APPLYING GIS AND FRACTAL ANALYSIS TO THE STUDY OF THE URBAN MORPHOLGY IN ISTANBUL

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Introduction

When the built structure of an urban area is examined, one sees the streets, railroads, airports, ports, buildings, parks, and vacant areas. They all look like a jumble of different shapes and patterns. Naturally, cities did not appear at the very instance that we are observing them, but in many cases are a composite of several time periods and the result of multiple influences. The essence of urban morphology is a study of the built environment and the forces that brought them into existence. By examining streets, buildings etc., one can 'read' the city. The urban built form is inseparable from the cultural, economic, political and technological conditions of the given year or era when they were constructed. Although urban morphology has a long history, it has until recently been allocated the status of an academic discipline, having before this time had a mimimal impact on applied urban geography and urban planning.

With the interrelated development of spatial technologies such as GIS and Remote Sensing, increasing computing capacity, advanced mathematical theories such as chaos, fractal analysis, and analytical techniques such as cellular automata and agent-based modeling, the study of urban morphology has in recent years changed dramatically. While quantitative methodologies for the study of urban geography date back to the 1950s, they were based on linear mathematics and were unable to adequately explore the complexity of cities. 'New' quantitative tools promise a way to examine cities in a non-linear and multi-dimensional manner.

Basic concepts in urban morphology

Urban morphology follows the assumption that there are forces that have shaped the urban built environment. The built form can be streets, housing types, parks, etc. An important assumption of urban morphology is also that these forces have shaped development and are continuing to shape them. The forces of urban morphology include:

1) The level of technological development (agricultural, industrial, informational);
2) The particular level and type of construction (e.g., stone, mud, brick, marble, steel, concrete);
3) The form of political organization (e.g., city-state, kingdoms, empire, nation-state, colonial, post-colonial, communistic, democracy, etc);
4) The type of economy (feudal, mercantile. centrally planned, capitalistic, globalization);
5) The dominant type of transportation and/or movement (walking, horses, stream engine, automobile, airplanes);

and

6) The religious culture and particular customs of the society being studies.

These factors are generally not mutually exclusive and are interconnected with each other. Each of the different stages of urban development was shaped by these different forces. However, as we peer into the next century, there is a realization that the forces that were once seen as progress (such as the automobile) are now causing a plethora of problems, such as pollution, sprawl, loss of farmland, and many others. The ability to have sustainable communities is directly related to urban morphology.

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When one views the landscape of the average city, it is apparent that there have been a variety of influences. For example, if one travels from the center of any European city to its edges, one is first struck by the narrow width of the streets, vestiges of past housing types, the close proximity of structures, public squares and perhaps monumental buildings such as palaces. As one travels outward toward the suburbs, one observes the proliferation of multi-lane arterials, multi-storied office and apartment buildings, one story manufacturing facilities, sprawling subdivisions of suburban single family or townhouses and other manifestations of modern society such as airports, container port facilities (in cities with major harbors), and railroad yards, etc. Trying to unravel this developing landscape is not an easy task, as it is the result of multiple decision-makers in industry, commerce, governments and other forces. The combination of fractal analysis and urban morphology may lend a clue to the urban environment.

Urban morphology, fractal analysis and chaos theory

The study of urban morphology – or urban morphogenesis – has been a discipline in geography for at least one hundred years. The pioneer of systematic urban morphology was Patrick Geddes. Geddes emphasized the detailed study of cities to understand the mechanisms at work. (Recently, the Center for Advanced Spatial Analysis – CASA -- at University College of London devoted a seminar to the influence of Geddes, who had a brief stint at UCL [CASA, 2007]). The forces that shape the city were further developed and conceptualized at the University of Chicago with the works of Homer Hoyt's Sectoral Model (1970), and later, by Chauncy Harris and Edward Ullman's Multi-Nucleated Model (1945). James Vance developed the Urban Realms Model (1977), expanded on the Harris and Ullman model conjecturing that each nucleus in a poly-nucleated city had a sphere or realm of influence. McAdams (1995) proposed a revision of these models, taking into the account the multi-polarity of many urban areas and the organic nature of their growth and developed the Multi-Nucleated Amoeba Model (McAdams, 1995). Specific models have been developed among cities in particular regions. For example, Arreola and Curtis (1993) and McAdams (2004) developed conceptual urban models of border Mexican cities based on those developed by Ford (1920; 1996) for Latin America cities. These models are descriptive and do not take into the account the dynamic nature of cities. However, they do give insight into the forces that were changing cities at a particular time period.

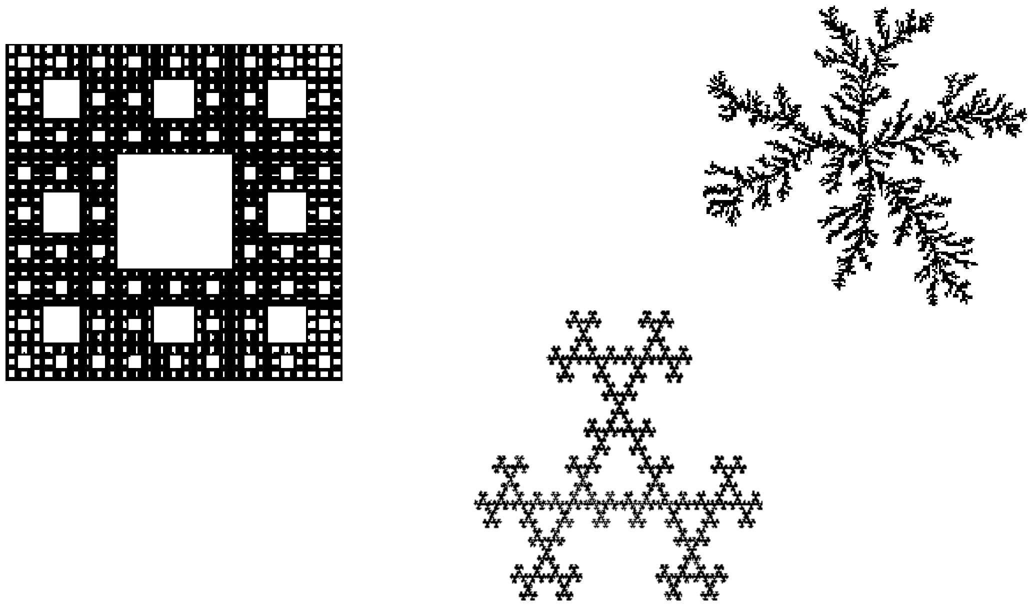
Some of the elements of fractal analysis were first introduced by D'Arcy Wentworth Thompson (1917, 1992) in his book *On Growth and Form*, indicating that although Mandebrot is credited with developing fractal mathematics, the roots obviously stretch back much further. Mandelbrot (1983) introduced the basic concepts of fractals and fractal analysis such as self-simularity, multiple iterations of simple formulas, and scaling and dimensions. Now, fractals and their analysis are robust areas of study in mathematics, but a still developing sub-field.

A simple definition of a fractal is that it is an object which is less than a plane and more than a line, possessing self-similar elements. It would follow that fractal analysis is the study of the characteristics of fractals. Theories of simplicity, complexity, chaos theory and analysis techniques such as agent-based modeling and cellular automata are intrinsically coupled with fractal analysis. The best example of a natural fractal is a tree. Everyone, even a small child, can recognize a tree. In this aspect, it is very simple. But, on more detailed inspection, it is apparent that a tree is not a simple organism -- being composed of leaves, roots, differentiated cells and having complex chemical and biological processes. The structure is also self replicating, which is one of the basic premises of fractal analysis. In other words, by examining the parts, we can explain the whole. Nature itself is one of the inspirations for fractal analysis, as is chaos theory.

Fractal analysis is a also a way of looking at an object in a non-Euclidian manner regardless of the scale or the individual characteristics of the object. The elements contained in fractals can be points, lines, polygons or pixels. However, one characteristic of fractals is that they are self-similar. For example, one line can divide into two and then those two lines can be divided into four and eight and so forth. Changes in a formula can create designs that 'almost take on a life of their own' and can be manipulated to mimic the growth of any entity. Fractal analysis is also linked to spatial metrics--the measurement of the fractals among themselves such as the distance between points or polygons.

Fractals can be analyzed in a number of manners. One of the most common is to examine the dimension, lucunarity, and scaling (Falconer, 2003). Dimension refers to the fractal variation. The dimension for a fractal is always between 1 and 2 with 1 being a line and 2 being a plane. Lacunarity refers to the texture of a fractal. A fractal with more gaps has a higher lacunarity. Fractal scaling refers to the iteration of certain patterns measured by changes in the dimensions. These have special meaning when examining the city with fractal analysis techniques. 'Real life' fractal dimensions have certain meanings when compared with abstract fractal objects (see Figure 1).

Figure 1: Abstract Fractals- Sierpenski Carpet, Dedrictic Pattern, and Sierpenski Triangle Variation



Abstract fractal objects which could be seen as the basis for examining cities as seen in the Sierpenski Carpet and Triangle and the dendrictic pattern (Tannier, 2005). The Sierpenski Carpet is similar to a regular gridded city. Its fractal dimension is 1.77 and lucunarity is 292.08 This indicates a pattern that is highly regular, but containing a large amount of gaps or 'bays'. A dendrictic pattern has a fractal dimension of 1.60 and a lacunarity of 29.91. A Sierpenski Triangle variation has a fractal dimension of 1.65 and lacunarity of 17.35. This also indicates a dendrictic type pattern and small bays. The closer to a the dimension to linear dimension indicates more hierarchy and the small lacunarity means smaller gaps or 'bays'. These dimension and lacunarity of abstract fractal can also be used as a comparison when examining a irregular fractal objects such as cities.

These two disciplines developed separately, but have recently been brought together by urban geographers working in the fields of advanced mathematics and spatial technologies. The seminal book by Michael Batty (1996)*Fractal Cities* introduced this author and many others to the fascinating world of fractals, complexity and urban morphology. These concepts have been further developed in his Batty's book *Complexity and Cities* (2005). There are now a host of urban geographers, mathematicians and others examining the city via fractal analysis and other related areas such as cellular automata and agent based modeling.

Urban morphology in Istanbul

Istanbul ranks as one of the world's mega-cities with a population of over 10 million. Its cultural and economic influence is increasing as it is again taking advantage of being at the crossroads of Europe and Asia (McAdams, 2006). The history of Istanbul has been one of accession, decline and rebirth. It has been the center of three major world cultures: Roman, Byzantine, and Ottoman. The city is at least 3,000 years old. The original settlement was across the Bosporus in Asia. It was later supplanted by a site that overlooked the Bosporus on the European side because of its strategic importance. This Greek settlement was named Byzantium. It became a Roman colony about 100 B.C.E. and then the capital (*Nova Roma*) of the Roman Empire under Constantine. Hence, later it came to be known as Constantinople and became the capital of the Byzantine Empire. In 1453, it was conquered by the Ottomans and became the capital of the Ottoman Empire. In 1923, the capital was transferred to Ankara and for several decades Istanbul languished. In the 1980s, with the liberalization of economic policies, commercial and industrial development increased. The economic opportunities increased in Istanbul and thus migration increased, particularly from the eastern part of Turkey. During the period from 1980 to 2007, the size of the city and its population increased at a dramatic rate. The forces of all these eras of development are found in Istanbul. The street patterns in the center are the result of the Byzantine and Ottoman Empires. However, the vast majority of the city's area is related to the Industrial and Post-Industrial era. (Freely, 1997)

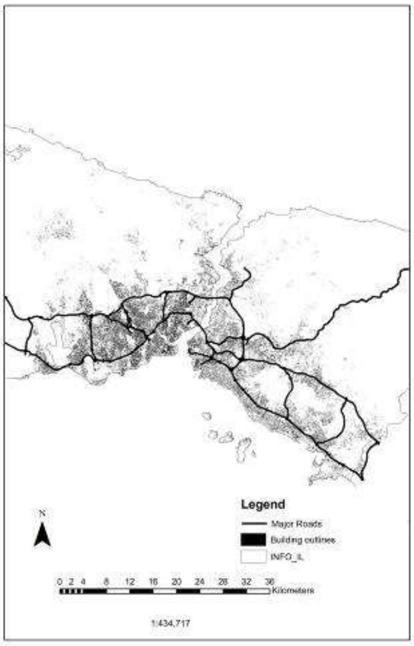
Urban morphology analysis of Istanbul using fractal analysis

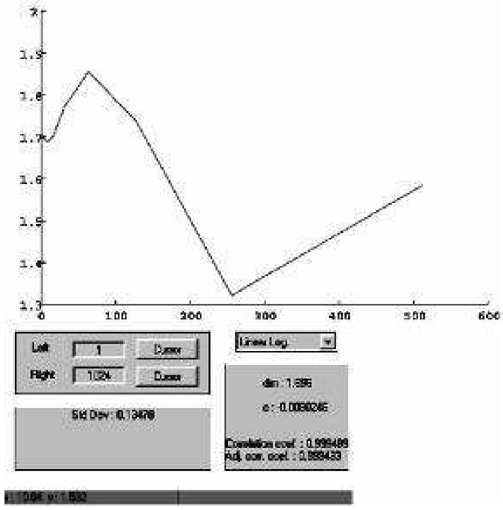
For the present study, fractal analysis was preformed using the street and building GIS database for Istanbul. The program that was utilized for determining the fractal dimension of Istanbul was Fratalyse (University of Franche-Comté, 2007) . The building outlines of the center of Istanbul, suburban areas on both the Asian and the European side and for the entire city were selected using ArcGIS and then exported into tiff format for use in Fratalyse. The method utilized was the box counting methods for pixels.

When one examines the overall fractal patterns of Istanbul (see Figure 2), one can visually detect some of the morphological patterns. The structure is dendrictic, following the major roads. The center is dense with very little vacant land. The the Bosphorus, the Marmara, and topography have shaped the growth of the city's development. The fractal dimension is 1.70 and the lucunarity is 121.34. This indicates that there is some degree of dedrictic paterrns but there are large bays or 'tearing'. In inspecting the scaling graph, it is evident that in the center that there is high irregularity (approximately 1.85) and then becomes regular with a dimension of approximately 1.3. There is an increase of irregularity as one nears the edges of the city. This is fairly evident in looking at the spatial patterns.

The central area of Istanbul (see Figure 3) exhibits a greater degree of regularity with a dimension of 1.75. This is near the dimension of the Sierpenski Carpet. The lacunarity of 208.59 is less that the Carpet, indicating smaller bays. However, if one inspects the scaling graph, if is apparent that there is greater irregularity near the center (approximately 1.9) but quickly becomes regular and uniform. The lacunarity of 208.59 indicates that the bays are large. This is due the large amount of open spaces in the center.

In the suburban areas (see Figures 4 and 5), there are some similarities to the central part of Istanbul, but also some differences. The dimension of the European side sample (see Figure 4) was 1.74. This is very near the Sierpenski Triangle which has a dimension of 1.75. This would indicate some degree of regular patterns. The lacunarity of 94.95 indicates smaller bays than those of the center. This is largely related to the center of the sample area which has dense building lots and not many open spaces. The Asian suburban sample (see Figure 5) has more irregularity with a dimension of 1.79. The lacunarity of 150.51 indicates that there are large bays as can be seen in the pattern. However, the bays are not as significant as in the central part of Istanbul. The scaling graph for the Asian side indicates that there is high irregularity in the center of the image, but it rapidly becomes regular.

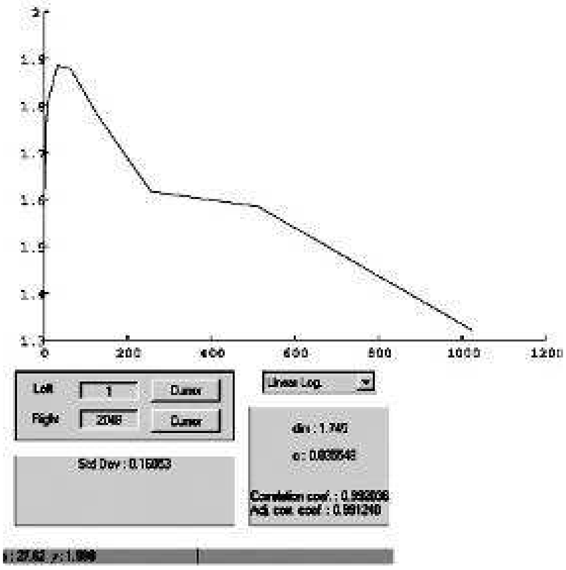




Dimension: 1.70
Lacunarity:121.34
Figure 2: Owerview of Istanbul

Figure 3: Central

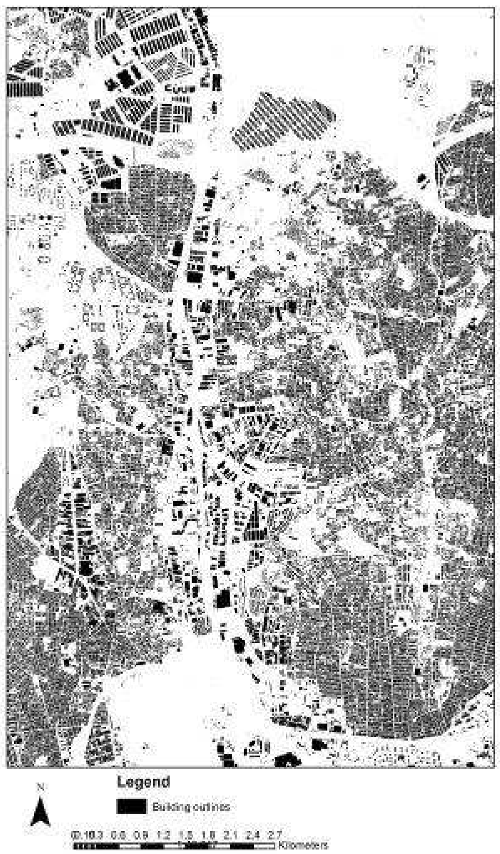
Istanbul

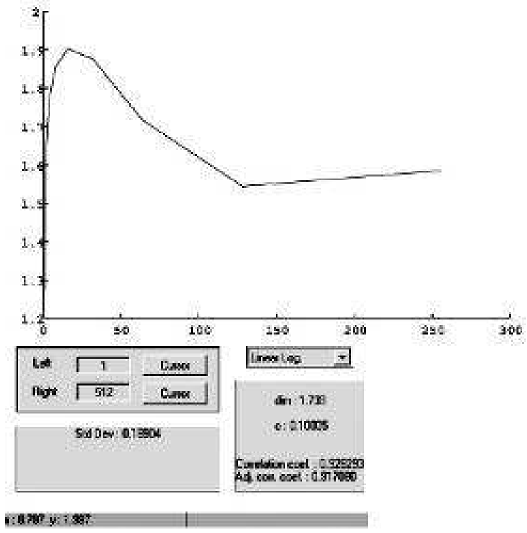


Dimension: 1.75

Lacunarity: 208.59

Figure 4: Suburban Istanbul (European side)

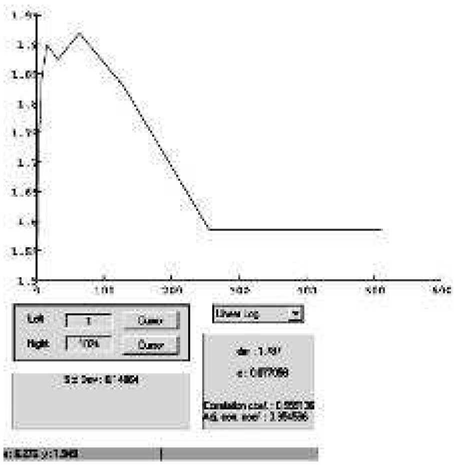




Dimension: 1.74

Lacunarity: 94.95

Figure 5: Suburban Istanbul (Asia)



Dimension:1.79

Lacunarity: 150.51

Discussion

The use of fractal analysis is a method for quantitatively describing the differences between cities and within cities. While one can describe a city qualitatively, the descriptions can not be compared, as they are idiographic. Cities are to some degree unique because of different histories and influences in their development. However, in other instances they show a great deal of regularity. The values of Istanbul are similar to other cities in Europe and the developing world. The range of dimensions are normally 1.7 to 1.8. Cities rarely have a value of 1.9. This would indicate a high degree of irregularity in the types of housing patterns. The scaling graphs give greater detail concerning the variety of patterns. Generally, in the center of cities in Europe there is high irregularity due to the different types of blocks and housing sizes. The slums of Narobi, Kenya are around 1.8 approximately according to the author's estimation using an aerial photograph. The scaling graph indicates that it at times approaches 1.9. There is, however, some variation due to the resolution of the photo etc. The lucunarity is still high at about 214. This may indicate larger gaps and variation. If one looks at a small French village, one can see some of the same patterns, but at a much smaller scale.

Conclusion

Fractal analysis is a diverse and promising method to examine the morphology of cities. While examining fractals in a theoretical manner is considerably advanced, its application for examining actual urbanization is complex and sometime results in conflicting measurements. The interpretation of fractal analysis is not an easy task, as there appears to be differences in measurements based on resolution and other factors.

The literature on fractal analysis and the ability to make accurate measurements lacks a clear method of analysis. There is also limited literature concerning measurements from different cities. What is evident is that there needs to be more research into this area, so as to standardize methods and interpretation. While there is ample evidence that fractal analysis and related analysis methods such as cellular automata are promising, they are remaining as theoretical tools. They have not entered the mainstream of urban analysis and planning. The developing area of urban syntax hints at additional new tools that can further examine the city with unique tools. At this time, research into fractal analysis, cellular automata and other analytical tools that seek to probe further into the composition of the urban environment are being conducted in a limited number of locations around the world. It is anticipated that this field will become even more diverse, yielding a whole set of tools that those who are working in the field of urban morphology and urban planning will utilize to better understand cities and discover new ways of managing them.

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