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ASSESSING TEXTURE PATTERN IN SLUMS ACROSS SCALES

An Unsupervised Approach

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1 ABSTRACT

According to the Global Report on Human Settlements (United Nations, 2003), almost 1 billion people (32% of the world's population) live in squatter settlements or slums. Recently, the perception of these 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 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 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 could not) represent distinct levels of urban poverty associated to spatial patterns. Such analysis are based on some complex theory concepts and tools, such 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.

2 INTRODUCTION

This paper presents some preliminary results from the 'Urban Dynamics' project, 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 four sections: Contexts, Concepts, Analysis and Challenges.

In Contexts, we present 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 objective of developing a morphological analysis that allows a preliminary comparison between geometric complexity and spatial data interpretation, obtained from satellite images: complexity, fractal dimension, lacunarity. Analysis is the focus of the third, 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. Finally, in the last section, Challenges, we comment on the intrinsic and external factors that may affect the binarisation process, as well as the supervised and unsupervised approaches.

3 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 upon urban spaces and their complexity. In this context, complexity is approached through analysis of images which can be then compared using statistical data and social-economical and cultural information. The city, so observed, is an assemblage 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, we need initially to simplify the complex relations that exist on urban environment, through the careful selection of relevant elements to the chosen approach, retaining only what is essential from 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 environments, the main issue is to observe patterns that would morphologically characterise the object or system. When forms are planned or they are expressions of a classic geometry, mathematically linear, so pattern analysis appears to be a straightforward and obvious analytical exercise. But, what should one do when form and space apparently offer no obvious signs of logic or linear order? How would one study spatial patterns that seem to be an expression of the complete absense of pattern (Figure 1)? At the same time, there is an intriguing issue: would the appearance of that apparent disorder, observed in urban structures, mainly in non-regular areas, conceal a deeper signal of a hidden order? (SOBREIRA, 2002).

All of these foci upon irregularity and diversity are in different ways related to the relatively new concept of ,Urban Planning' spoused by Latin American governments since the beginning of the 1980s. This is 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 settlement patterns are still being considered similar. As a result, only a small number of slums (or areas within them) are being upgraded by local authorities, while other areas, which 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 a way to improve the management and planning of such settlements.

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

4 CONCEPTS

4.1 Fractals: Geometry and Complexity

Questions about complexity and apparent disorder of form did not appear in urban planning debates and observations of cities. Spatial pattern analysis of objects and systems that seemed to be logical but that could not be explained using traditional tools and theories from usual mathematics and classic geometry started to get scientific attention 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 is, by its very nature, non-linear.

The logic behind Fractals is derived by observing an object through successive scales. A circle, a square or a triangle (classic examples of Euclidean Geometry) can be described according to a linear geometry, that is based upon integer dimensions as new details will not be noticed as one observe the object closer. But, if one observes a mapped coastline, 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 them, so more details will be found, similar through scales. A similar pattern can be observed in the city: at each scale of observation, a variety of details, forms, textures becomes apparent. Generally, all systems, objects or geometric patterns which reveal a richness of details through scales, have fractal properties and cannot be described using 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 cannot 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 conical, coastlines are not circles, trees are not smooth and lightnings are not straight lines", one could affirm that cities are not like the orthogonal, one-scale, chess tables.

4.2 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).

4.3 Lacunarity: analysing texture

Considering that cities are fractal systems, and admitting that urban textures present a wide variety of patterns, how would one distinguish one texture from another? Or, how identify differences within similarities? The concept of Lacunarity was established 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 observes intra-urban and consolidated squatter settlements, 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 slums, on the other hand, a more detailed view of slums urban textures will reveal the socio-economic and cultural diversity that is 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 the 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 distribution, lacunarity wil be low. Several fractals can be generated and present the same fractal dimension, but nevertheless be characterised by distinct textures, related to different lacunarity levels. Applications to lacunarity were firstly registered in research 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 a powerful analytical tool, especially 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 indicate 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 indicates 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.

5 ANALYSIS

5.1 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. The advance of research findings about complex systems is directly related to computational development in the 1960s.

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.

5.2 Experiments and Preliminary Results

Images analysed in this paper were initially selected according to 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 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 box counting 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 (slum) 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. According 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 slums, 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 slums in two distinct cities: Campinas and Rio de Janeiro. Contrary to what might be expected, 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 the following important considerations:

I. If Fractal Dimension reveals that distinct parts of the city are similarly complex, Lacunarity complements 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 established between slums, 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;

6 CHALLENGES

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 does the binary image classification process influence the results? When a complex multispectral image is converted into a simple binary one some decisions should be taken into account and another question arises: Should the binarisation process be supervised or non-supervised by the image analyst? Before answering those questions it is necessary to understand the internal and external factors that affect the binarisation results.

In analysis through binary images of urban textures, dissimilar land uses with different spectral signatures such as built and non-built areas, if covered by shadows, clouds or by vegetation could have similar slopes of their spectral reflectance characteristics and may appear similar (figure 5). Images affected by these *intrinsic factors* are called 'intensity blind' and this problem is particularly troublesome in areas where the land uses are continuous and of similar image texture (LILLESAND & KIEFFER, 2000). Shadows strongly disturb the binarisation process by modifying surface appearance and sometimes involve loss of information under the surface they covered. Some few techniques to detect and remove shadow based on spectral, textural, contextual information on high spatial resolution images are published (MASSALABI et al, 2003; ADLER-GOLDEN et al, 2004).

Moreover, built features on satellite images of some urban environments are composed of a variety of surface materials and, as a consequence, have a wider range of grey levels and are less distinguished from non-built features than images of urban areas which have more homogeneous building typologies. This is particularly evident in rapid urbanization areas of developing countries or in urban areas with different land uses. Different binarisation results may also be expected when we compared satellite images from areas with very distinct inhabitability conditions where buildings and roads are composed by different surface materials (non-paved and paved roads).

Besides these *intrinsic factors* related to the characteristic of the original images, there are *external factors* that only depend on some human decisions. Among these factors, the scale and the binarisation method adopted stongly affect the results. Even if we are analyzing images through multi-scale measures, the scale of the original image can change the associated patterns of reality, which has obvious implications for understanding any spatial structure or texture. Beyond the cartographic concept of scale as a relation between the real and represented dimension of an object, an important characteristic of scale lies in the distinction between *grain* and *extent*. *Grain* refers to the smallest intervals in an observation set, while *extent* refers to the range over which observations at a particular grain are made (O'NEILL & KING, 1998). In remote sensing, *grain* is equivalent to the spatial resolution of the pixels composing an image, while *extent* represents the total area that an image covers. Figure 6 shows examples of images with different scales, spatial resolutions, sizes and shapes.

A supervised approach is based on the assumption that the binary images resulted from the analysis should be able to resemble particular features or classes on the original image such as built and non-built areas.This approach requires a high level of human interaction in the binarisation process, and depends on the *intrinsic* and *external* factors described above. Besides that, this approach is also both time-consuming and is very subjective (DONNAY, BARNSLEY & LONGLEY, 2001), it requires great deal of training and practice on visual interpretation of satellite images, and it is not necessarily replicable from place to place and time to time (WEEKS, 2003). Moreover, intensive field survey may be necessary and could be problematic in some slums, especially those where accessibility is inhibited for security reasons (BAUDOT, 2001).

An unsupervised approach assuming that 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 is also dependent on *external factors* that affect the binarisation process (even if the level of human interaction here is much lower than the supervised approach), but it does not focus on the specific elements of the image and does not consider its *instrinsic factors*. 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 approach, trees or shadows are not considered as problems or barriers to image interpretation, but simply compositive elements of a general texture.

In this article, we have suggested an unsupervised approach. The main issue was to keep the same method to all samples to permit a comparative analysis, limiting the changing variables. Even if the binary images may not resemble built and non-built areas, and may yield different lacunarity curves, we can observe through analytical experiments using IMAGEJ that this approach does not change the fractal nature of the image because the richness of details through scales is mantained.

7 PERSPECTIVES

We suggest, considering these 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, especially 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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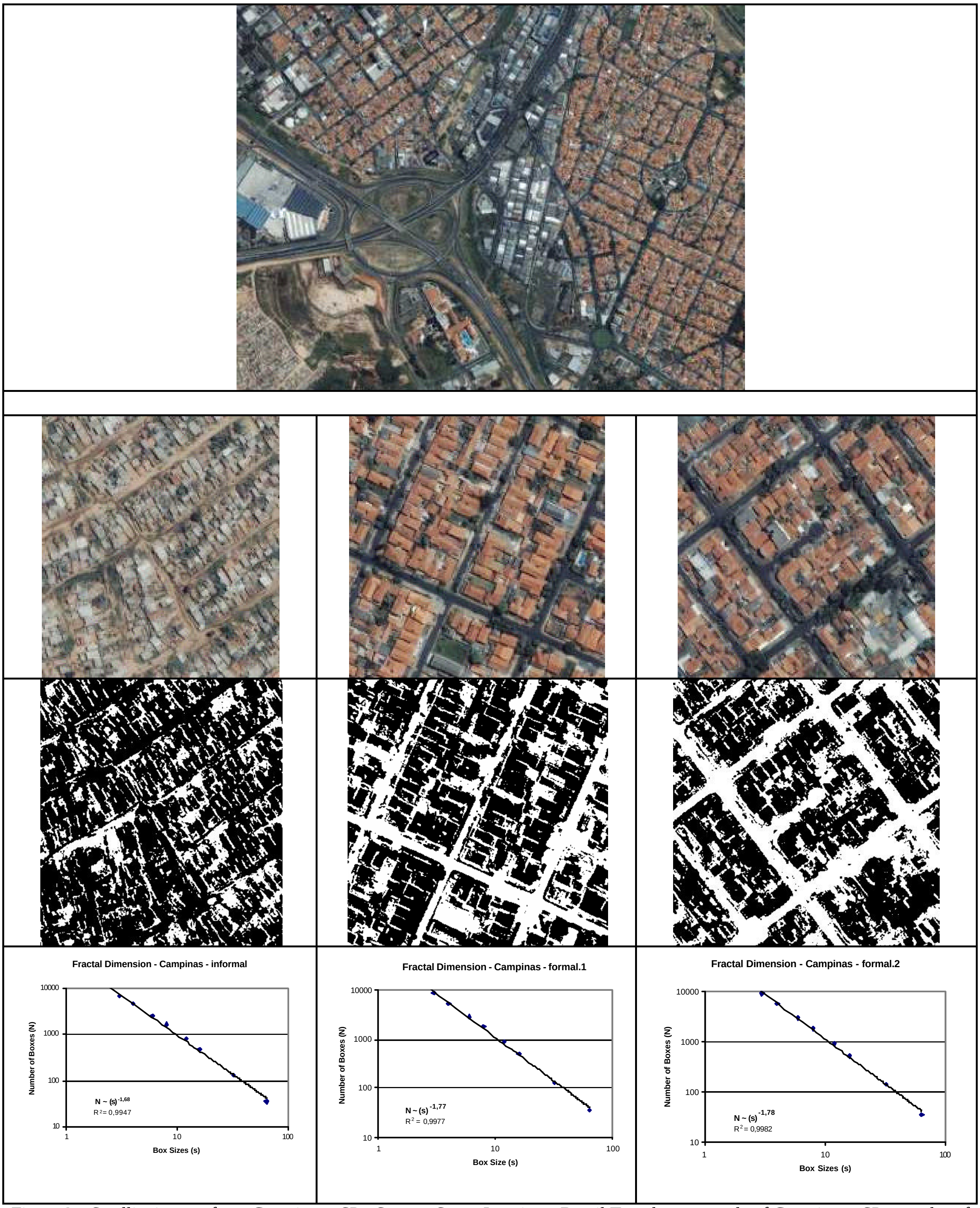


Figure 2 – Satellite images from Campinas - SP - Source: Space Imaging - Brazil.Top-down: sample of Campinas - SP; samples of regular and irregular areas; binary versions of images; Fractal Dimension (D) – log x log graph indicating relation between the number (N) and size (s). Fractal dimension is indicated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

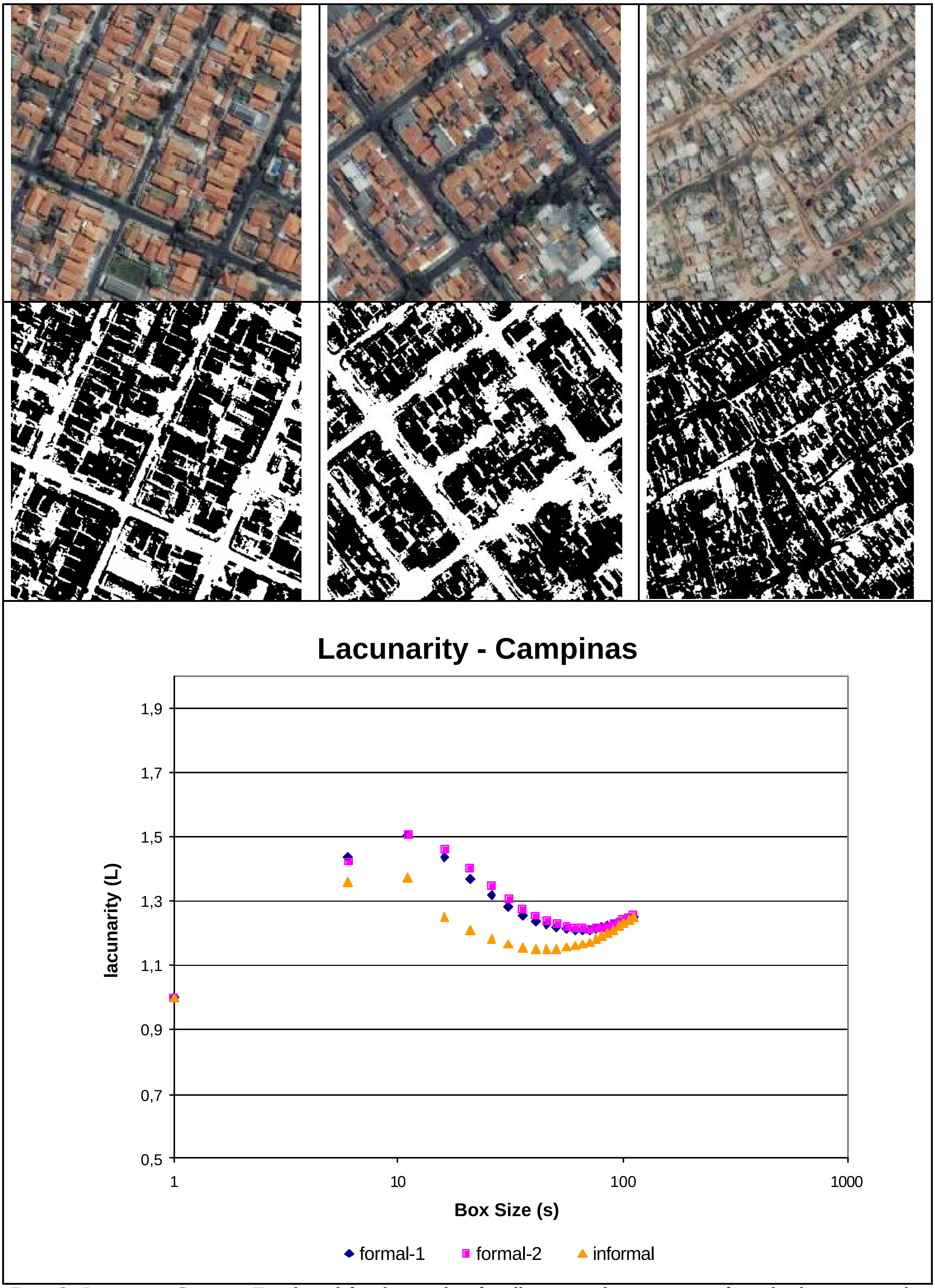


Figure 3 - Lacunarity - Campinas. Top-down, left-right: samples of satellite images, binary versions of samples, lacunarity graph, describing variation through scales.

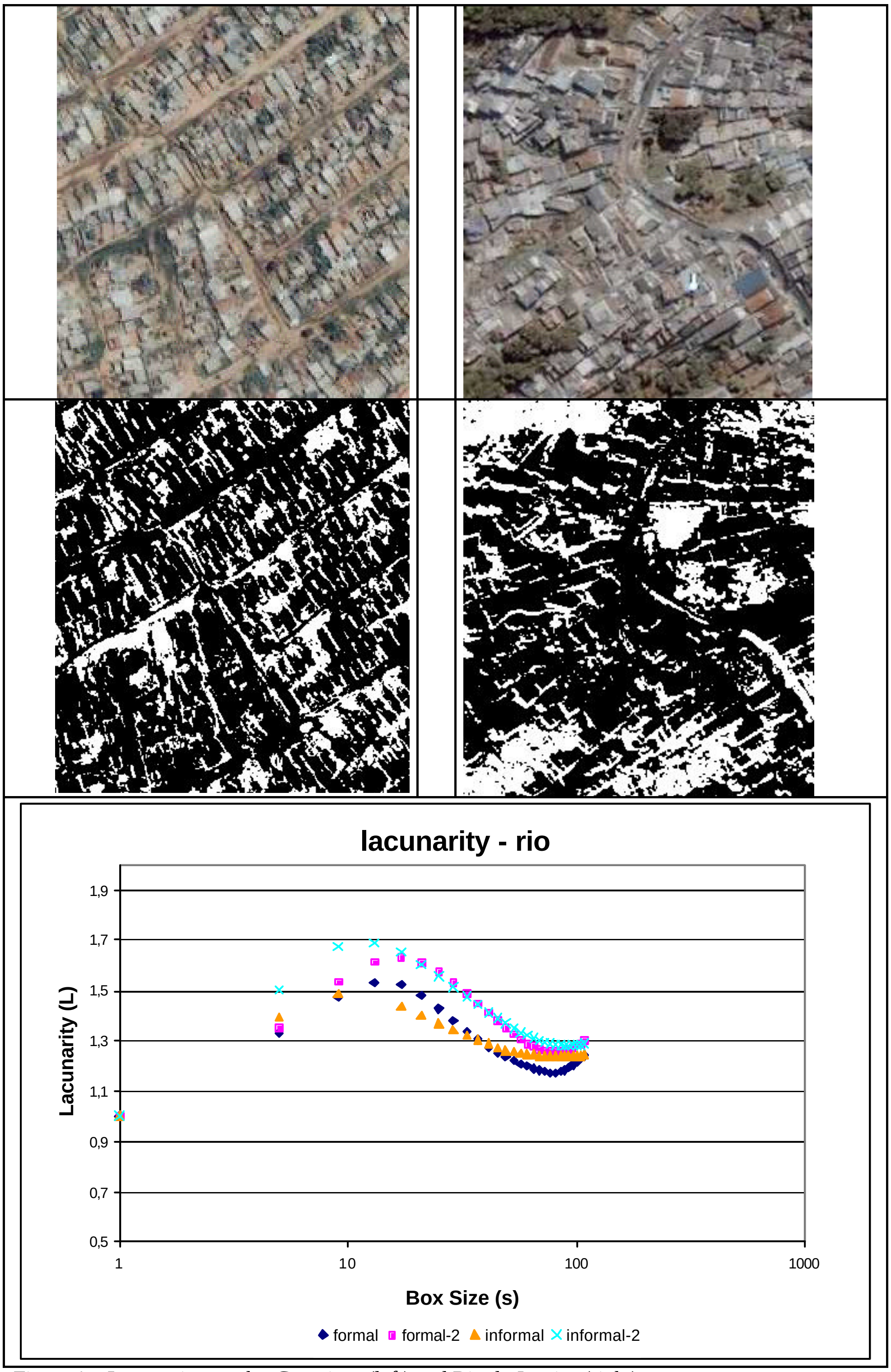
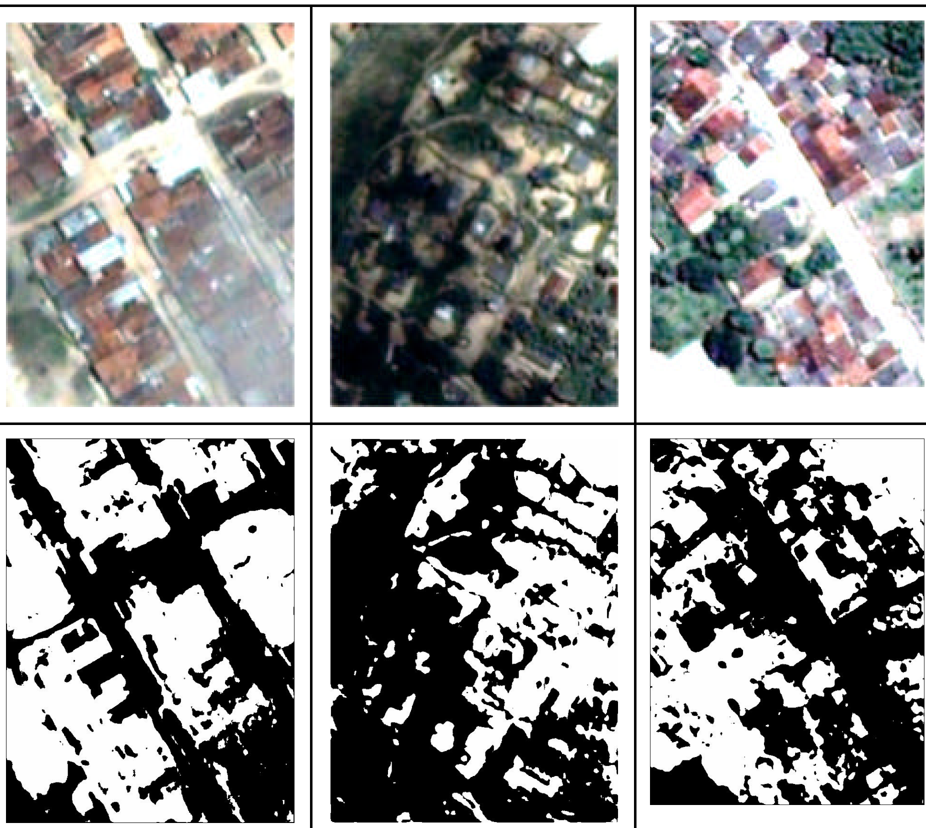


Figure 4 – Lacunarity graph - Campinas (left) and Rio de Janeiro (right).

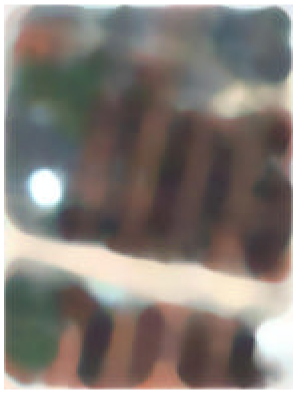


A	B	C

Figure 5: Intrinsic factors that affect binarisation process

Original and binary images from urban areas covered by clouds (A), by shadows and by vegetation (B). The binary image from the urban area A can better separated built from non-built areas than the binary imagem from urban area C.





A B C

D



E F G

Figure 6: External factors that affect binarisation process

The same urban area (A) may yield different binary results when changes occurs in its scale (B), in its spatial resolution (C) or in its sample size (D). Binary images from the same urban area resulted from different classification methods: automatic threshold (E), unsupervised (F) and supervised classification (G).