, protrusions, complexity. Ferns are truly examples of fractal geometry, as the closer we look at it, more details will be found, similar through scales. A similar pattern one can observe in the city: at each scale of observation, a variety of details, forms, textures. Generally, all systems, objects or geometric patterns which reveal a richness of details through scales, have fractal properties and can not be described by Euclidean Geometry. Nowadays, several studies affirm that city is a systems with fractal features, and that is not a simple expression of rethoric. Such studies confirm that cities are the result of a non-linear logic, whose patterns can not be measured by usual concepts and tools from Classic Geometry (BATTY & LONGLEY, 1994; FRANKHAUSER, 1997; SOBREIRA, 2000). After all, considering that, as Mandelbrot´s said that “clouds are not spherical, hills are not connical, coastlines are not circles, trees are not smouth and lightnings are not straight lines“, one could affirm that cities are not like the orthogonal, one-scale, chess tables.

3.2 Fractal Dimension

The Fractal Dimension quantifies the degree of irregularity or fragmentation of an object of spatial pattern (MOREIRA, 1999). There are several ways to measure the fractal properties of an object or geometrical structure. One of the easiest and more common procedures to quantify fractality is the box-counting method, whose result is the fractal dimension of an object or image. A box-counting fractal dimension indicates the level of complexity or the amount of details through scales (BATTY & LONGLEY, 1994).

3.3 Lacunarity: analysing texture

Considering that cities are naturally born fractals, and admitting that urban textures present a wide variety of patterns, how would one distinguish one texture from another? Or, how to identify differences within similarities? The concept of Lacunarity was stablished and developed from the scientific need to analyse multiscaling texture patterns in nature (mainly in medical and biological research), as a possibility to associate spatial patterns to several related diagnosis.

Focusing on the urban perspective, if one observe intra-urban and consolidated squatter settlements (*favelas*), despite their apparent disorder, the conclusion will be that they share the same spatial features, regarding fragmentation and scaling of morphological structure, wherever in the world (SOBREIRA, 2001). But, if fragmentation patterns reveal what is the common feature in favelas, on the other hand, a more detailed view of *favelas* urban textures will reveal a socio-economic and cultural diversity, so typical of these settlements.

Lacunarity can be understood as a complementary measure to fractal dimension, as it describes the texture of a fractal or any other spatial pattern. Lacunarity is related to size distribution of empty spaces (lacuna) of an image. Generally, if empty spaces in an image with fractal properties present a huge diversity of sizes, it will have a high lacunarity pattern of texture; or, if a fractal is almost invariant in its empty spaces sizes, lacunarity wil be low. Several fractals can be generated and present the same fractal dimension, however, they can be characterised by distinct textures, related to different lacunarity levels. Applications to lacunarity were firstly registered in researches related to image processing in Ecology, Medicine, Biology and other related fields (GARDNER et al, 1996). Our conjecture, in this paper, is that one can use lacunarity as an indicator of urban texture and, probably, as a tool that will permit to associate satellite images to social and economic patterns.

Regarding texture analysis of urban spaces registered by satellite images, lacunarity is the more appropriate analytical tool, specially if associated to fractal analysis, as they are multiscalar measures, that is to say, they permit an analysis of density, packing or dispersion through scales. Lacunarity measures are not based on a unique scale, but through multiscalar graphs that reveal the texture variation at several scaling levels. At the end, it is a measure of spatial heterogeneity, directly related to scale, density, emptiness and variance. It can also indicates the level of permeability in a geometrical structure.

Ben Wu and Sui (2002), in a paper about urban segregation analysis in residential areas through lacunarity, present an algorithm based on a sliding box with a varying size. According to that algorithm, the lacunarity to a box (square section of an image) of size "s" will be:

$$1 + (var(S)/E^2(S)),$$

where E(S) is the average and var(S) is the variance of mass values of boxes of size "s". Variance is the square of standard deviation ($var(S) = std(S)^2$).

A low lacunarity, generally, indicates homogeneity, while high lacunarity means heterogeneity. The higher the lacunarity, the bigger will be the variation of pixels distribution in an image. In other words, high lacunarity means that pixels are grouped in a wide variety of sizes of islands, surrounded by a widely variant emptiness, indicating heterogeneity of spatial pattern or texture.

4 ANALYSIS

4.1 Computational tools: FracLac and ImageJ

Spatial analysis of complex objects as the city requires a considerable capacity of data processing. Dealing with fractal and lacunarity analysis, in which scale multiplicity is a basic issue to understand the complexity of systems or spatial patterns, this task would not be possible without computational aid. It is not casual the direct relation we can observe, mainly from the 1960's, between computational development and the advance of research findings related to Complex Systems.

To develop analysis of urban textures in this research the computational tool applied is FracLac, a freeware Windows-based application associated to a image processor (also freeware) called ImageJ, both used and disseminated by scientists and researchers interested in issues like high complexity analysis of spatial patterns and textures, from a wide variety of fields.

4.2 Experiments and Preliminary Results

Images analysed in this paper were initially selected according to samples availability and morphological features, considering both regular and irregular patterns. Samples of high resolution satellite images were selected, originally captured by the IKONOS (Space Imaging – Brazil) and freely available to download through the internet, only for no-profit research and evaluation purposes. Experiments, as they were developed in this research, are divided in two approaches: fractal dimension and lacunarity patterns.

The fractal dimension was obtained through ImageJ that applies the boxcounting algorithm. The procedure is simple: the program generates grids over the analysing image, successively, each time with box (grids units) of a different size (2,3,4,6,8,12,16,32,64), depending on parameters defined by the user. To each size of box, it is registered the number of box that contain at least on pixel inside. From this procedure, FracLac calculates the Fractal Dimension, that is the slope of the log-log graph, in which the x-axis means box size and y-axis means number of pixels.

In this analysis we selected three images from the city of Campinas, Brazil: 02 regular (orthogonal geometry) samples and 01 irregular (favela) sample (figure 2). The preliminary result is that all the samples present similar Fractal Dimension. Despite natural expectations of possible differences in fractal patterns because geometrical dissimilarities of the urban samples, we could argue that, irrespective of spatial configuration, both one pattern and another are rich in details through scales, as would be expected if we remember that we are dealing with real cities and not just geometrical patterns or textures. So, as they are complex structures, we could agree with the conjectures presented by researchers as BATTY & LONGLEY (1994) and FRANKHAUSER (1997), according to whom the City is Fractal.

The second experimental analysis refers to the use Lacunarity concepts to evaluate urban textures, selected from satellite images. In this case, it was also used FracLac and ImageJ as computational applications. The algorithm of FracLac that calculates Lacunarity is based on sliding box counting, as described previously. Accorging to this algorithm, the box slides over the whole image, registering the number of pixels inside the box at each stop of the sliding process. At the end, it is calculated the average and standard deviation of the number of pixels registered in each stop. FracLac calculates Epson – E (actual box size / maximum box size), average, standard deviation and Lacunarity, that can be viewed through numbers and graphs which show the lacunarity variation through scale (according to distinct box sizes). Actually, the best way to analyse lacunarity is not through isolated numbers, but through graphs that ilustrate its variance across scales. To be analysed, the pictures need to be converted to binary images.

Figure 3 shows the main results obtained from analysis of samples in Campinas, São Paulo. As one can observe, differently from fractal dimension, which indicated similarity among the structures, when the issue is lacunarity it is possible to distinguish two groups of configuration and texture. The regular (orthogonal) areas present, in average, higher values of lacunarity, what is probably a consequency of the outstanding emptiness of spaces, associated to large and regular avenues, and overall low density. On the other hand, when analysing the *favelas*, the result is low lacunarity, indicating low permeability, resulting from typical feature of such urban structures: highly dense occupation and tortuous alleys.

Figure 4 correpond to confrontation of data of two favelas in two distinct cities: Campinas and Rio de Janeiro. Differently from what could be expected, that would be similariy of patterns, the two irregular areas diverge considerably in their lacunarity patterns. If one observes the results and at the same time analyse the spatial configuration, one will understand that differences result from morphological and social particularities of each community.

So, results of these preliminary experiments with lacunarity patterns seem to indicate important reflections:

I. If Fractal Dimension reveals that distinct parts of the city are similarly complex, Lacunarity complement that analysis, revealing differences of textures hidden by similarities in fragmentation and scale;

II. It is clearly possible to distinguish, through lacunarity graphs, differences of textures related to regular and irregular areas;

III. When a comparison is stablished between favelas, one can observe that differences of density, urbanisation, land parcelling and, probably, levels of urban poverty, generate distinct textures that will be reflected in lacunarity patterns;

5.3 About Image Processing and Analysis

We have seen that Fractal and Lacunarity analysis are basically texture-based pattern interpretation. As it requires binary images for application, a question arises: how the process of binarisation influences the results?

Naturally, as we use different process to ´binarisation´, the results will difer, as we will have different textures. Even though, we can observe through analytical experiments using IMAGEJ that changes in binary process do not change the fractal nature of the image (because the richness of details through scales is mantained). So, the main issue in this regard is not to discuss the best process of bynarisation, but keep the same criteria through the whole sequence of images to be analysed. Doing that, we will be able to establish comparative analysis, whatever the chosen binarisation process. If the purpose is comparing images which apparently represent spaces with distinct levels of inhabitability, the main procedure we have to keep in mind is keeping the same analytical process to all samples, so that it will be possible to properly analyse the results, limitting the changing variables. There would be a problem only if we had chosen a different process of binarisation to each new sample of image.

So, the answer to the question "how the binarisation process affects results" is: changes in binarisation process obviously will change the fractal dimensions, but it does not change the fractal nature of the images. So, to establish a proper comparative analysis, we just have to choose the binary process that seems to keep the main visual properties of the original image, and repeat the parameters to the whole set of image samples to be analysed.

In analysis through binary images of urban textures, dissimilar land uses with different absolute radiances, such as built and non-built areas, if covered by shadows or by vegetation could have similar slopes of their spectral reflectance curves and may appear similar (LILLESAND & KIEFFER, 2000). That would affect the results, if analysis were depending on strict identification of built or non-built elements. But the approach suggested in this paper is based on texture, irrespective of being built or non-built elements. This analytical methodology does not depend on direct and strict visual interpretation of satellite images.

Afterall, should the binarisation process be supervised or non-supervised by the image analyst? In this context, we can suggest a non-supervised approach assuming that, in this case, it is not necessary to classify land use types from the image, such as built and non-built areas, because the image's spatial elements are considered as inherent parts of a specific global texture pattern generated by the combination of such features. This approach can also be justified by the fact that a supervised binarisation procedure requires a great deal of training and practice and it is not necessarily replicable from place to place and time to time (WEEKS, 2003). A supervised approach is also both time-consuming and is particularly subjetive (DONNAY, BARNSLEY & LONGLEY, 2001). Moreover, intensive field survey should be necessary and can often be problematic in some slums, especially those where accessibility is inhibited for security reasons (BAUDOT, 2001). However, the texture patterns resulted from a non-supervised binarisation procedure do not properly resemblance their original satellite images and the comparison between them can lead to wrong conclusions because they are affected by different surface materials and illumination conditions, presence of clouds, etc. To avoid that, the original images should be previously analysed, classified and properly selected before the binarisation process.

In this sense, the combination of shadows, trees, voids, cars, river, buildings, plots or the absence of all these elements in the *binarised* image will generate a specific kind of texture. What one should focus at that moment is whether the way those elements are interrelated and distributed through the image will correspond to a texture and specific pattern that could allow any kind of classification. Thus, in this case, trees or shadows are not problems or barriers to image interpretation, as they can be interpreted as inherent parts of a global texture that characterises a space. That is the main difference between analysing satellite images through methods as lacunarity (focusing on global texture), in comparison to the traditional analysis of direct observation of photos (focusing on specific elements). We all know it is hard to intepret images traditionally, focusing on speficif elements, because of resolution levels and barriers, as trees, shadows and other elements usually seen as barriers to the viewer. But, interpreting textures, the elements usually seen as barriers are simply compositive elements of a general texture.

5 PERSPECTIVES

We suggest that, considering preliminary results, that high resolution images, when combined to computation tools, analytical procedures and theoretical concepts based on Complex Systems approach, can be powerful instruments to manegement and monitoring urban spaces.

At the same time, if on one hand one can observe how complex and similarly fractal the urban structures are, on the other hand, one can not deny the diversity of patterns and textures behind similarities. Fractal Dimension reveals what is in common among those structures, that is the multiplicity of scales and inherent social complexity. Lacunarity reveals a possible relation between texture and economical, social and cultural patterns.

We believe that a natural and inevitable step towards spatial analysis of cities and its urban structures and consequently its morphological correlation with social events will be the attempt to establish relation between spatial and geometrical patterns and social and economical data, specially when associated to GIS and Remote Sensing techniques (BARROS FILHO, 2000). To achieve that expectation, it is necessary concentrate effort in municipalities, with the purpose of make viable and accessible all the technology and scientific knowledge that presently is restrict to academic groups and institutions.

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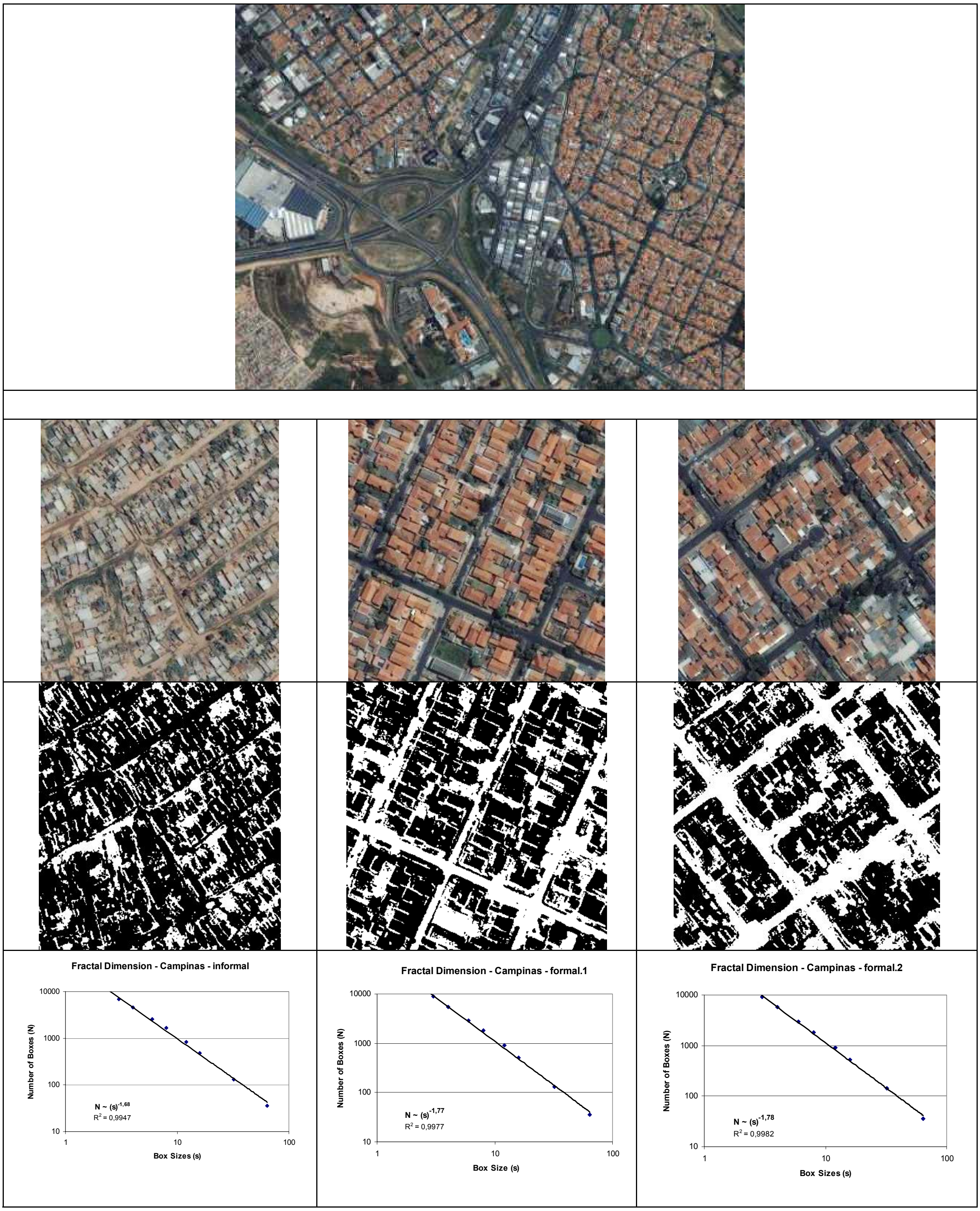

Figure 2 – Satellite Images - Campinas - SP - Source: Space Imaging - Brazil.Top-down: sample of Campinas - SP; samples of regular and irregular (*favelas*) areas; binary versions of images; Fractal Dimension (D) - logxlog graph indicating relation between the number (N) and size (t) . Fractal Dimension is indicated by the graph slope.

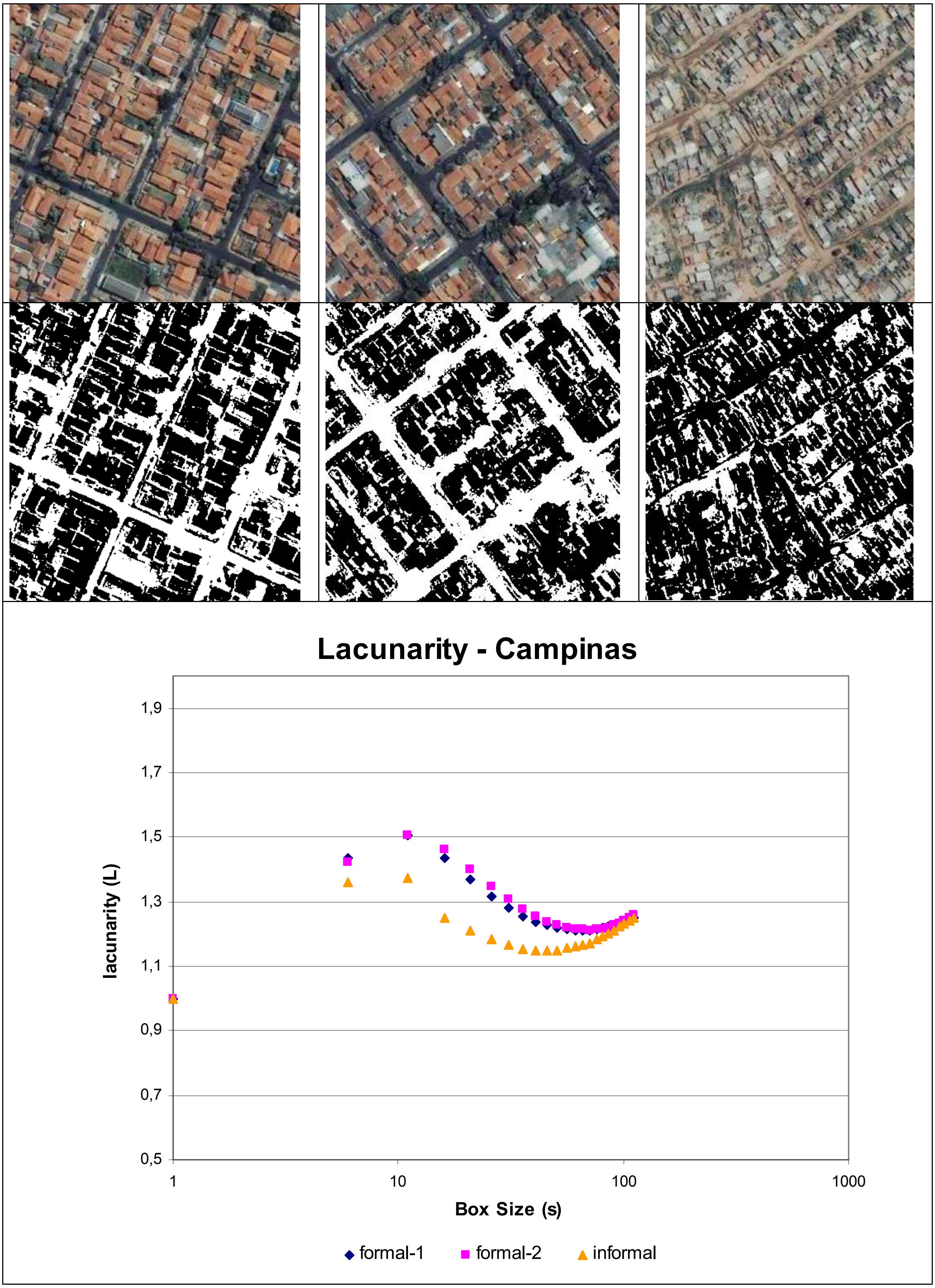

Figure 3 - Lacunarity - Campinas. Top-Down, Left-Right: samples of satellite images, binary versions of samples, lacunarity graph, describing variation through scales.

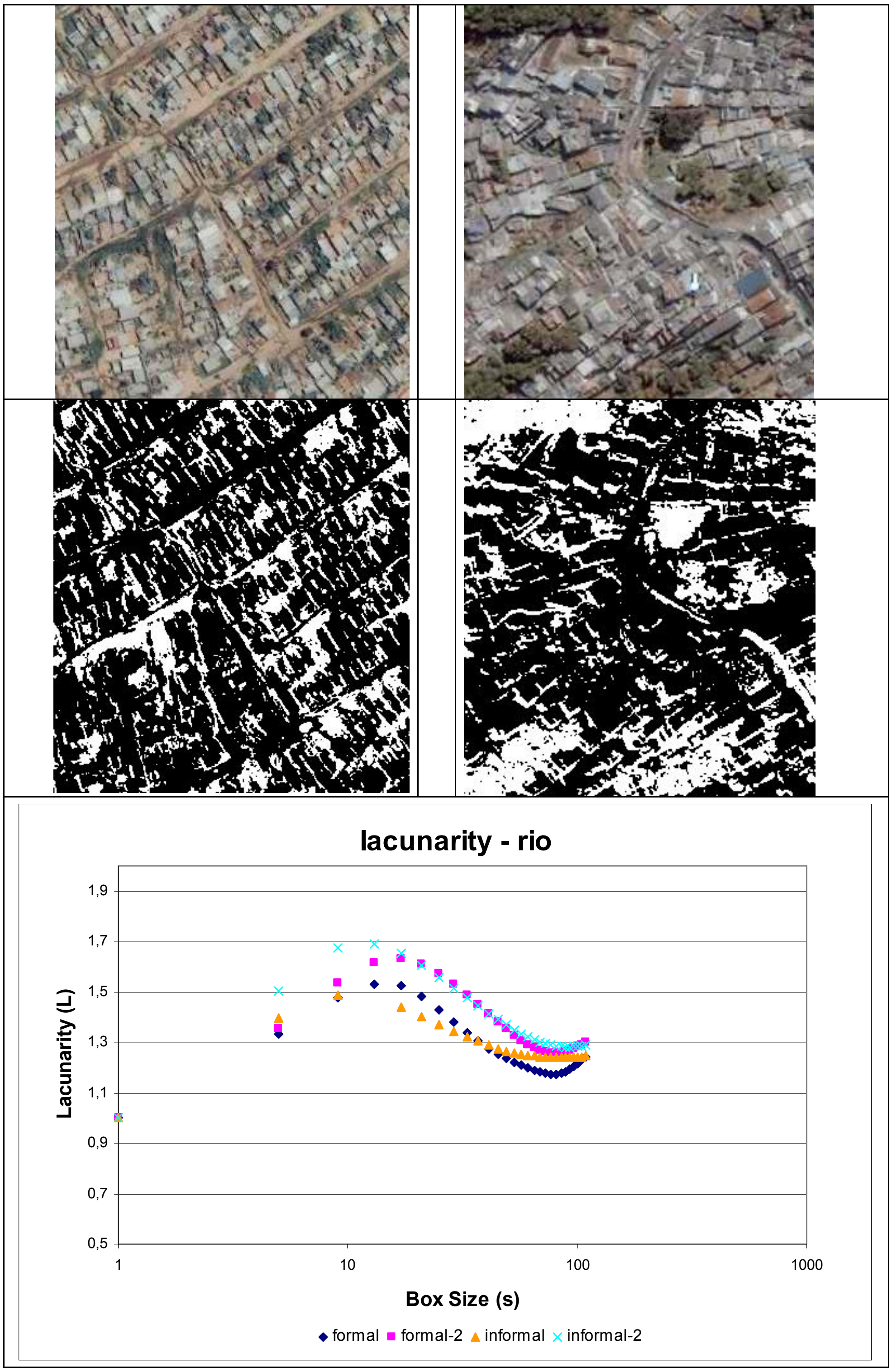

Figure 4 – Lacunarity Graph - Campinas (left) and Rio de Janeiro (right).