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Examining Spatial Efficiency of Cities Using Fractal Dimension

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Urban growth,
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Space-filling efficiency

Abstract: The dynamic structure of the urban changes and the specification of the parameters affecting this process facilitate the perception, designing and description of the space. The aim of this study is to discuss the urban growth phenomenon based on sustainability principle and the urban macroforms, shaped as the spatial reflection of this phenomenon. The study aims at developing a method suggestion for urban space analysis under the frame of the determined acceptances and limitations to be able to attain these purposes. In this sense, 29 randomly chosen cities are defined as samples fractal sizes are measured. The comparable parameters groups, which are considered to affect the space-filling efficiency of the urban macroforms is formed and whether there is a reasonable relation between fractal dimension value, which is admitted to be the criterion of space-filling efficiency through multiple direct regression analysis. The study is considered to contribute, accompanied by urban macroform parameters which are shaped as urban growth phenomenon and spatial reflection of that phenomenon, over the organization of the space and leading the development. Furthermore, fractal parameter considered that a new method approach based on the space-filling efficiency presented will have a leading role in the future for urban planning.

Kent Makroformlarının Mekânı Kullanma Verimliliklerinin Fractal Boyut ile İncelenmesi

Anahtar Kelimeler
Fraktal boyut,
Kentsel büyüme,
Kentsel morfoloji,
Mekansal verimlilik

Özet: Kentsel mekân, kullanıcı ve fiziksel çevrenin birbirini etkilemesi ile vücut bulur. Kentsel mekândaki bu değişimler, farklı yerleşmelerin kendilerine özgü dokular geliştirmesine neden olmaktadır. Bu çalışmanın amacı, sürdürülebilirlik ilkesi temelinde kentsel büyüme olgusu ve bu olgunun mekânsal yansıması olarak biçimlenen kentsel makroformlarının göstergeler eşliğinde fraktal boyut ve regresyon analizleri yoluyla tartışılması ve mekânsal verimlilik açısından yorumlanmasıdır. Çalışma, bağlamda ulaşabilmek için belirlenen kabuller ve kısıtlılıklar çerçevesinde mekânsal verimlilik analizine yönelik yöntem önerisi geliştirilmesi hedeflemektedir. Bu kapsamda, Dünyada en yoğun nüfuslu ilk 500 kent arasından rastgele seçilmiş farklı dinamiklere sahip 29 kent örneklem olarak belirlenmiş, seçilen kentlerin uydu fotoğrafları üzerinden kentleşme lekeleri üzerinden belirlenmiş fraktal boyutları ölçülmüştür. Örneklem kentler için kentsel makroformların mekânsal verimliliğine etki edebileceği öngörülen karşılaştırılabilir sosyo-ekonomik göstergeler seti oluşturulmuş ve mekânsal verimliliğin ölçütü kabul edilen fraktal boyut değeri ile bu göstergeler arasında anlamlı ilişki olup olmadığı çoklu doğrusal regresyon analizi ile ölçümlenmiştir. Çalışmanın, kentsel makroformların göstergeler eşliğinde kentsel mekânın organizasyonu ve gelişimini yönlendirmesi üzerinde karar vericiler ve mekânsal plancılar için katkıları bulunacağı düşünülmektedir. Aynı zamanda, fraktal parametrelerin gelişmekte olan ülkelerin kentsel teorileri ve planlamaları açısından yardımcı olacağı, ortaya konulacak mekânsal verimlilik temelli yeni bir yöntem yaklaşımının gelecekte kentsel sistemlerin yönetimi ve kent planlama açısından da yol gösterici olacağı düşünülmektedir.

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1. Introduction

The urban population, which is rapidly increasing in parallel with the changing and transforming socio-spatial and economic priorities of the phenomenon of urbanization, and the spatial distribution problem of this population, can be regarded as one of the most controversial issues in the world today. From this point of view, it is possible to say that the spatial development demands and trends based on radical increases in the urban population ratio cause adverse effects on the environmental footprint. With the Industrial Revolution of the nineteenth century, urban growth became the main topic and gained even more momentum following the World War 2, especially in the context of urban renewal, restructuring and efforts to establish new cities. Thus, in the twentieth century, the main topic of the urban planning agenda was the emphasis on limiting the phenomenon of urban growth. Within this emphasis, the principle of sustainability come into prominence for the protection of natural and cultural heritage.

In the twenty-first century, which is described as "Millennium" of the cities, it is observed that the urban growth phenomenon continues to grow with urban deprivation, poverty and violence. In this process, it is possible to observe that with the rapid population increase parallel to the rapid urbanization movements, the cities have gained a spatial identity that grows uncontrolled in widespread areas while consuming natural resources. As a matter of fact, when the urban growth rates are examined, it can be seen that the world urban growth rate is 2.50% [1]. This ratio is more than three times higher than the average of the developed countries at 0.70% and the urban growth rate in the underdeveloped countries is higher than the world urban growth rate at 3.30% [1].
According to UNFPA 2000 data; It is recorded that in 1999, 47% of the world population (about 2.8 billion people) lived in urban areas and the population living in cities increased by about 60 million people every year. According to the results of the United Nations Population Fund 2014, if this trend continues, it is expected that the population living in cities will reach 3 billion by 2030 [1].

Academic research findings that are based on population growth, urbanization and level of development indicate that 2 people live in urban areas in developing countries, for every single person lives in the city in developed countries. If this trend continues, it is expected that by 2034 the proportion of the urban population in the developed countries to the urban population in the developing countries will be 1 in 4 [2].

It is clear that as the disparities in income distribution balance continue in the developed-welfare / underdeveloped-poverty dilemmas that exist in the world countries, immigration from rural areas to urban areas and urban population will continue to increase. It will be possible to observe the obvious effects of this urbanization tendency in the coming years especially in the big cities of developing countries such as China and India.

In the light of the findings and evaluations above, if the urbanization and population growth trends continue at the same pace, it is clear that there will be problems such as destruction of natural habitats (agricultural areas and forests) and deterioration of environmental balance, pollution in the urban areas and that will cause serious problems on housing and work areas, transportation and traffic, healthcare and education. From this perspective, it can be said that the current agenda and interest of urban researchers focuses on "what the socio-economic and environmental consequences of the changing rural-urban distribution of the world population might be" and "how to control rapidly growing cities”.

The aim of this study is to analyze the urban growth phenomenon based on the sustainability principle and the urban macroforms shaped as spatial reflection of this phenomenon by means of fractal dimension and regression analysis and evaluating in terms of spatial efficiency. More precisely, explaining the factors affecting the spatially compact (concentrated, collective) development of the urban macroform with geographic information systems which is accompanied by fractal dimension and regression analysis using a set of indicators. In the study, it is considered that the information obtained through the examination of the physical texture will contribute to the organization and development of the urban area.
Within this scope, twenty-nine (29) cities with different dynamics which are randomly selected from the first five hundred (500) cities with the most densely populated areas in the world were identified as samples. For the sample, a set comparable indices that could influence the spatial efficiency of urban macroforms was measured and regression analysis was used to determine whether there is a significant relationship between the fractal dimension value considered as the measure of spatial efficiency and these indicators (parameters).

In this context, 6 (six) key indicators (parameters): (1) Elevation / altitude of the cities from the sea, (2) Per capita national income of the countries, (3) Origin / age of cities, (4) The total area of the countries, (5) Number of vehicles per 1000 people, (6) Unit prices in m^2 of land in the cities, were selected out of the sixty-seven (67) variables tested with the purpose of explaining the fractal dimension of urban macroforms across the sample.

In the context of geographical information systems, spatial data (macroform size / settlement pattern) of selected cities was created with ArcGIS 10.0 program. These datas has been measured in the context of the fractal dimension using the open source FRACTALYSE program developed by research center ThéMA "Mobility, Urban and Transportation" and written by Gilles Vuidel.

In addition to being a simple, useful and powerful tool to measure, the fractal dimension method is a preferred method because it enables comparison of fractal based parameters calculated with different fractal methods, interpretation of spatial difference changes with the indicators in addition to comparison of urban form at different times. Regression analysis has been used as a supporting statistical method to examine the relationship between the fractal dimension and the indicators that are expected to affect urban growth. It is a statistical analysis technique used for estimating the relevance and direction of the relationship between two and / or more indicators with cause and effect relation between them, and for estimates about the related subject.

2. Theoretical Framework

In this study, it is aimed to develop a method proposal for the analysis of the urban space, which will contribute to the understanding of the dynamic structure of the city. The intended method is based on the assumption that the city has a fractal structure. It focuses on the physical structure of the city and takes it as a dynamic and complex system.

The concept of urban macroform is residential patterns that are shaped based on spatial and functional relations that are redefined from urban growth. This pattern is shaped and directed by urban development-growth dynamics and urban production, consumption, and waste associations. It can be said that the urban macroform mainly shows 2 (two) different tendencies. The first one is a compact (concentrated, collective) development model, defined as high density, single-centered development [3]. The second is the process of spreading, which transforms the natural resource areas of the urban settlement pattern into structured areas. This process can be interpreted by the concept of urban sprawl.

Many factors affecting the urban macroform have been revealed by studies. Transportation [4,5,6], urban density [4,5,7,8,9,10], accessibility [11], energy consumption [4,5], socio-economic factors; Household income [13], gasoline consumption [4], labor force [13,14,6] are variables that are related to the urban macroform by various researchers.
The concept of "urban macroform" in the context of this research expresses urban spots which show a compact / sprawled settlement pattern in the context of spatial productivity and the efficiency of using the space is questioned.

Spatial efficiency is often defined as use of space [15,16]. The concept of spatial efficiency, which is often used as an architectural term, includes the distribution of the composition created by the constituent elements of the building at the architectural scale and keeping each other in balance despite the usefulness of the space. There are two imprtant points in terms of urban planning. The first is the land use efficiency and the second is the floor space efficiency, which is the ratio of the gross floor space usage to the total space utilization.

It is also possible to measure the use of the ground area and land use distribution to measure spatial efficiency, as well as the economic-based spatial value [16].

Measuring the concept of "spatial productivity", which is considered in the scope of this research, is based on the urbanization pattern, i.e., the use of the ground area. It is possible to say that the measurement of the use of the ground area can be made by many different methods such as change of land use, logistic regression, fractal dimension, etc. In this study, spatial efficiency is measured by fractal dimension.

Fractals are irregular shapes that can have different forms depending on the scale. The inability of Euclidean measurements to capture the nature of irregular shapes reveals the concept of fractal dimension. Fractal dimension (Hausdroff-Besicovitch dimension) is a statistical magnitude that measures how well a space of a fractal which is defined by Hausdorff and Besicovitch is filled [17]. Fractal dimension is used as a powerful tool for geographical modeling and spatial analysis in urban studies for a long time [18,19,20,21,22,23]. Fractal dimension is seen as a very effective, easy and economical measurement technique in terms of more refined and accurate measurement of space structure compared to Euclidean geometry. Fractal geometry measures the degree of independent complexity from formal differences and can evaluate the interactions between space elements and the process of formation. Fractals aren't at the core of the structure of the urban form, but are seen as a consequence of urban evolution [24]. Fractal geometry is preferred by researchers because it can explain all of the layers, systems, and forms that make up the city. In the study's research resources and method section, more detailed explanations of the measurement of fractal geometry and fractal dimension have been made.

According to the urban fractal dimension theory, the city has a sprawl as the fractal dimension approaches 1, and a compact structure as it approaches 2. In this study, the concept of fractal dimension was used to measure the compact (concentrated) or sprawled (scattered) state of the urban space as an indicator of efficiency.

One of the factors limiting work is the limitation in the availability of comparable data in the context of indicators for the cities identified in the sample. In order to overcome this limitation, the data were used based on the country's local data of the selected cities.
Second restrictive factor is the inability to find data that belongs to the same periods for all of the indicators. In this context, the current data for the period 2010-2014 is based on in order that the parameters used within the scope of the study are meaningful and periodically comparable. Only the 2009 data for gross national product purchasing parameters, which is the most up-to-date data, is based on this study.

Thirdly, urban growth methods based on remote sensing method and land use have been used to generate city stains produced by digitizing 2012 images from GoogleEarth satellite images because of being easily accessible, up-to-date and reliable source due to limitations such as time, financing and absence of single sourced images of the same period.

3. Material and Method

In this section of the study, the methods used for fractal dimension analysis of the twenty-nine cities selected from the results obtained from literature searches will be explained. In the study, a box counting algorithm was used for fractal dimension analysis and a multiple linear regression method was used to establish linkage with urban growth.

Linear regression in terms of variables is used in the study. Regression is the task of establishing a correlation (relationship) between a variable and one or more variables [25]. Regression analysis is the estimation of the behavior of a variable using a model and the mathematical determination of the relationship between two or more events assumed to be related. It refers to the development of a mathematical approach to describe the behavior of a variable of interest (Şehirlioğlu, 2008). In any system where variable quantities are present, there may be hard to understand functional relationships between variables. The effects of these variables on others are approximated by mathematical functions.

When multiple independent variable models are used, the multiple regression formula is written as:

$$Y=\alpha+\beta 1X_1 + \beta 2X_2+ \beta 3X_3 \dots\dots\dots \beta kX_k+ \varepsilon \qquad (1)$$

In this formula,
Y: Dependent variable,
X_i: Independent variable,
b_0: The value that the dependent variable can take when X = 0 ,
b_i: Regression coefficient for variable i,
e : Term of error (mean = 0 and variance = s2),

"ε" is the total effect on random variables over Y that can not be determined in the regression plane. It is the difference between the actual value for the dependent variable in each observation pair and the value predicted by the model. The assumptions about the error term (ε) are that the expected value of ε is 0, the successive values of ε are independent of each other, the variance of ε (σe^2) is constant, and the distribution of ε is a normal distribution.

b_i; It is called the coefficient of the variable i and shows how a unit change in Xi will change the value of Y. Regression analyses were performed to determine the positive / negative effects of the independent variables on urban growth and their relevance.

18 dependent variables including different fractal dimension analyzes , and a total of 70 independent variables either directly or by meaningful multiplication, division or aggregation of variables with each other, and real, logarithmic and square forms of these variables were tested. Regression analyzes were performed to determine the positive / negative effects of the independent variables on urban growth and their relevance.

In this study; Considering the population factor, which is the most important cause of urban sprawl, as it is aimed to introduce and generalize the factors that cause urban expansion, a sample formed among the cities in the first 500 population in the world population rank according to the United Nations, (2011) by using simple random sampling method.

In the study, the formula used to determine the variance value is used in case that there is no variance value which can be obtained from a different operation. This variance value was obtained for the variance value needed to find out how many samples to choose from the top 500 cities with the highest population in the world.

$$\sigma^2 = \frac{(\text{city with max}\, population - city\ with \min population\,)^2}{16} \qquad (1)$$

$$\sigma^2 = \frac{(34400000 - 843531)^2}{16} \qquad (2)$$

$$\sigma^2 = \frac{(33556469)^2}{16} \qquad (3)$$

$$\sigma^2 = 70377288234247.56 \qquad (4)$$

Then according to the minimum sample selection formula:

$$n = \frac{N\sigma^2}{\frac{(N-1)B}{4} + \sigma^2} \qquad (1)$$

$$\frac{500 * 70377288234247.56}{\frac{(500-1)3521574}{4} + 70377288234247.56} \qquad (2)$$

$$n = 21.75 \cong 22 \qquad (3)$$

As a result of applying the formula, the minimum sample size is 22 (city). Taking into account the size of the sample and the fact that not all data can be found for every city, the sample size was determined as 29 cities in the first place.

Table 1. 29 cities that are the subject of this study and the population of these cities

Order	Countries of the Selected Cities	Order of the Cities According to Population	Cities	Population of the Selected Cities
1	Mexico	9	Mexico Cıty	23,200,000
2	India	10	Delhi	22,900,000
3	Egypt	12	Cairo	15,600,000
4	Thailand	28	Bangkok	13,700,000
5	Iran	23	Teheran	13,500,000
6	Turkey	20	Istanbul	13,300,000
7	China	26	Tientsin	9,800,000
8	United States of America	19	Chicago	9,750,000
9	Democratic Republic of Congo	22	Kinshasa	9,550,000
10	Japan	18	Nagoya	2,266,249
11	Vietnam	41	Saigon	7,750,000
12	Malaysia	30	Kuala Lumpur	6,450,000
13	Chili	47	Santiago	6,100,000
14	Indonesia	85	Bandung	5,600,000
15	Republic of Sudan	58	Khartoum	5,050,000
16	Angola	88	Luanda	5,050,000
17	Russia	35	Saint Petersburg	5,050,000
18	Spain	73	Barcelona	4,575,000
19	Saudi Arabia	63	Riyadh	5,800,000
20	Brazil	84	Recife	4,136,506
21	Japan	1	Tokio	13,159,388
22	Norway	375	Oslo	1,502,604
23	Japan	172	Yokohoma	3,697,894
24	Japan	235	Kobe	1,533,852
25	South Korea	247	Doejean	1,476,736
26	Tunisia	148	Tunisia	702,330

A large proportion (48%) of the cities identified by simple random selection (Table 1) are located in Asia. The continent with the second largest (24%) number of cities in the sample is Africa (Figure 1).It is seen that the distribution of the data set is parallel to the world population distribution obtained according to world population data in 2011-2012 (Figure 2). Therefore, it can be said that the selected sample has a high level of representation in terms of geographical distribution due to the scale.

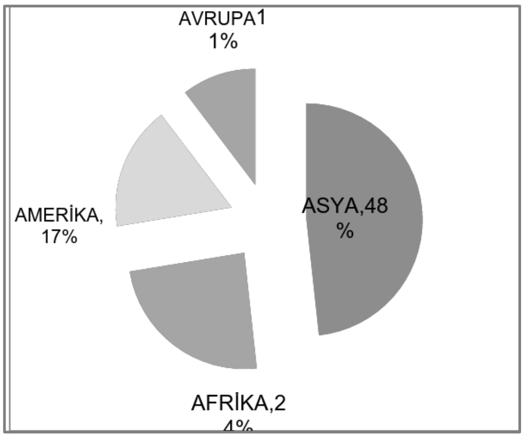

Figure 1. Distribution of cities in the dataset by scale

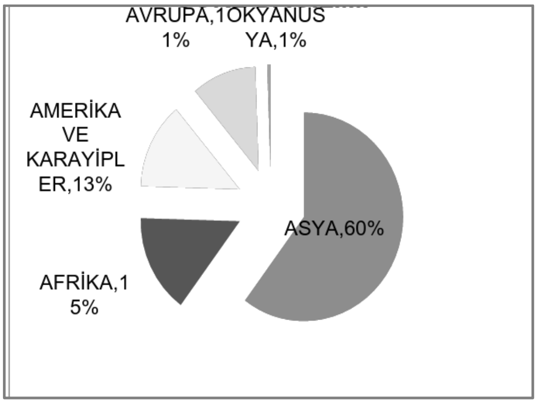

Figure 2. Distribution of the world population by continents

In the literature survey, although it is mostly done by using the land use maps, it is not possible to obtain the land use data of all the cities in this study. Remote sensing techniques have been tried with the pilot study, but serious losses have been detected with regard to real urban staining. For this reason, the remote sensing method was not preferred, and the urbanization stain of each city was were manually digitized from satellite images from 2012 provided by GoogleEarth. The drawings made by one person and that have reduced the losses and mistakes that can occur.

Samples obtained from the GADM (Global Administrative Areas) web site were added to the study file of the administrative borders of the cities, and the stains were plotted at a height of 6.80 km.In the second stage, fractal dimensions images were obtained ın .tif format from the urban reconstruction images that were vectored with the help of QuantumGIS, Photoshop and ArcGIS programs.As an example (Fig. 3), urbanization stain of Chicago city presented in the .tif format.

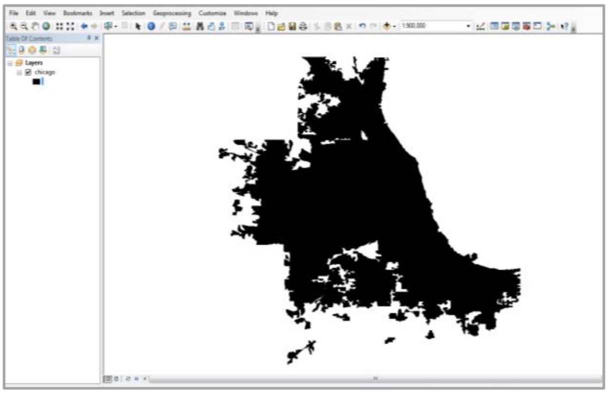

Figure 3. Chicago urbanization staines vecctored by ArcGIS program

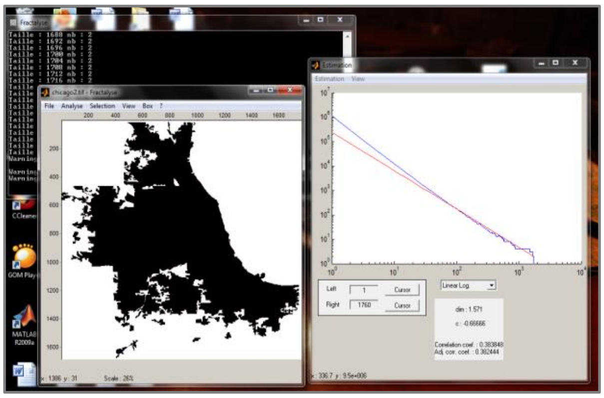

Figure 4. Calculation of fractal dimension of Chicago city with FRACTALYSE program

The fractal dimension values of these urban stains are calculated by using the open source FRACTALYSE program (Dilation, Box-Counting, Linear) with different fractal dimension calculations. As an example (Figure 4), urban stains of Chicago city can be seen as calculated by FRACTLAYSE program.

Box-counting is a method of analyzing the spatial distribution of urban restoration texture and the rass madius method is one of the more successful methods used in cities with single-centered growth or circular growth while investigating the urban growth process in terms of capturing the connection between the urban core and the urban wall.In this study, Fractal Exponential Linear values obtained by Box Counting method as independent variable in regression model are used as fractal dimension values.

4. Findings

For the 29 selected cities, fractal dimension values calculated with different mathematical forms (Figure 5) and descriptive statistics related to these values were given (Table 2).

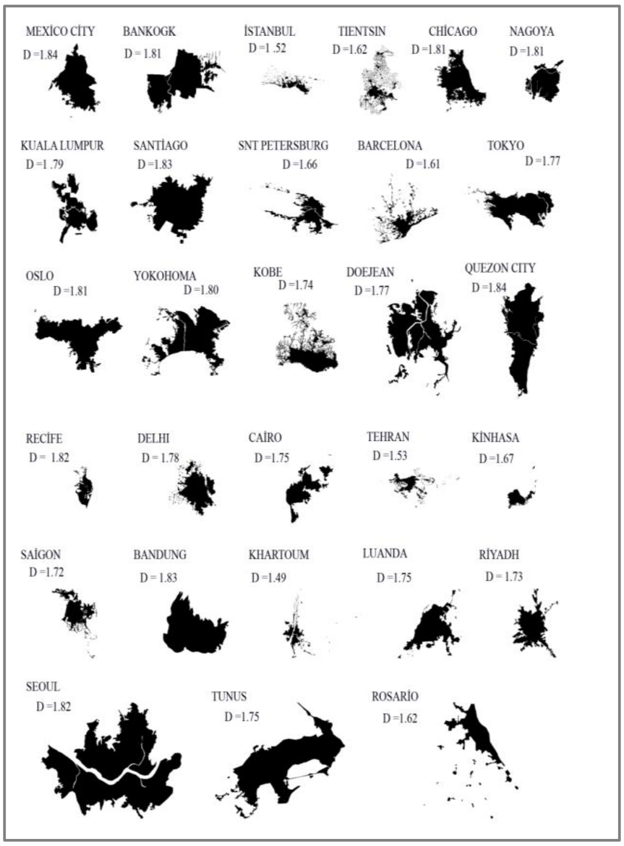

Figure 5. Fractal (FnLin) values of 29 randomly selected settlement stains

Table 2. Descriptive statistics on dependent variables

Fractal	Number of Variables	Minimum	Maximum	Average	Standard Deviation
Fractal Exponention Linear	29	1,4900	1,8400	1,7355	0,1024

Mexico City (Mexico) and Quezon City (Philippines) has the highest Fractal Exponential Linear fractal dimension value with 1,84 and Khartoum (Sudan) has the lowest value with 1.49.

Fractal dimension is an important parameter for urban form and growth models, but cities with different populations may have the same fractal dimension (Shen, 2002). Bankogk, Chicago, Nagoya, Oslo (D = 1.81); Mexico City and Quenzon City (D = 1.84); Tokyo and Doejean (D = 1.77) have the same fractal dimension values even though they have different population numbers (Figure 4.5). This indicates that the Fractal dimension is an indicator for urbanized areas, but it is not a good measure for urban density [23]. Within this framework, it was aimed to explain the fractal dimensions of the cities and their demographic, socio-economic and physical characteristics using the regression model. At the next stage of the research, the relationship between the fractal dimension value and these indicators was questioned by establishing a set of 70 independent variables, indicators, which are thought to affect the spatial development of the urban macroform, taking into account the hypothesis that population size is not a sufficient explanatory value alone for fractal dimension values.

The database of 70 independent variables created in the related literature consists of these: (1) total country area, (2) altitude, (3) city population rank in the world, (4) the age of the city, (5) the population of the city, (6) the area of the city, (7) the population density of the city, (8) population change, (9) human development level index, (10) quality of life index, (11) total forest area in the country, (12) 2009 gross national product purchasing parity, (13) 2009 gross national product, (14) 2011 urban population, (15) CO2 emissions, (16) country population, (17) United Nations data for number of cars per 1000 people, (18) World Bank data for number of vehicles per 1000 people, (19) United Nations data for number of vehicles per 1000 people, (20) price of gasoline, (21) gross national product per working person, (22) total workforce, (23) the ratio of total population to total workforce, (24) the ratio of the central government's total debt to the gross national product, (25) urban population accumulation (the ratio of the population living in cities with more than 1 million inhabitants to total population of the country), (26) gasoline consumption of the transportation sector (except trucks, aircrafts and ships), (27) land unit prices and the squares and logarithms of these datas. It is important that the independent variables used in the study are comparable and same database is beig used in terms of reliability and universality in collecting the data, and to ensure that the database used has data from all of the countries. Data sources:

1. Altitude, age of city, population of city, information of urban area, are obtained from official websites of cities,
2. The population ranking of the city in the world, population change, index of quality of life, total forest area in the country, 2009 gross national product, 2009 gross national product purchasing parity, 2011 urban population, CO2 emissions, World Bank data for number of vehicles per 1000 people (Excluding trucks, airplanes, ships), gasoline pump price, gross national product per employee, total labor force, rate of total population to total labor force, total government debt, urban population accumulation, transportation sector gasoline consumption (Excluding trucks, aircraft, ships) are obtained from World Bank data,
3. United Nations data for number of cars per 1000 people, United Nations data for number of vehicles per 1000 people, are obtained from United Nations data,
4. The human development level index was obtained from the data of the human development report,
5. The country population is obtained from the citypolulation.de website and the total country area is from the worldatlas.com website,
6. M^2 land unit prices are obtained from different sources for each city,

The logarithm, ln's and squares of the data are calculated from the main data.

In order to explain the spatial efficiency of the research subjects, 70 independent variables forming the data set were used in different combinations. The model that best explains the data observed from the obtained results is chosen as the model to explain the spatial efficiency. Fractal Exponential Linear, which is obtained by dependent variable box counting method according to the selected final model, taking into account the results of multiple linear linear regression obtained in the study. The independent variables are the country area (km^2), altitude (in ln form), age of the city (years), GNP ($), number of vehicles (in ln form) and m2 land price (square form) ($). In other words, the selected model contains six independent variables.

5. Results

As a result of the study, 11 cities out of the 29 cities in which the fractal value cannot be calculated for the model are left out of the sample because there are no independent variable data and the model is completed with 18 cities (Table 3).

Table 3. The cities in the sample of the selected model(n=18)

	Cities
1	MEXICO-CITY
2	BANGKOK
3	ISTANBUL
4	CHICAGO
5	TIENTSIN
6	NAGOYA
7	KUALA LUMPUR
8	SANTIAGO
9	SNT PETERSBURG
10	BARCELONA
11	TOKYO
13	KOBE
14	DOEJEON
15	QUENZON CITY
16	SEUL
17	TUNISIA
18	OSLO

The parameter estimates of the final model obtained are presented in terms of statistical significance and statistical significance (Table 4). As it is understood from the model expressed by the dependent variables, it is possible to explain 91,6% of the variance of the independent variables and the dependent variables (R^2=0,916, Adj. R^2= 0,870). R^2 = 0.916 is a good level of description when it is considered that there is no previous study that establishes a relationship between fractal dimension and socio-economic data. All of the variables except one were statistically significant at the 0,050 level.

The number of vehicles per 1,000 people is significant at the level of 0.10.

Table 4. Parameter estimates of the independent variables used in the model

Variable	Estimated Coefficients (Not Standardized)	Estimated Coefficients (Standardized)	Standard Error	t	p statistic (Pr > | t |)	VIF
Constant	1,878		0,069	27,225	0,000	-
Total Area of the Country	$-8,632 * 10^{-9}$	-0,439	0,000	-4,842	0,001	1,076
GNP 2009	$1,965 * 10^{-6}$	0,504	0,000	3,822	0,003	2,271
Number of Vehicles (ln)	$-2,608 * 10^{-2}$	-0,252	0,014	-1,804	0,099	2,552
Age of the city	$-3,654 * 10^{-5}$	-0,775	0,000	-8,455	0,000	1,097
m^2 land price	$-8,108 * 10^{-11}$	-0,270	0,000	-2,682	0,021	1,322
Altitude (ln)	$1,696 * 10^{-2}$	0,311	0,006	3,030	0,011	1,374

According to the regression model obtained, the year 2009 gross national product and altitude are found to be directly proportional to the fractal dimension. In other words, the increase in these values increases the fractal dimension value, which indicates that the city is more compact. The total country area, the number of cars per 1000 people, the age of the city, the unit price of the land per square meter is inversely proportional to the fractal dimension. The increase in these values means that the value of the fractal is decreasing, and that the city has a sprawled structure.

The regression equation for model describing spatial efficiency within the scope of the study is,

Fractal Dimension Value (Exponential Linear) = 1,878 + (1,965* 10-6) Gross national product 2009 – (8,632 * 10-9) Total Country Area – 0,026 * ln Number of Cars Per 1000 people + 0,017 * ln Altitude – (3,654 * 10-5) * The Age of the City – (8,108 * 10-11) Price per square meter (1)

One dollar increase in the gross national product increases the fractal value of the city by 1,965 * 10-6 units, decreases the fractal value of the urban city by 3,654 * 10-5 units and the decreases number of vehicles by 0,026 units. The increase of one square kilometer in the area of the city where the city belongs to reduces the size of the city by 8,632 * 10-9 units, while the increase of square meter of land price by 1 dollar reduces the size of the city by 8,108 * 10-11 units. One meter of increase of the height of the city from the sea level increases the fractal value of the city by 0.017 units.

The results of the final multivariate linear regression model obtained were evaluated for regression assumptions. When the histogram graphs of the distribution of the nonstandardized residuals obtained in the model that are evaluated (Figure 6), average of the residual values are -1,04 * 10-17 and the distribution is very close to the normal distribution.

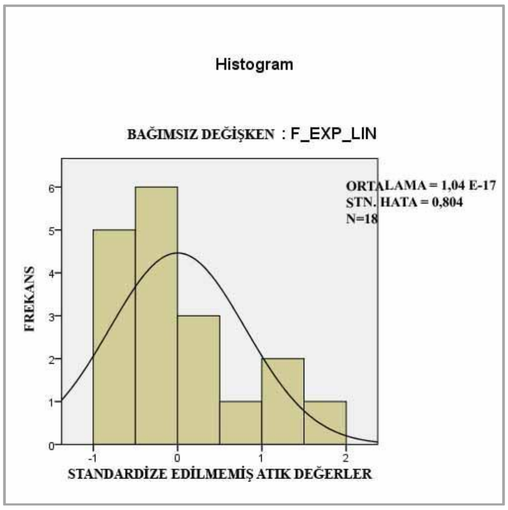

Figure 6. Normal Distribution Curve of Dependent Variable

Non-standardized residuals and non-standardized independent variables do not show a certain pattern according to the spreading graph of the estimated values (Figure 7 and Figure 9). The absence of patterns in the scatter plot shows that there is no significant relationship between the estimated values and the residual values, and in summary, and indicates that there are no variables that affect each other and the model is meaningful.

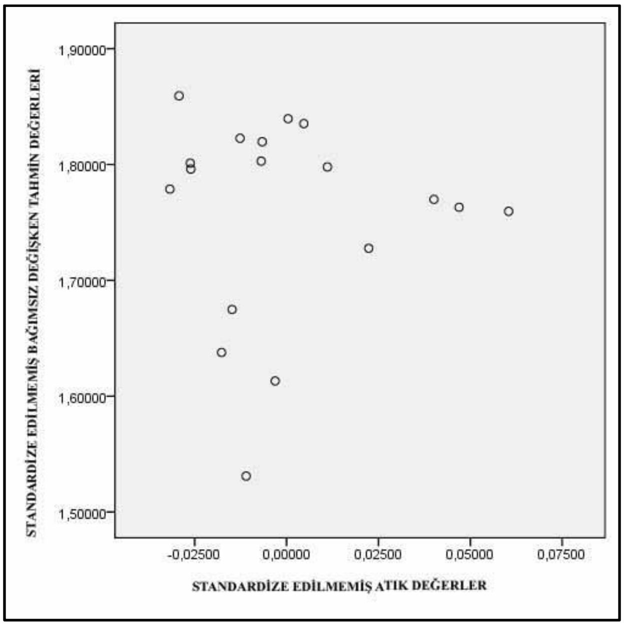

Figure 7. Residual fit plot

The expected cumulative probability values for the obtained multivariate regression results and the observed cumulative probability values are acceptable when the graph is analyzed (Figure 8).

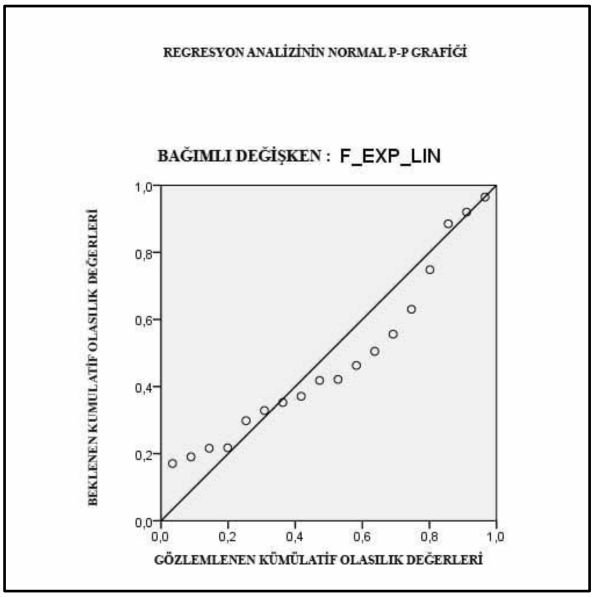

Figure 8. Normal P-P graph of regression analysis

Point graphs were created to determine whether there is a relationship between the residual values used in the model and the independent variables. It is observed that there is no relation between the independent variables of the residual values obtained. As a result, the resulting final multivariate regression model proved to be inconsistent with the basic assumptions of the regression technique. With this reason, regression analysis was not required to be re-scaled by standardizing (normalizing) the data.

The hypothesis is accepted that the standard error values of the independent variables are small at 0.05% at 95% confidence interval. According to the model; The gross national product, height of the city from sea level, total area of the country, number of vehicles per capita, age of the city and m^2 land unit price have a significant effect on the fractal dimension. Multiple Collinearity tests were performed for independent variables in the study and the independent values were below the value of 5, which indicates that the VIF values are significant in the literatüre [26]. This means that the independent variables used have no linear relationship with each other.

6. Discussion and Conclusion

It can be said that cities are shaped as dynamic organisms by a variety of factors such as natural disasters, wars, economic inadequacies, social development inequalities, deprivation, migration, overpopulation, wrong location choices. This situation has brought the aim of shaping cities in favor of the living in the agenda of urban planners, adhering to contemporary urban planning principles.

Rapidly increasing world population, developing technology and vehicle-based approaches in recent years have led to rapid urbanization processes. Urban planning approaches continue to be important in this context as spatial expansion of urban areas can be sustainable and ecological in the context of conservation of natural resources and values. Spatial growth affects the urban macroform, land use, urban systems and their interrelationships. The compact and fuzzy growth that arises as a result of this interaction is a frequent problem among the researchers with its positive and negative aspects in the urban planning discipline. Understanding the causes, effects and consequences of the spatial growth process, good management of the growth process, sustainable and efficient use of spatial space is necessary. In the current urban expansion process as a spatial reflection of the urban population growth, pressure has been created on farming areas, forest and pasture areas, water sources and semi-rural living areas surrounding urban areas. At this point, the loss of fertile land by transforming into an urban structure reduces the ability of cities to feed themselves. This causes the natural resources in the areas of outsourced urban interaction to become difficult to find.

Urban expansion is often described by High-cost infrastructure with urban area spreading to the waterside, Increase in energy consumption, Social seperation, Fragmented structure in land use and the tendency to travel with personal vehicles that they reinforce in areas with low urban population [27,28,29,30,31,32,33,34]. As a result, they are faced with aa weary process that is accompanied by increasing traffic congestion, energy consumption and pollution emissions [35,36,37]. The physical consequence of urban expansion is to use space inefficiently and to push governments to produce new policies. Expressing urban sprawl only by how much land is used compared to the population is weak in terms of understanding the city. Many studies have attempted to link urban sprawl to population, but noted that the population alone can not make meaningful evaluation [37,38,34,33].

The aim of this study is to discuss the urban growth phenomenon based on sustainability principle and urban macroforms shaped as spatial reflection of this phenomenon through fractal dimension and through regression analysis and to interpret in terms of spatial productivity. The aim of the study was to develop a methodology for the analysis of urban space within the framework of the assumptions and limitations that are required to achieve these goals. For this reason, twenty nine (29) cities with different dynamics from the first five hundred (500) cities with the most densely populated urban areas in the world were randomly selected and fractal dimensions of urban settlement sizes were measured. So, this study is looking for a model that will reveal the factors affecting the efficiency of using space efficiently through sampling cities.
In the study, according to the regression model, urban altitude is the determined variable to reduce

urban sprawling. As the height above sea level increased in the regression model, the fractal dimension of the city increased and the city showed more compact spatial development. This is remarkable in terms of research findings on urban areas in the United States that have population over 50,000. In the survey, it is seen that consumption of urban land is higher in coastal cities than in terrestrial cities, and this phenomenon is attributed to more intensive use of coastal cities [37]. It has been determined that the old historical cities which have developed in a definite and defined spatial evolution process and have the traditional settlement roots spatially show a more sprawled settlement pattern than the cities which are newly established or have not a rooted settlement tradition. In other words, although it is stated in the literature that the old cities whose spatial frame defined by the transportation means of the period and distances that are focused on human focused traffic show a more compact spatial development than cities shaped according to today's needs, the model obtained in the study yielded the opposite result of this hypothesis. With the introduction of automobiles into urban life, cities have transcended their spatial boundaries, thus leading to the emergence of new low-density residential areas and the decentralization of urban functions [39]. It is possible to say that this situation led to the development of the cities towards the walls and formation of a more sprawled (fringed) settlement pattern. The model shows that younger towns has more compact settlement texture. It is possible to link this to prioritizing the principles of sustainability of younger cities, a planned settlement development instead of a spontaneous one and urban services that can include a combination of different land uses that are characteristic of compact cities originating from urban centers. Similarly; It is possible to say that automobile dependency is high and spatial development takes place intermittently in cities which are subject to urban expansion phenomenon [29,33,34,40]. Parallel to the regression model in operation, as the number of vehicles increases, the city shows a sprawled structure and as the city grows its vehicle ownership increases. In planning studies, designs and decisions that reduce the use of special vehicles may be used as an important factor to reduce the level of urban fringing. According to the regression model, another variable that have a negative effect on urban expansion is the per capita gross national income. The gross national product per capita is positively correlated with the fractal dimension, which is the efficient use of space. As the gross national product per capita increased, it came into light that the city had a compact structure. Sprawling is also based on housing development [41]. Urban sprawls are encountered in countries with low gross national income per capita (especially in poor countries with high population density) [37]. There is a meaningful relationship between land value and urban sprawl, and land prices are higher in compact cities [42]. Land values also change the use of land. [42,43,44,45]. Using a linear regression analysis, a meaningful relationship between urban land value and population and household income was obtained [44]. Empirical studies have shown that there is a positive and meaningful relationship between urban growth and housing values [46]. Similarly, an empirical study of Los Angeles revealed a meaningful relationship between housing land values and urban area [47]. According to another empirical study of Istanbul, it is concluded that there is a significant trend between urban growth and land values [45]. In parallel with the studies mentioned in this study, there is a meaningful relationship between land value and urban sprawl, but the result is that cities with high land square meter prices show a fringed structure and use the place inefficiently. In parallel with the studies mentioned in this study, there is a meaningful relationship between land value and urban sprawl, but cities with a high land price per square meter showed a fringed structure and that they used the place inefficiently. It can be said that the reason for this is the fact that the new settlement areas resulting from the excessive increase of the land prices in the city center have shifted to semi-rural, semi-urban and low cost agricultural lands in the urban area. As the area of the country to which the city is affiliated grows, it can be seen in the regression model that the city is fringing (sprawling). As the area of the country where the city is located grows, it is seen in the regression model that it is studying that there is fringing in the city. However, no empirical work has been found in the literature to support this.

Urban change and urban growth methods and related urban analysis techniques are used to understand the urban structure. A better understanding of the urban growth dynamics is the basis for an effective planning of the city's possible future. Sprawl is seen as a widespread infrastructure and a costly form of urban development [41]. This research is seen as a prototype for fractal dimension analysis applications. Urban planning is a process involving many different constraints and development criteria. In order to make the measurements about the cities which are subject to this research more reliable, the urbanized areas of the cities have not been determined by the remote sensing method although they take a shorter time and the urbanization spots of selected cities have been spotted manually for more precise measurement. The fact that this approach takes more time and that very few cities have been worked on due to limited budget is one of the constraints of this work. Another constraint is the lack of comparable data for all cities and therefore the use of country data.

The proposition presented at the beginning of the work is that the indicators including altitude, per capita gross national product, the origin and age of the cities, the total area of the countries, the number of cars per capita and the unit price of the land in cities affects the development, thus this has an effect on the spatial productivity. It has been determined that variables such as altitude from the sea, historical background, land value, area of the country, gross national product, vehicle ownership influence the spatial productivity of the city, but other variables do not have a significant effect on the spatial productivity of the city.

Within this context;

1. The assumption that the city has different scales and the systems it contains, and that it contains continuity features and has a fractal structure has been verified. The structural properties of the city can be measured by fractal dimension.
2. The assumption that urban macroforms show a compact spatial pattern and increases spatial productivity when the results of fractal dimension analysis are high is confirmed. In this context, in line with Shen's 2002 approach, cities with fractal dimension values approaching 2 can be defined as high spatial efficiencient and compact.
3. It has been shown that the parameters affecting the development of urban texture can be modeled by interactivity features and mathematical approaches and their influence directions and influence magnitudes. For the 29 cities, the effect sizes and directions of the independent variables affecting the regression model were determined and 92% of the variance could be represented.

Even though the urban planning discipline includes social, economic and cultural development studies, spatial design and planning-implementation studies at the focal point. It is thought that this research will contribute to the organization and development of the urban space in accordance with the information obtained through the examination of the physical texture. Also, the result of the study is thought to be a good guide for policy-makers and city managers of high-populated cities. Fractal parameters are thought to help developing countries in terms of urban theories and planning. At the same time, with this new method approach, future researchers will be able to obtain more realistic models through detailed data sets with the help of technology and budget support, and other topics will be discussed and it may be the subject of other investigations that researchers will come up with new methods.

Conflict of Interest

No conflict of interest was declared by the authors.

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