# FRACTAL ANALYSIS AND THE URBAN MORPHOLOGY OF A CITY IN A DEVELOPING COUNTRY: A CASE STUDY OF ISTANBUL

## *(Gelişmekte Olan Bir Ülkedeki Bir Şehrin Kent Morfolojisi ve Fractal Analizi: Örnek Alan Çalışması Olarak İstanbul)*

***Yrd. Doç. Dr. Michael A. MCADAMS*** *


### *ÖZET*

*Şehirler sosyal, ekonomik ve teknolojik faktörlerin ve fiziki çevre şartlarının sonucunda ortaya çıkan karmaşık oluşumlardır. Şehirlerin gelişimlerini etkileyen unsurları anlamak onların sadece tarihteki değil gelecekteki gelişmelerini de anlamaya yardımcı olabilir. Fraktal analiz, şehir morfolojisi ve yapısının incelenmesinde yeni bir teknik olarak ortaya çıkmıştır. Bu çalışmada Fraktal analiz orta düzeyde gelir seviyesine sahip gelişmekte olan bir ülkedeki bir şehre örnek olarak İstanbul üzerinde uygulanmıştır. Çalışmada fraktal analiz sonucunda ortaya çıktığı üzere, İstanbul'un şehir yapısı Avrupa ve ABD'nin New York ve London gibi büyük şehirlerindeki yapı ile benzer özellikler taşımaktadır. Bununla birlikte, İstanbul'da görülen gelişme yoğunluğu, gelişmekte olan ülkelerdeki diğer kentsel alanların bir göstergesi olabilecek şekilde, gelişmiş bölgelerdeki benzer şehirlerden daha fazladır. Fraktal dokusunun ölçümüne dayalı (laucunarity ölçümü) yapılan ayrıntılı analizlerin şehir yapısının incelenmesinde daha iyi sonuçlar verdiği görülmektedir. Sonuçta, politik, kültürel yada ekonomik farklılıklara rağmen teknolojinin küreselleşmesi nedeniyle şehir dokularında giderek artan bir şekilde benzerlikler ortaya çıktığı görülmüştür.*


***Anahtar Kelimeler:*** *Fraktal Analiz, Kent Morfolojisi, Alan Analizi Şehir Planlama, İstanbul*


### *ABSTRACT*

*Cities are complex entities which are the result of social, economic, and technological agents and the physical environment. Understanding the elements influencing the development of cities can assist in understanding not only their historical, but also their future development. The use of fractal analysis is proving to be an innovative technique to study urban morphology and urban*


* Fatih Üniversitesi, Fen-Edebiyat Fakültesi, Coğrafya Bölümü, 34500 Büyükçekmece - İstanbul. E-posta: mcadams@fatih.edu.tr

*form/structure. In this paper, the fractal analysis is applied to Istanbul, as an example of a city in middle income developing country. This study found that the fractal dimension measurements of Istanbul indicate that its overall or global urban structure is similar to major cities in Europe and the United States, such as New York and London. However, the intensity of the development (or fractal dimension) in Istanbul is higher than comparable cities in developed regions, which may be indicative of other urbanized areas in developing countries. The addition of the lacunarity measurement (the measurement of a fractal's texture) would seem to give greater clarity when examining urban fractals. Overall, it appears that due to the globalization of technology that urban structure is making urban structure increasingly similar regardless of the political, cultural or economic climate.*

***Keywords:*** *fractal analsyis, urban morphology, spatial analysis, urban planning, İstanbul*

## 1. INTRODUCTION

When one views a city from an aircraft or via a satellite image with its the streets, railroads, airports, ports, buildings, parks, and vacant areas, it appears to be a random jumple of different shapes and patterns which are impossible to decipher. How does one interpret the urban built-form? This question is the essence of the discipline of urban morphology. Simply stated, urban mophology examines the built-form of urban areas and the social, political, economic, cultural and technological forces that brought them into existence and continues to shape them.

Recently the tools of urban morphology has been augmented with the incorporation of non-conventional mathmathics/modeling techniques and theory which not only includes fractal analysis, but also chaos theory, cellular automata, agent based modeling, artificial intelligence, nueral networks and spatial metrics and facilitated with spatial technologies (i.e., Geographic Information Systems and Remote Sensing.) To a growing number in the scientific community, chaos theory, complexity theory and associated areas (i.e., artificial intelligence) represent a major paradigm shift in the methods one can understand numerous phenomena (Gleick 1987, Wolfram 2002, Merali and McKelvey 2006). In the field of urban morphology and geography, these developing areas are having a major impact on its direction.

Michael Batty in his seminal book, Fractal Cites (1996) revealed the promise of using fractal analysis in studying cities. Recently, he explored agent based modeling and cellular automata in eliminate Cities and Complexity (2005). The combination of these tools are 'unraveling the urban fabric' and giving urban geographers, urban planners and others interested in urban development greater insights. In particular, fractal analysis has revealed that urban areas have patterns which can be distinquished, measured and dissected quantitatively, revealing the simplicity and complexity of their geometric formation. Spatial metrics is also contributing to our knowledge of the geometry of urban areas and intergrating with cellular automata and fractal analysis (Batty 2004). Fractal patterns can be interpreted to describe the complex nature of urban structure, exceeding or complimenting previous spatial analyis techiniques such as density, cluster analysis, regression etc. The analysis of urban areas using fractal analysis literature is developing and software is proliferating such that there is a growing number of urban geographers which are utilizing it to study different aspects of urban development.

Studying the urban structure of cities has been one of the major themes in urban geography and urban morphology. The majority of studies in this area have concentrated on urban structure in North America and Europe. This is likewise the same in the literature concerning the use of fractal analysis for the study of urban areas. It has been shown that there are different 'fractal signatures' for cities in Europe and North America. However, the fractal analysis of cities in developing countries is limited. In this article, the author examines one city with fractal analysis-Istanbul. Istanbul represents an interesting study in fractal analysis for numerous reasons such as rapid urbanization, limited planning, and the physical aspects of the city. The primary questions when examining Istanbul with fractal analysis were: Are there distinquishable differences between Istanbul's fractal measurements and those from European and North American cities?; and Can there be an reasonable explanation for these differences?

## 2. URBAN MORPHOLOGY AND FRACTAL ANALYSIS

The study of urban morphology or urban morphogenesis has been a discipline in Geography for a least one hundred years. Urban morphology follows the assumption that there are forces such as technology, construction types, politics, economy, transportation and culture shaped the urban built environment (Vance 1977; Batty 1996). These forces are not mutually exclusive but are inherently interconnected with each other. These different forces have shaped each of the different stages of urban development. 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 other problems. The ability to have sustainable communities is directly related to their urban morphology. However, as illustrated by Whiteland and Morton (2004), urban morphology has often been largely overlooked or at least not correctly understood by those involved in urban planning.

Urban morphology has a rich and diverse history. In the U.K., urban morphological research in 20th Century was developed by such key figures in the discipline as: Patrick Geddes (1915, 1949), M.R.G. Conzen and Whitehand alongside with the French and Italian schools (Mugavin 1999). European studies have delved into housing types city plans, the interrelationship between urban morphology and urban planning and many more areas related to urban structure. In the United States, urban morphology owes a great deal to the urban ecological school of urban morphology centered in the University of Chicago which included such primary figures as Homer Hoyt (1970)-the Sectoral Model, and Chauncy Harris (1945)-the Multi-Nucleated Model. Building upon the urban ecological theories, James Vance (1977) with the Urban Realms Model expanded on the Harris and Ullman model conjecturing that each nucleus in a poly-nucleated city had a sphere (realm) of influence. Later, 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 descriptive models have been developed for cities in particular regions. For example, Arreola and Curtis (1993) and McAdams (2004) developed conceptual urban models of border Mexican cities based on those Ford (1920; 1996) developed for Latin America cities The developing sub-discipline of urban morphology is becoming more robust as it is linked with urban planning and applications.

How did fractal analysis become a part of urban morphology? Fractal analysis, grounded in mathematical theory, developed independently of urban morphology. Those involved in urban morphology and urban geography, being involved in disciplines which are inherently inter-disciplinary became to realise that the attribues of abstract fractals were similar to those of the form of urban areas. The seminal book by Michael Batty, Fractal Cities (1996) was the first comprehensive examination of the use of fractal analysis to examine urban structure. Batty (2005) further developed these ideas in his book Complexity and Cities (2005), incoporating complexity theory and related fields such as cellular automata and agent-based modeling. These areas have been facilitated (if not brought into existence) by Geographic Information Systems, Remote Sensing and the development of advanced spatial analysis tools. The areas of complexity and chaos theory along with related spatial analysis techniques such as agent-based modeling, simulation, and cellular automata have a rapidly developing literature in urban geography and spatial analysis, challanging the traditional areas of examining cities such as applications of regression analysis, econometric models etc., which are grounded in logic-positivism. Although some may disagree, this author perceives that this is beginning of a major paradigm shift that is not emerging in Urban Geography, but in other disciplines. To introduce the basis for fractal analysis, the next paragraphs will discuss its development and some of its major tenents. However, it should not be considered a comprehensive analysis of this subject, but an overview to give the unfamiliar reader an understanding of the analysis contained in this paper.

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

The basic elements related to fractal creation/generation and analyis are: 1) an object; 2) a generator (initiator) and 3) the emerged form. Fractal analysis is concerned with the study of the emerged form.

For example, the object may be a line. This line may be subject to different rules or a generator (i.e, divide the line by a third) and reiterated for an established amount of times. At the conclusion of those iterations, which theoretically could be infinite, an emergent form appears. The resulting form will not be the same as the original obeject as it is not a replication but, a mutation. However, the paradox is an abstract fractal actually has self-similarity and scalelessness so in essence it is a replication but, is mysteriously different. The best example in nature would be a tree whose structure was initiated by the bifurcation (dividing by 2) of a single twig and repeated numberous times. Cell development or mutation is similar. A another 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 celluar automata are intrisically coupled with fractal analysis. The 'butterfly effect', the most simple explanation of the chaos theory, states that a butterfly flaps his wings in South America and a hurricane developes in the Atlantic Ocean. This concept of one acton repeated and mutated is also one of the basic tenents of fractal generation. (Gleick, James Glieck 1987), himself a mathamatician, gives a more detailed explanation of the history of the development of chaos theory and also fractals in his entertaining book, Chaos: making a new science.)

Fractals can be analyzed in a number of manners. One of the most common is to examine its dimension, lucunarity, and scaling (Falconer, 2003). Dimension refers to the fractal variation or how much the fractal fills the space. The dimension for a fractal is always between 1 and 2 with 1 being a line and 2 being a plane. Dimension for a point would be 0 and for a cube, 3.

**The formula for calculating a fractal dimension is as follows:**

Dimension (Dim) = log (number of self-similar pieces)/log (magnification factor) (Devaney 1995)

Or $Dim = -(\log N_k/\log r_k) = \log N_k/\log (1/r_k)$ (Batty 1995)

Whereas the negative of the logarithm of the number (N) of self similar objects (vector or raster) is divided by the log of the scaling ratio ($r_k$). Therefore, for a square which is divided into 4 equal parts and a scaling dimenison of 2, the dimension would be 2.

Fractal dimenison can be better analyzed when combinded with lacunaity. Lacunarity refers to the texture of a fractal. A fractal with more gaps, bays or tears has a higher lacunarity. Tolle et al. (2003) state, 'Fractal dimension only measures how much space is filled. Lacunarity complements fractal dimension by measuring how the data fills the space.' Tolle et al. (2003) further state that multiple fractals may have the same dimension, but will have different lacunarity.

While there are muliple types of fractals that can be generated. Only a few can be used as models for the city (i.e., Seripenski, diffusion). This demonstrates that although the city is complex, there are limited forms that are being manifested in urban areas. 'Real' urban fractal dimensions can be compared against abstract fractal objects (see figure 1) as a standard to determine the simililarity or difference of different urban forms. Abstract fractal objects which could be seen as the basis for examining cities are: the Dendrictic Pattern (a), Sierpenski Carpet (b) and Sierpenski Triangle Variation (c) (Tannier, 2005). The Sierpenski Carpet is similar to a regular gridded city. Its fractal dimension is 1.77 and luncanrity is 292.08. This indicates a pattern that is highly regular, but containing a large amount gaps or 'bays'. The Dendrictic Pattern, similar to the growth of urban development along transportation lines, has a fractal demenison of 1.60 and a lucanarity of 29.91. The 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 dimenision to linear demenision indicates more hierarchy and the small lucanity means smaller gaps or 'bays'. These dimension and lacunarity of abstract fractal can useful as a means to compare the different fractal of cities.

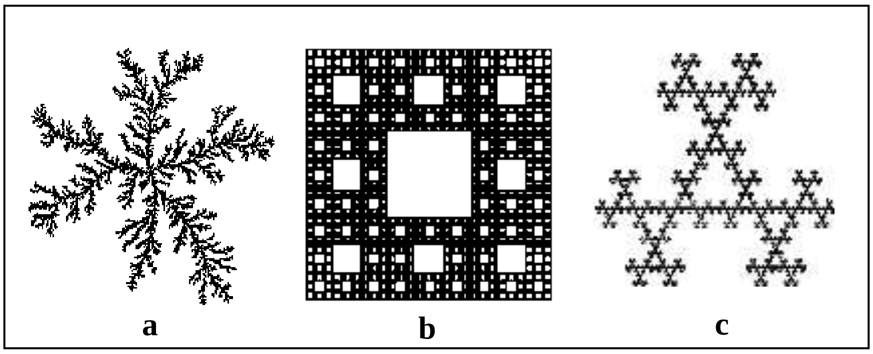



***Figure 1.*** *Abstract Fractals:* ***a-*** *Sierpenski Carpet,* ***b-*** *Dendritic Pattern, and* ***c-****Sierpenski Triangle Variation*
***Şekil 1.*** *Abstract Fractals:* ***a-*** *Sierpenski Örgü,* ***b-*** *Dendritic Mode ,ve* ***c-****Sierpenski Üçgen Değişim*

In the urban environment, as opposed to a theoretical one, 'real' urban fractals are also subject to the influence of physical topography which limits and shaps its direction and form. The fractal formation in an urbanized area is not equal in the way it developes over time. The economic and technological agents effect the manner in which the fractal grows or diffuses. In addition, there are entropy factors based on economic functioning of the city. In a polycentric city, the distance from the core is related to the ability of commercial and industrial concentrations to form on the perifery of the urban agglomeration (McAdams 1995). Some of these issues are being taken up in the application of agent based and cellular automata modeling of cities.

## 3. RESEARCH PROBLEM AND METHOD

### 3.1 Comparative Fractal Analysis of Cities

There are two objectives when analyzing the fractal dimension and lacunarity of urbanized areas. One is to examine the characteristics of a particular city and the other is to compare it with that of other cities. There have been several studies which examined the fractal aspects of urbanized areas. Batty (1995) conjectured that all cities have fractal dimensions between 1 and 2. In this spectrum, there are high amounts of variability depending on the time period of the analysis. Batty (1995) stated that most of the values were greater that 1.4 and most between 1.6

and 1.8 with a mean of 1.7. However, this was for a global analysis of entire urban area. Frankhauser (2004) took a different approach and compared cities with idealized geometric structures. He stated that, 'the value of the fractal dimension of the occupied sites is directly linked to the parameters of the generator, in particular to the number of N of elements and the reduction factor.' (Frankharuser 2004).

In examining French and other European cities, Frankhauser (2004) found that city centers were between 1.8 to 1.95, regular estates without public space were between 1.8 and 1.99, new towns between 1.6 and 1.77 and irregular or less controlled growth between 1.64 and 1.85. It should be noted that these measurements are not mutually exclusive, having a significant amount of overlap in some cases. In a study of Milan (Caglioni and Giovanni 2003), a global analysis indicated a low fractal dimension of 1.075. Near the periphera of the urban area, the fractal value was 1.601, but near the center it was close to 1.804. This is consistent will other values found by Frankhauser (2004). In a study by Lagarias (2007) of Thessaloniki, Greece the dimension of a selected suburban area was 1.741 In North America, the fractal dimensions of city were investigated by Shen (2002). He stated, concerning past studies using fractal analysis of cities, that 'While these studies have provided some interesting theoretical formulations and empirical results revealing the fractal nature of urban form and growth, they are not systematic in the sense that cities were not selected according to a spatial scheme (e.g., city or population size hierarchy) and a common set of parameters (i.e. map coverage, resolution, scale). Thus, the results are incomplete and less useful for purpose of inter-city comparison from the urban system perspective.' Shen (2002) selected 40 cities ranked by 1992 population and examined the relationship between population and fractal dimension. In this study, it is concluded that overall population size when regressed against dimension does reveal a good fit if population is regressed against the fractal dimension. If one inspects the highest populated city, New York City and the lowest city, Omaha, Nebraska, in the study it was found that their fractal dimensions are 1.701 and 1.277 respectively. Shen (2002) did not inspect the fractal dimensions of sub-areas such as central city versus suburban areas in these urbanized areas, nor did he analyze the lacunarity of these cities. Shen (2002) emphasizes that fractal dimensions do not appear to be related to density and that other factors are influencing the fractal nature of a city.

Despite some irregularity in fractal dimensions, there appears to be some quidelines as to the fractal dimensions of cities. In the center, if a city is occupied with buildings and little open space, the fractal dimenison would be approximately 1.8 or above. This would appear to be particulary true of large metropolitan areas There could be some indication from some of the author’s preliminary studies using remote sensing images that this could be lower for smaller cities, perhaps in the range of 1.75. As the city diffuses outward, there is a tendency for less concentration and more dendricity due to uneven development and also more space devoted toward highways, which occupy a large amount of space in modern cities. The tendency is for the dimension of approximately to be near to 1.8 in the center to rapidly change to one of about 1.75. This seems to indicate that cities are being fragmented by the forces of modern urbanization processes.

### 3.2. Study Area

Istanbul is a fascinating city that is at least 2,000 years old. The original settlement was across the Bosporus in Asia near present Üskardar. It was later supplanted by a site that overlooked the Bosporus on the European side because of its strategic importance overlooking the entry to the Bosporus-the only passage between the Mediterranean and the Black Sea. 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 by Constantine; hence, later it came to be known as Constantinople and became the capital of the Byzantine Empire. The original plan of Constantinople was based on that of Roman cities with forums, villas and palaces As Rome’s influence declined, Constantinople took over the role of the dominating city in Europe and the center of Christianity. As such, it contained numerous churches and monasteries in addition to other pubic buildings. The most spectacular structure and still standing was Aya Sofia (Hagia Sofia) which became the mother church of Orthodox Christianity before Istanbul was conquered by the Ottomans. Gradually due to a numerous factors, such as the split between Roman and Orthodox Christianity (which also determined political alliances), development of rivals such as the Venetians, inept leadership and particularly the expansion of the Ottoman Empire, Constantinople was reduced to a declining city-state in the last century of its existence. In 1453, it was conquered by the Ottomans and became their capital. The city structure was transformed by the presence of the Ottoman who superimposed Islamic city structure over the existing Byzantine one characterized by mosque complexes (which included schools, hospitals, kitchens for the poor, shops etc.), kervansarays (hotels for traveling merchants), bazaars and private short streets. Being the capital of the Ottoman Empire, numerous palaces and public buildings were also constructed with the most magnificent being Topkapi Saray (the Ottoman Palace), which was located on the same site as the first Byzantine palace. In the 19th Century, similar to another capital, St. Petersburg, Istanbul became the Ottoman's 'window to the West' with subsequent changes in the city structure. In 1923 with the establishment of the Republic of Türkiye, the capital was transferred to Ankara and for several decades, Istanbul languished (Freely 1997; McAdams 2006; Kinross 1979: Norwich 1998).

Today, Istanbul is a dynamic and rapidly growing 'Super Metropolitan' area or Mega City with a population of over 10 million according to the 2000 census (see figure 2). The unofficial boundary of the urbanized area stretches nearly 100 kilometers from the European to the Asian side. In the early part of the 20th Century, after the founding of the Republic of Türkiye, the population was estimated to be approximately 1 million (Karakuyu 2001, Freely 1998). At this time, the city had little industrialization, as industrialization came fairly late to the Ottoman Empire and Türkiye was largely still an agricultural country at the turn of the last century. During the 1930s, several foreign urban planners, Elgötz (Germany), Agache (France) and Lambert (France) contributed to the urban planning in Istanbul (Karakuyu 2001). These plans resulted in industrial relocation and the widening of streets in the center, similar to Haussmann superimposing the boulevards over the medieval street patterns in Paris (Bacon 1967). This resulted in additional suburban development on the outskirts of the city. In the latter part of the 1800s, two commuter rail lines were constructed, with one on the European and the other on the Asian side. These did tend to push the population outward from the center, but they would appear to have a much lesser impact on development when compared to the impact of commuter rail systems in Europe and North America that were more extensive and directly linked with development. The role of water on the development of Istanbul is a significant factor. Seaside villages were present even in the Byzantine period. During the late Ottoman period, steamship companies provided transportation to the villages along the Bosporus and the Marmara. This access increased the development of these cities (Karakuyu 2001). In the last part of the 20$^{th}$ century, several factors caused the Istanbul area to grow to its present population and size: the rural migration to Istanbul; the building of two bridges across the Bosporus, the construction two major highways (E-5 and Trans European Motorway (TEM) and increased automobile ownership (Yenen, 2001). These resulted in a phenomenal outward growth built around the two major urban arterials (E-5 and TEM) as the population grew to its present level of more that 10 million. In the period after the 1980s, Türkiye's economy grew with the liberalization of the economy. Istanbul received a great share of the growth and such new industrial areas were constructed throughout the city. Construction of housing also reflected new trends. Up until the 1960s, most houses were at a maximum five stories and mainly in the center. With the increasing demand for residential building and limited space, high-rise apartments proliferated, as the city grew outward. The appearance of illegal self-constructed housing or *gecekondus* proliferated as the result of poor population from rural areas migrating to Istanbul. While most tourists see only the historic area of Istanbul with its own distinct character, the vast majority of the metropolitan area of Istanbul is a mass of nondescript buildings, representing a mix of unregulated and often incompatable land uses set between the ribbons of major highways. However, this is not only characteristic of the urban structure of Istanbul, but worldwide. Simply substitute the name of almost any major city and the desciption would fit.

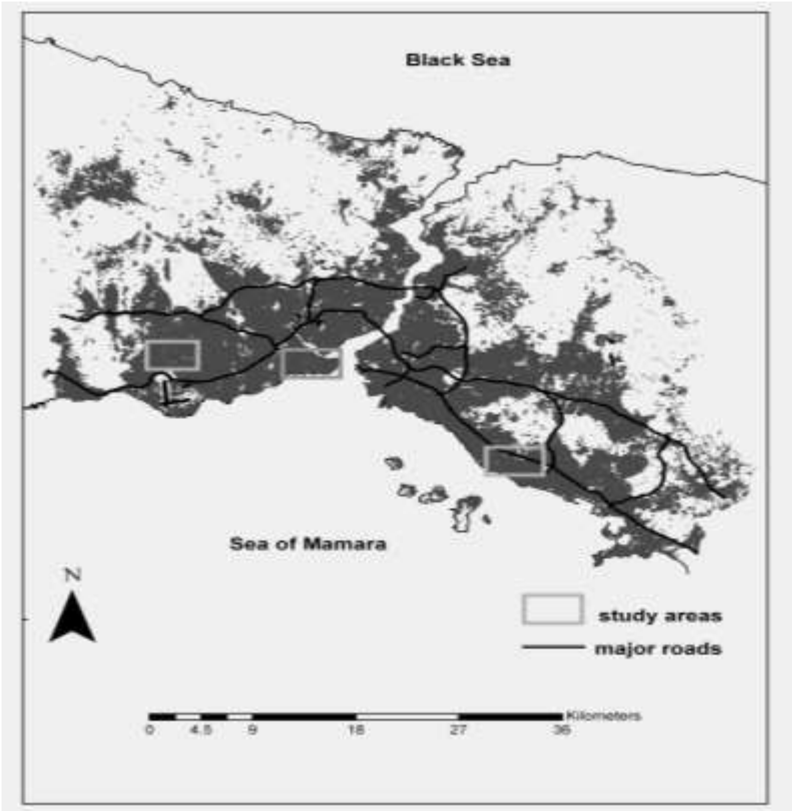


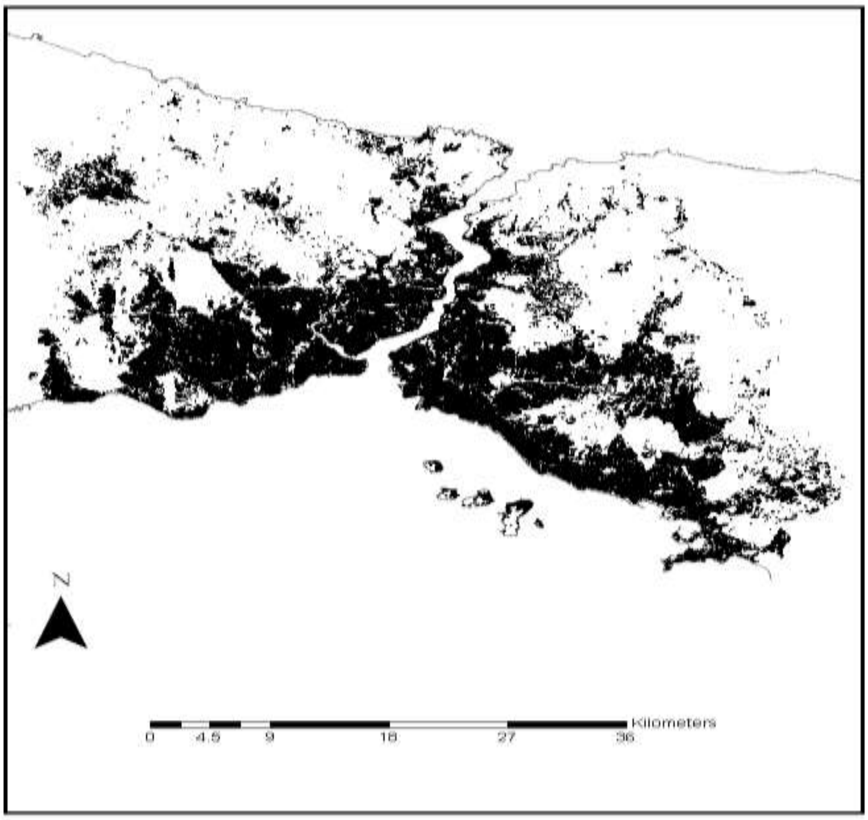

***Figure 2.*** *General Map of Istanbul and Study Areas*
***Şekil 2.*** *İstanbul'un ve Araştırma Sahasının Genel Lokasyonu Haritası*

### 3.3. Methods

The study used a 2006 GIS database provided by the Istanbul Metropolitan Government for the analysis. It included most of the urbanized area of Istanbul. The GIS database contained building footprints for all buildings in Istanbul. Streets and other transportation features such as airport were considered as 'open space' or areas not occupied by buildings. This was done so that one could assess the impact of infrastructure on the urban fabric. Four areas were selected for analysis: the overall area, the historic core, a European suburban area and an Asian suburban area (see figure 2). ArcGIS was used to extract the building data and to dialate (expand) these objects to obtain an improved resolution. Once the areas were selected, the image of the area was saved in TIFF format so that it could be analyzed in Fractalyze—a fractal analysis program geared for the study of urban areas (University of Franche-Comté, 2007). The images were analyzed to determine their fractal dimension, lacunrity and scaling.

### 4. RESULTS

When one examines the overall fractal patters of Istanbul (see figure 3), one can visually detect some of the morphological patterns. The structure is dendrictic, following the major roads, but also along the Bosporus.



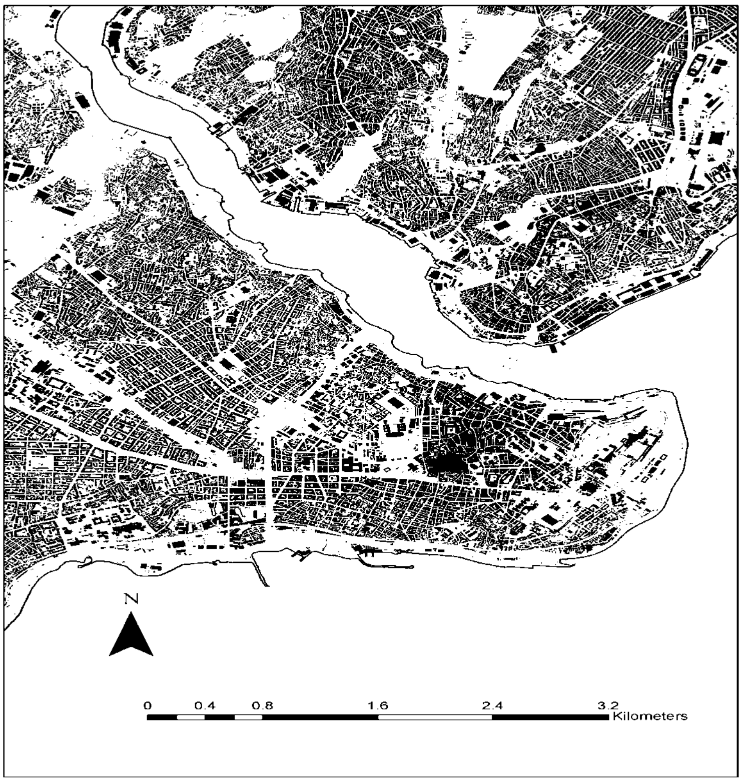

**Dimension:1.723 Lacunarity:187.705**

***Figure 3.*** *Istanbul Metropolitan Area (buildings only)*

***Şekil 3.*** *İstanbul Metropolitan Sahası (sadece binalar )*

The growth along the Bosporus is a vestiage of pre-automobile era when access to these locations were mainly by water. These settlements grew when shoreline roads were constructed. Ferry transporation to and from various locations, still represent a major form of transportation and access to the settlements along the Bosporus and Marmara. The center is dense with very little vacant land except for the historic penisula which contains some open space related to Topaki, Aya Sofia, the Sultan Ahmet mosque, the hippodrone and other historic buildings. The presence of the Bosporus, the Marmara and the topography have set the parameters for Istanbul's development. The fractal dimension 1.723 and the Lecunarity is 187.705. This indicates that there is some degree of dedrictic patterrns but, there are large bays or 'tearing'. In one inspects the dimensional scaling, the center has high coverage area with a fractal dimension of approximately 1.85, but the dimensions rapidly decline to approximately 1.3, indicating a dentritic pattern. This could be thought of as a 'palm and fingers' of a human hand. The gaps depending upon the locations could be indicative of: land will soon beome urban; the results of the fragmentation related to the Bosporus and/or Marmara; unbuildable land related to topography; or the presence of major infrastructure such as highways or airports. The areas above Istanbul are protected forests, but illegal housing or *gecekondus* and other developments one encroaching upon this area. If this area remains to be protected and continues to confine urban development depends on the ability of the regional government to maintain their protected status in opposition to a growing demand for housing and industrial areas.

As a comparison with the global examinaton of the Istanbul area, the central area of Istanbul, also know as the Golden Horn or the historic center of Istanbul was examined (see figure 4). This area was the center of the Byzantine and Ottoman Empires and thus contains a great concentration of the historical monuments of Istanbul such as Aya Sofia, Topkapi Sarai (the former palace of the Otoman Sultans) and Sultan Ahmet Mosque (Blue Mosque). This area is contained by the Theodosian walls which were built during the Byzantine period. However, the area still represents a major area of residental development and other instituions such as Istanbul University and the Çapa medical complex. The dimension of 1.828 reflects that the coverage area is occupied by buildings. This is similar for other central areas in Europe and reflects the morphology of pre-industrial cites.The lacunarity of 218.07 indicates that the area has significant gaps or bays. The scaling indicates several areas where there is large amount of coverage of buildings, but also a significant amount of dentricity due to the number of short and narrow streets related to pre-industrial cities and open areas related to historic monuments and major streets. In this area, one progresses from the center from large public such as mosques, parks to short narrow streets with narrow lots and buildings.




**Dimension: 1.828  Lacunarity: 218.07**
***Figure 4.*** *Golden Horn (Historic Penisula)*
***Şekil 4.*** *Haliç-Altın Bonuz (Tarihi Yarımada)*

An area in the western suburbs (European) and easter suburbs (Asian) of Istanbul. These were selected to determine if fractal analysis would reveal different themes based on their development elements. The western suburb sample (see figure 5) is an area which is located near several major transportation features, the Yenibosna metro station (the terminal for the Istanbul Metro with a large intra-urban bus terminal), the E-5 (one of the major arterials in Istanbul) and the the Atatürk International Airport. The intensity of development is reflected in the dimension level of 1.813 which is somewhat lower than that of the center, but still not dentrictic. The presence of the airport and significant areas devoted to street and airport infrastructure results in the higher level of lacunarity of 445.62. This indicates that the major infrastructure (Ataürk International airport, E-5 and feeding arterials) have 'carved up' the urban fabric of this area. The eastern suburban (Asia) sample (see figure 6) has a dimension of 1.787, indicating intenstity of development, but having more dentritic elements. The lucanrity of 264.184 is due to major roadways in the study area. However, it is not a large as the European example because it does not have significantly large infrastructure that are dividing and separating the area.

**Dimension: 1.813 Lacunarity: 445.62**
***Figure 5.*** *Suburban Istanbul-Europe*
***Şekil 5.*** *Avrupa Yakası Uzak Semtleri*

**Dimension: 1.787   Lacunarity: 264.185**
***Figure 6.*** *Suburban Istanbul – Asia*
***Şekil 6.*** *Anadolu Yakası Uzak Semtleri*

These results show some similar fractal dimension when compared to European cities. What is distintive is the high levels of the dimension in the central area and the eastern European sample, respectively 1.828 and 1.813. Althougth these areas developed at completly different time periods, the intensity of development reflects some of the same trends, small lots, short streets and high coverage. What is different is the large bays which are reflected in the marketly different measurements in lacuanrity which demonstrates the difference between pre-modern and automobile-oriented development. The Asian side reflects a more planned environment and one that is still developing.

## 5. DISCUSSION

The urban morphological studies by others (i.e., Whitehand and Conzen) have provided and continue to provide invaluable insight to the structure of past and present urbanization processes. Fractal analysis expands the developing field of urban morphology by being able to to compare the structure of cities with a new set of methods and hopefully giving greater insight to urbanization. However, it must be regarded as being intimately part of a other 'new' methods of analysis such as cellular automata, agent based modeling, spatial metrics, artificial intelligence, nueral networks non-linear simulation and fractal generation. All these methods represent a desire to examine phenomen from the 'bottom up' and not through complicated and linear based models that despite their perceived accuracy result in systematically flawed results. The theoretical basis for these methods is chaos theory which is rapidly supplanting logical-positivism and its methods of analysis such as statistics and associated modeling techniques. The ability to analyze the processes of urbanizaiton has been greatly inhanced by increasing abililty to collect and process geographic information that is now found in the spatial technologies such as GIS and Remote Sensing. These new techniques such as fractal analysis are being rapidly intergrated with the standard spatial analysis tools associated with these technologies.

Fractal analysis accentuates that cites are unique because of the different histories and influences but they that they are similar in many aspects regards of size. The fractal dimension values of Istanbul are similar to other cities in Europe and the developing world. The range of dimensions are normally in the range of 1.7 to 1.8. Cities rarely have the value of 1.9. This would respresent an urban area which is almost completely covered with buildings. This would be highly improbable in post-industrial and even pre-industrial urban structure. In the overall fractal stucture of Istanbul, this gradualy rapidly changes to values around 1.7 and lower due to the modern means of construction and accompanying infrastrure (i.e., gridding of streets and hierarchy. What is peculiar to Istanbul and probably other urbanization in developing countries is that intense development does not fall as rapidly but continous almost to emerging edge of the urban area. In my cursory examination of urban structure in Mexico, particularly in Monterrey, this also appears to the case. However, measuring the lacunarity of the urban structure in Istanbul demonstrates that regardless of the intensity of development large areas are being devoted to highway infrastructure similar to other cities in the developed world. Given common global technologies, urban forms are becoming more similar, if not identical regardless of regional location.

## 6. 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 methods when examining actual urbanization is complex and sometime results in conflicting measurements. There is a developing literature concerning measurements from different cities. The study of Istanbul futher demonstrates that fractal analyis can prove to be a worthly technique to study urban structure but also brings up a multitude of questions that can not be adequately addressed within the scope of this article.

What is evident is that there needs to be more research into this area as to standardizing the 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 and 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 enivironment 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 utitize to better understand cities and discover new ways of managing them. These tools and chaos theory are likely to have major changes in urban planning theory and methods of analysis in the future.

## BIBLOGRAPHY

Arreola, D., Curtıs, J., (1993). The Mexican border cities: landscape anatomy and place personality. Tucson: University of Arizona Press.

Bacon, E., (1967). Design of cities. New York: The Viking Press.

Batty, M., Longney, P. , (1996). Fractal cities: a geometry of form and function. Academic Press, London and San Diego.

Batty, M., (2004). A new theory of space syntax, CASA Working Paper 75, Center for Advanced Spatial Analysis (CASA).

Batty, M., (2005). Cities and complexity: understanding cities with cellular automata, agent-based models, and fractals. MIT Press.

Caglıonı, M., Gıovannı R., (2007). Contribution to fractal Analysis of cities : a study of metropolitan area of Milan, Cybergeo, article 269, put online 20 April 2004 and modified 04 July 2007. (Can be accessed online at: http://www.cybergeo.eu/ index3634.html. Last accessed on 10 september 2007.

Center for Advanced Spatial Anaysis (CASA), University College of London, (2007). Patrick Geddes and the digital age.

Devaney, R., (1995). Chaos in the classroom: fractal dimensions, Last retrieved 1 September 2007 from http://math.bu.edu/ DYSYS/chaos-game/node6.html# SECTION 0006000000 0000 000000.

Falconer, K., (2003). Fractal geometry: mathematical foundations and applications, 2nd edition, John Wiley and Sons Ltd.

Ford, L., Grıffın, E., (1980). "A model of Latin American city structure", Geographical Review, Vol. 70. No. 4: 397-422.

Ford, L., (1996). "A new and improved model of Latin American city structure," Geographical Review, Vol. 86. No. 3: 437-440.

Freely, J., (1998) Istanbul: the imperial city, Penguin Books.

Frankhauser, P. , (2004) Comparing the morphology of urban patterns in Europe a fractal approach, in : European Cities Insights on outskirts, Report COST Action 10 Urban Civil Engineering, Vol. 2, Structures, edited by A. Borsdorf and P. Zembri, Brussels, 79-105. (can be accesed online at at: http://urd.let.rug.nl/ekoster/isuf2/online_unlimited/um199902_95-99.pdf , last accessed 10 September 2007.Last accessed 10 September 2007.

Geddes, P, (1949). Reprint of 1915 version. Cities in evolution, Williams and Norgate, London.

Gleıck, J., (1987). Chaos: making a new science, London, Penguin Books.

Harrıs, C., Ullman, E., (1945). "The nature of cities," The Annals of the American Academy of Political and Social Science, 252: 7-17, 1945.

Hoyt, H., (1970). [c1933]. One hundred years of land values in Chicago. Arno Press, New York.

Karakuyu, M., (2001). The physical growth of Istanbul: a case study, unpublished Master of Arts in Geography thesis, Fatih University, Istanbul, Türkiye.

Kınross, L., (1979). The Ottoman centuries, New York, William Murrow and Company.

Langarıas, A., (2007). Fractal analysis of the urbanizaiton at the outskirts of the city, measurement and explantion, Cybergeo, article 391, put online on 16 July 2007, retrieved on 3 September 2007 at http://www.cybergeo.eu/index8902.html

Mandelbrot, B. B., (1983). The fractal geometry of nature. 3rd Edition, W.H. Freeman, San Francisco

Merali, Y., Mckelvey, B., (2006). Using complexity science to effect a paradigm shift in information systems for the 21st century, *Journal of Information Technology*, 22(3) 211–215. (can be accessed online at: http://www.palgrave-journals.com/jit/journal/v22/n3/ index.html, last accessed 26 Eylül 2013.

Mugavın, D., (1999). A philosophical base for urban morphology, Urban Morphology, 3(2), 95-99. (can be accesed online at:

http://urd.let.rug.nl/ekoster/isuf2/online_unlimited/um199902_95-99.pdf ,last accessed 10 September 2007.

Mcadams, M., (1995). The land use impact of an airport and urban structure : a case study in Milwaukee, Wisconsin. University of Wisconsin-Milwaukee, Unpublished Dissertation.

Mcadams, M., (2006). Global cities as centers of cultural influence: a focus on Istanbul, Turkey, Global Cities 2006 Conference, 29-30 June 2006, Liverpool, United Kıngdom.

Mcadams, M., (2004). “The urban structure of *El Centro* in border cities: a case study of Reynosa, Tamaulipas, México.”, Revista Internacional de Derecho y Ciensas Sociales, Vol. 2, No. 2, May. 2004, pp. 127-160.

Norwıch, J., (1998). Byzantium: the early centuries, New York, Alfred A. Knopf.

Tannıer, C., Pumaın, D., (2005). “Fractals in urban geography: a theoretical outline and an empirical example’, *Cybergeo*, No. 307, 20 April 2005 http://193.55.107.45/articles/307res.htm.

Thompson, D.W., 1992 [c1917], On growth and form, Cambridge University Press, Cambridge.

Tolle, C., Mcjunkın, T., Rohrbaugh, D. , LA Vıolette, R., (2004). Lacunarity definition for ramified data sets based on optimal cover, Physica D 179 129–152, Alternatively retrieved 2 September 2007 at: http://www.inl.gov/physics/ d/lacunarity_ physicad2003.pdf.

University of Franche-Comté, France, (2007). ThéMA research group, documentation for Fractalyse, http://www.fractalyse.org/

Vance, J., (1977). The scene of man: the role and structure of the city in the geography of western civilization., New York: Harpers College Press.

Whiteland, J.W.R, Morton, N.J., (2004). Urban morphology and planning: the case of fringe belts, Cities, 21(4), 275-289.

Wolfram, S., (2002). A new kind of science, Champaign, Illinois, Wolfram Media.

Yenen, Z., (2001). A world city on water: urban development of Istanbul and transformation of townscape, *NED Journal of Architecture and Planning: Townscapes,* Volume 1. Retrieved 8 September 2007 from http://www.neduet.edu.pk /Arch_2Jne/Arch11/JRAP-2001/JRAP%201/Istanbul-ZY.pdf