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USING THE FRACTAL PERSPECTIVE IN THE ANALYSIS OF THE URBAN PERIPHERAL FABRIC. CASE STUDY: PANTELIMON, ILFOV COUNTY

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Abstract: This article approaches the matter of analysing the urban peripheral fabric from a fractal perspective. The urban peripheral morphology, through its generally discontinuous character, raises great questions signs upon the fairness of using the classical instruments of analysis, especially in what concerns the usage of density gradients. The purpose of this scientific undergoing is that of bringing into spotlight the usage of the Fractalyse program, as a better-adapted tool to the fieldwork, since the accent is set on the elements distribution in space and on the distances between them. We, thus, reach to a multiscalar approach of the urban fabric, from the town scale to the neighbourhood scale and that of the building itself, for a more pertinent analysis over the alternation between constructed spaces and empty parcels. In order to represent this undergoing, three types of fractal analysis will be studied (dilation, radial and space correlation analysis) to achieve a comparative approach of the urban fabric evolution in Pantelimon, which is situated nearby the Capital city and has been, over the last two decades, deeply marked by the urban sprawl phenomenon.

Key words: Fractal analysis, Fractalyse, urban sprawl, Discontinuous urban fabric, Distribution, Density.

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Introduction

The fractal theory and analysis belong to a larger context of theories developed by mathematicians and physicians over the second half of the 21st century, which target the study of systems' self-organization capacity, the internal structural balance and the space segmentation. These theories focus on the way a space with nonhomogeneous features influences the urban sprawl evolution, the ranking of the settlements system, the selection of a particular type of localization or the distribution of forms and urban functions within an urban agglomeration. The main theories belonging to this category are: the catastrophe theory, the dissipative structures theory, the synergistic theory and the fractals theory (Boulanger 2006).

Fractal geometry has come to life due to the research of Benoit Mandelbrot (Mandelbrot 1983), which focuses upon objects that show structure similarities on different scales of analysis. These mathematical objects have been used to describe shapes and spatial relations which outrun the regularity of the Euclidian geometry, being defined through the alternation of areas of continuity and fracture, of concentration and diffusion.

The definition itself of fractal structures, from the Romanian Explanatory Dictionary, highlights their specific feature which targets the study of shapes and which, in their distribution, contain a seeming chaos.

> "FRACTAL (French; Latin Fractus <frango "to overcome, to break, to tear") Adjective Fractal structures = class of mathematical, physical, biological structures (objects) etc. that cannot be studied by classic mathematical methods (ex.: geometry fractal structures cannot be studied with Euclidian geometry methods, and the physical ones cannot be studied with Newton's dynamic methods) and that, from their point of view, are considered chaotic or even "pathological". (...)Fractal structures can be found everywhere in nature, from galactic swarms to orogenic structures, hydrologic networks, tree branches, bronchi and bronchioles ramifications, snowflakes etc."

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This new vision over objects and the relation between them has been adopted and used right from the beginning in the Geography field, more specifically in the shorelines analysis. However, the most frequent practices of fractal geometry in the field of Spatial Sciences refer to the analysis of urban fabric features, particularly to the asymmetrical relations between centre and periphery.Consequently, after the publishing of Benoit Mandelbrot's work in 1983, geographers Michael Batty and Paul Longley have started, in 1986, to conduct researches on the urban fabric, aiming to simulate the urban expansion.

Another remarkable contribution to the field has been made by Pierre Frankhauser, who, in 1991, began to focus his research undergoing over this aspect. After defending his Doctoral thesis in Physics and Geography, he has set the basis of a research centre within the ThèMA laboratory, focused particularly on the analysis and shaping of the urban fabric through the fractal geometry lens. Through the perspective of his results, P. Frankhauser has managed to beat the principles of the dense city and to demonstrate the effectiveness of a fractal urban form. The city is seen as an intricate socio-spatial system, with a dynamics characterized by flow interchanges (matter, energy, information) through a fractal surface which allows a maximization of these interchanges. This follows, on certain aspects, the principles of the Athens Charter, which supports the growth of human density, providing, at the same time, each individual with easy access to open spaces, air and light.

In the same period of the 90s and throughout the following decade, a group of researchers have intensively used this working method in the study of urban structures, independently or with the collaboration of Pierre Frankhauser. It is to be mentioned the contribution to this matter of the following researchers: Cyrille Genre-Grandpierre (Frankhauser & Genre-Grandpierre 1998), Jean-Philippe Antoni (Antoni 2001), Cécile Tannier and Gilles Vuidel (Tannier, Vuidel & Frankhauser 2008).

The introduction of this method in the scientific national context occurs due to the need of having a more appropriate view over sprawled urban fabric, over the distribution of built elements and empty spaces, a spatial reality insufficiently described by using classical indicators of density.

This study was conducted during a PhD. thesis that treated the territorialization forms of the urban exodus in Bucharest metropolitan area, with a particular focus on Pantelimon, Ilfov County. The case study was chosen in terms of its representativeness for the evolution of the settlements surrounding the Capital City and due to its close spatial interactions. In fact Pantelimon and Bucharest are two administrative units separated by a natural limit-Pantelimon Lake.

Methodology

Fractal Geometry: a model of theory and analysis over the urban fabric

The principles of applying the patterns specific to physics in the urban fabric analysis have been thoroughly explained by Pierre Frankhauser in his Doctoral thesis, which has been later on published in 1994 – „La Fractalité des structures urbaines" . Without resuming his theoretical approach, we will specify only the basic principles of this method and their practical application which is to be done in the town of Pantelimon.

Fractal geometry proposes a work method which stands above the limits of the Euclidian geometry. This is due to the fact that, in the evolution of the ancient and the medieval cities - all surrounded by walls and often paved with orthogonal cobblestone and with continuously built fabric – radical changes have been made, especially after the Industrial Revolution, which, on one side, are due to the cities' tentacular extension along the transport axes (for instance, tramway lines), and on the other, due to the emergence of discontinuities in the urban fabric, called loophole. This fragmented aspect makes the overall of an urban agglomeration seem „shapeless, amorphous, with no refferences or possibilities of analysis in the geographical field."

However, in this apparent chaos, there is a law of internal order that governs the way in which the evolution and spatial distribution of these aggregates develops in the different stages of the urban organism's growth. Thus, the fractal geometry stands on the repetition of an element on different scales of analysis, a repetition that takes place endlessly. (Figure 1)

In a simple fractal contruction, two elements are enough to characterize this structure:

The shape of the basic structure, called initiator or initial figure – generally an object specific to Euclidian geometry, such as a circle, a square or a line. The initiator plays a minor role in the fractal theory, embodying the Euclidian part of the fractal object. It mainly specifies if an object resembles more to a square, circle, etc. The initiator is associated to a non-fractal parameter, called shape factor.

The repetition rule that generates the hierarchy spatial system is called the Fractal Generator. It constitutes the essential element in the description of the fractal dimension, because this rule defines the way in which we pass from one scale to another. It also holds information regarding the parameters that feature the scales of analysis overlap. In figure 95, the parameters of this rule of repetition are featured by the reduction factor r and by the elements number N.

A fractal contruction is generated by applying this rule repetitively. Different stages of iteration are, thus, being distinguished, each of them having a certain

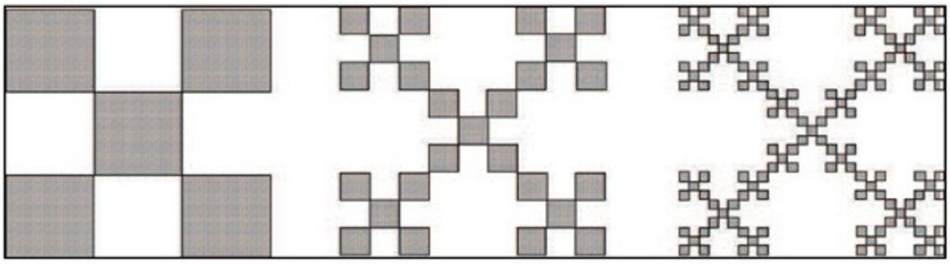

Figure 1. The first three stages of iteration of a Sierpinski carpet, based on a square with a reduction factor of r=1/3 and a number of elements factor of N=5
Source: Frankhauser, P., 1994:52

structure, built from replicas of the initial figure, which are called occupied elements of structure. The assembly of these occupied elements form the occupied mass of a fractal, in a particular stage of iteration.

Based upon the observation of these elements, there are different types of analysis that can be performed regarding the existing urban fabric or his potential, on different scales: the neighborhood scale, the city scale or the urban agglomeration scale.

The fractal analysis of the urban fabric corresponds better to spatial realities, because, in the course of its evolution, the city has developed areas with different densities, interweaving built areas with empty spaces, the urban fabric having a nonhomogeneous distribution in space.

Pantelimon. From the urbanization of the rural space to its de-urbanization

In order to exemplify the methods of fractal analysis, we have chosen the present case study over the Pantelimon village, stated as urban settlement in 2005. Pantelimon is situated nearby Bucharest, at the East of the Romanian capital. (Figure 2)

Between 1990 and 2010, the settlement goes through a process of extensive urban development, with weaker and weaker density gradients. The rate in which the built-in area has increased in Pantelimon is quite surprising. The town registers, throughout two decades, a multiplication of its built-in area by 7.4 (Cîrnu 2013). In what concerns the urban morpholofy generated throughout this period, we witness a radical perspective change, from a Fordist type of urban fabric to a Post-Fordist one. Consequently, it can be noticed, in Image 3, the print of the areas built in 1990, with the spotlight on collective residencies which have been included in the central part of the settlement as a result of the National Systemisation Program (1976-1980). This program has been accelerated by the end of the 80s and its prospected result was the gradual erasure of the differences between the rural and the urban environments, through what was then named the "rurbanization", a term with a different connotation from that of its contemporary, western European counterpart. These dense and compact forms, with thoroughly systemized streets and parcels which did not surpass 200-250 m2 (Figure 3) have been replaced by a sprawled urban fabric, with its nucleus – the individual home.

The urban fabric with a residential target has been shaped between 1990 and 2010, and presents various features, with forms and manifestations that include characteristics of both a chaotic urbanization and a rigorous systemization, in the special case of real estate complex projects. It is an urban fabric which defines itself through a 100% heteroclithic character, and which reflects, on one hand, a diversity of the real estate forms of production and, on the other hand, a critical lack of global vision over the urban development of the targeted settlement.

The Fractal analysis of the urban fabric

In order to facilitate the analysis over the urban fabric from the fractal perspective, the Fractalyse program has been developed. This program is capable of realizing different types of analysis, based on counting and distributing aggregates on different hierarchy scales. This program has been developed in 2001, within the ThèMa laboratory of the Franche Compté University, being constantly improved up to its current 2.4 version.

In each of the counting stages, the number of pixels contained by the defined perimeter is taken into account. On each time, the size of the defined perimeter is also modified. In this sense, the two main elements are the elements number (black pixels marked by the print of the built area) – N – and the size of the defined perimeter or of the referential element (ε). A series of points are obtained with the absciss ε and the ordinate N, doubled by the relation N = εD or N = ε-D,D being the fractal dimension. D falls between the values 2 and 0. The value of this dimension characterizes the level of concentration of the constructed mass in a certain area of the urban fabric. A value close to 2 corresponds to a homogeneous structure, without a pronounced hierarchy, while a value close to 0 corresponds to a

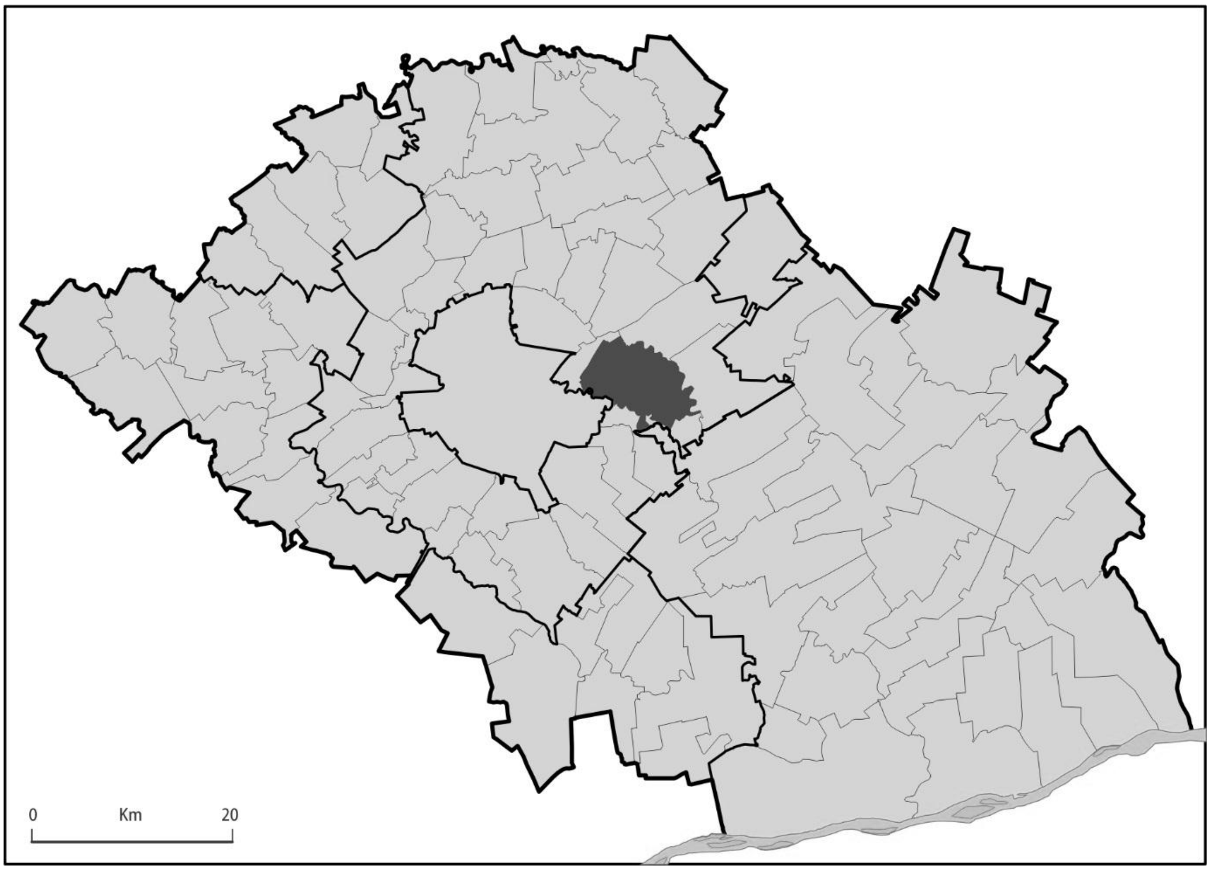

Figure 2. Pantelimon within Bucharest Metropolitan Area

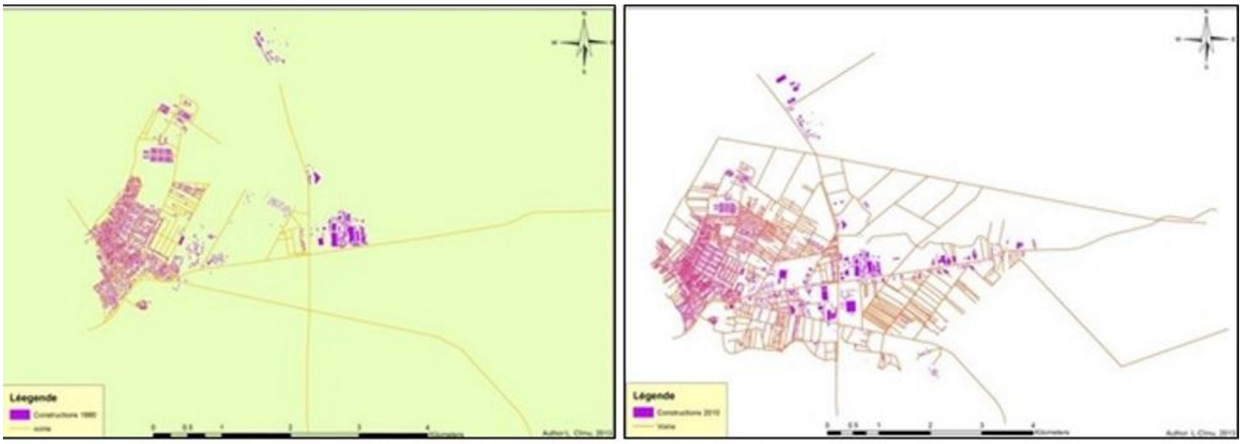

Figure 3. The evolution of the built area and the approved axes points in the Pantelimon settlement in 1990 (left) and 2010 (right)

strong hierarchy in terms of elements, with mass concentrations on particular points and isolated concentrations from the other elements made possible through void spaces.

With this analysis software, we will apply three methods of urban fabric fractality analysis for the town of Pantelimon between 1990 and 2010: radial analysis and dilation analysis on the entire urban fabric, along with the spatial correlation analysis method, on the scale of the selected perimeters. For this purpose, we have selected graphic material that illustrates the print of the built surface with a 300 dpi resolution.

The Dilation analysis

The dilation analysis implies the replacement of empty spaces within an urban structure through the dilation of previously occupied squares, within certain iteration stages, which results in the progressive disappearance of the empty spaces and their replacement by aggregates. These aggregates unify within the iteration stages. After numerous empirical experiences, it has been ascertained (Frankhauser 2000) that this method is the surest in determining the fractal dimension of the urban fabric, regardless the window size or the counting centre, since that particular indicator is set for weak variations. For the existing fabric in 1990, 12 stages of dilation have been applied by the moment of a central cluster display and the progressive disappearance of the empty spaces (street diagram) from within it (Figure 4).

We have also looked upon a higher as possible value of the correlation coefficient. In this way, the 12th stage of dilation has been reached, with a value of D=1,674 and a correlation coefficient of 0,999961, very close to 1, meaning a good adjustment of that certain indicator compared to an ideal curve. The number of resulted clusters is of 28, while the resulted lacunas are 8 in number. The total surface of extracted borders is of 704284 points.

However, for the year 2010, after 12 of these stages, the following data has been obtained: D = 1,588 and a lower correlation coefficient compared to the year 1990 (0, 999785). 52 clusters and 36 lacunas were resulted, with a total borders surface of 1058745 points.

Although the dilation analysis method finds its applicability especially in the analysis of urban agglomerations, the information provided by it in the analysis made upon Pantelimon is complementary to the urban fabric analysis from the 3rd chapter, the second part of the work. Consequently, a slight difference between the D values between 1990 and 2010 is observed, reflecting a sensitive increase of the heterogeneity level. What is, though, more important to the level of given information, is the way in which clusters are being formed throughout the iteration stages and the alterations that appear on the lengths of the borders (Table 1). We can, thus, notice the difference between the lengths of the existent borders in 1990 and 2010, on the level of undilated elements, and that of each iteration stage, which highlights the larger area, which is the one occupied by constructions in the year 2010. A longer border in 2010 shows a weaker degree of compactness of the urban fabric, with an elements distribution mainly in the space that engulfs more important non constructed areas. Also, the more emphasized grade, negative on the level of the same year compared to that of 1990, indicates the existence of a large number of aggregates, situated close enough for them to merge.

The way in which these clusters are formed in the course of each stage completely proves this aspect. This way, for instance, for the year 1990, from 784 clusters, we witness in the 3rd stage to 416 clusters, while two decades later, from 928 clusters, the 3rd stage then results in 358 clusters. Thus, for 1990, the number of clusters found in the 3rd stage had been reduced with 46, 9%, while in 2010 these have diminished with 61, 4%. These values come to demonstrate the fact that in 2010, the number of aggregates (more important) were situated on smaller distances one from the other, which allowed them to merge easier, which is a definite sign of urban sprawl. It must be taken into consideration the fact that, for the year 1990, there were one main nucleus and two other secondary ones of residential habitats, separated by croplands or military installments. Until 2010, these empty spaces have been almost entirely occupied by residential buildings which have led to the decrease of the distances between the above-mentioned nuclei and between the newly implanted aggregates.

The Method of radial analysis

The radial analysis refers to a certain point within the study perimeter compared to which it is analyzed the

Table 1. The characteristics for each dilatation stage for the built fabric of Pantelimon

Year	Step	Area	Border	Lenghth	Objects	Clusters	Year	Step	Area	Border	Lenghth	Objects	Clusters
	0	248619	69351	1444	660	784		0	296366	98787	2528	1600	928
	1	339331	54412	838	274	564		1	427225	80635	1459	634	825
	2	404743	41804	598	136	462		2	523198	62998	1048	375	673
	3	453100	32301	511	95	416		3	596231	52225	626	268	358
	4	489965	26262	285	79	206		4	657373	46988	408	199	209
	5	520528	23207	184	64	120		5	712205	43645	289	163	126
1990	6	547804	21462	130	53	77	2010	6	762984	41455	235	137	98
	7	572860	20049	88	46	42		7	810854	39545	197	119	78
	8	596425	19326	66	40	26		8	856313	38204	159	101	58
	9	619076	18868	63	36	27		9	899986	37010	145	87	58
	10	641059	18570	52	35	17		10	941957	35565	117	75	42
	11	662540	18203	43	32	11		11	982180	34564	110	66	44
	12	683544	18024	39	30	9		12	1021068	33706	103	60	43

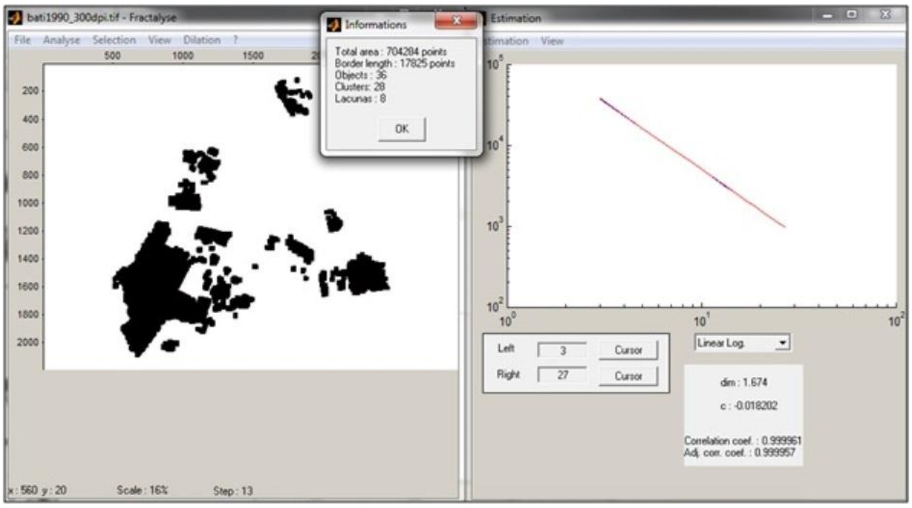

Figure 4. The built fabric of the settlement in the 12th stage of dilation. 1990

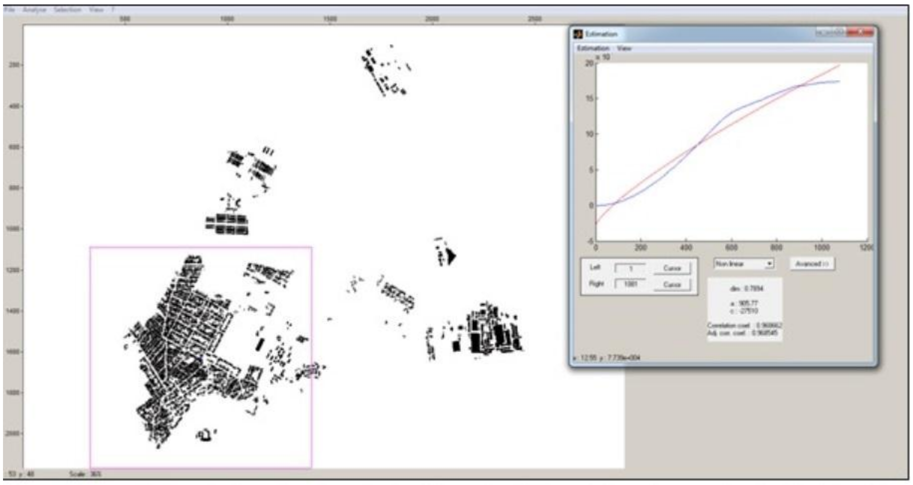

Figure 5. The radial analysis methofabric of the Pantelimon from 1990

distribution of the other elements (Frankhauser 1998). This selected point is called "counting centre". This centre is surrounded by a square or a circle with a progressively increased radius, having the ability to determine, each time, the number of occupied elements by buildings within the circle. Having a higher precision rate than that of the dilation analysis, this method targets essentially the elements of microstructure of the urban fabric, since the analysis scale is very high. Throughout this method, various comparisons can be made, between different areas of centrality.

This analysis allows the identification of the sections within the morphology of the constructed fabric and the identification of the limits between the different types of urban fabrics, according to their level of homogeneity. A valuable indicator for this purpose is the interpreting of the scaling behavior curve.

For the constructed fabric from 1990, the chosen counting centre was the crossroad between the Sfântu Gheorghe, Mioritei and Tudor Vladimirescu Streets, area in which were, and still are, situated most of the town's public institutions. Because of the open space that separated the edified areas, the radial analysis was able to target only the perimeter of the central nucleus (Figure 5).

In this global approach of the constructed mass distribution compared to the selected centre, the value D is 0,7894, and that of the correlation coefficient is 0,968662, value which reflects a mild adjustment of the fractal relation towards an ideal situation. However, following the scaling behavior of the function coordinating this distribution, we can identify perimeters with more important values of this indicator.

Thus, a first stage corresponds to the limit drawn by the Drumul Garii Street on the West, and on the South and the East, by the emergence of the open areas. Up to this stage, the radial analysis shows a D value of 1, 905 and a correlation coefficient of 0, 999823.

A second stage corresponds to the transgression from the constructed areas to the open ones, on one side, and to the contact with the individual residencies nucleus, located in the North-East side of the settlement, on the other. In this case, D = 1, 326 and the correlation coefficient = 0, 990747.

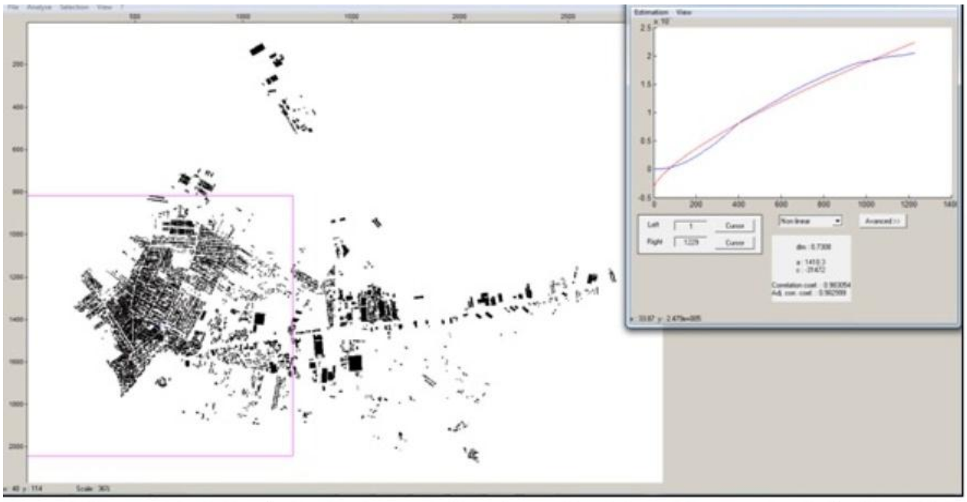

Figure 6 The method of radial analysis applied on the scale of the entire constructed urban fabric of the Pantelimon from 2010.

Coming back to the global situation, we can finally ascertain a last stage, located where the constructed fabric disappears, leaving room for the designated croplands.

In 2010, the counting centre remains the same. However, the values are different (Figure 6). The fractal dimension is D = 0, 7308 and the correlation coefficient has the 0, 9083054 value. In this case, we can identify certain stages/fractions in the constructed mass distribution, from the interpretation of the scaling behavior.

A first stage marks the ending of the continuous constructed fabric. At this stage, D = 1, 731 and the correlation coefficient is equal to 0, 999134.

A second stage emerges, in the North side, defining the grafted fabric on the already-existing diagram in the year 1990 and the later on developed areas. In this case, D = 1, 158 and the correlation coefficient has the value of 0, 992465.

A third stage intervenes after the inclusion, in the counting perimeter, of the old Poultry Farm (Avicola) halls and the pavilion fabric located nearby the main nucleus. D = 0, 9052 and the coefficient of correlation equals to 0, 990381.

A final stage and, subsequently, the limit of the counting area are defined by the desultory constructed area between the Rascoalei and Campului Streets.

The radial analysis method, both in the case of the urban fabric from 1990 and that of the existing one in 2010, illustrates a variation of the fractal dimension value from the centre towards the outskirts, which indicates the distribution manner of the constructed mass. Also, we can notice its high values and those of the correlation coefficient within the perimeter of the "old settlement", where, both in the case of the individual residencies and the collective ones, we can acknowledge a similarity between their distribution and the absence of certain important void spaces, that can impose a certain hierarchy inside the urban fabric. The scaling behavior, through its modulations, has given way to the identification of stages that can allow the individualization of perimeters, over which the spatial correlation method can be, and will be applied.

Spatial Correlation Analysis

The spatial correlation analysis consists of counting, from every point of the aggregate, the number of points situated at a certain inferior Euclidian distance of a value ε, which varies according to every iteration stage (Frankhauser and Genre-Grandpierre 1998). This conveys an image over the distribution of points/perimeters occupied by constructions, and it subscribes to a logical system similar to the one of the radial analysis, only that this one realizes point counts occupied with constructions for every occupied point, situated inside a chosen window of analysis. The importance of the spatial correlation analysis is found in the delivery of precise information regarding the occupied points distribution in a perimeter and in relation with another. From the empirical experiences done by Pierre Frankhauser and his team, it has been ascertained (Frankhauser 2000) that, for a correct interpretation of the values of fractal dimension, the correlation coefficient for this analysis needs to contain 9 in the first 5 decimals (ex: 0, 999991).

In the application of this method we will use the previously identified perimeters with the help of the radial analysis, but also on randomly selected areas, according to their common features.

Thus, for the year 1990, on the level of the entire constructed perimeter, the value of the fractal dimension is quite reduced, with a D of 1, 42 and a correlation coefficient of 0, 999614 – inferior to the minimally accepted value as necessary for a relevant analysis.

This result can be explained by treating a diversity of urban forms together (individual pavilion, collective residential, agricultural and industrial production units, military installments) separated by open areas.

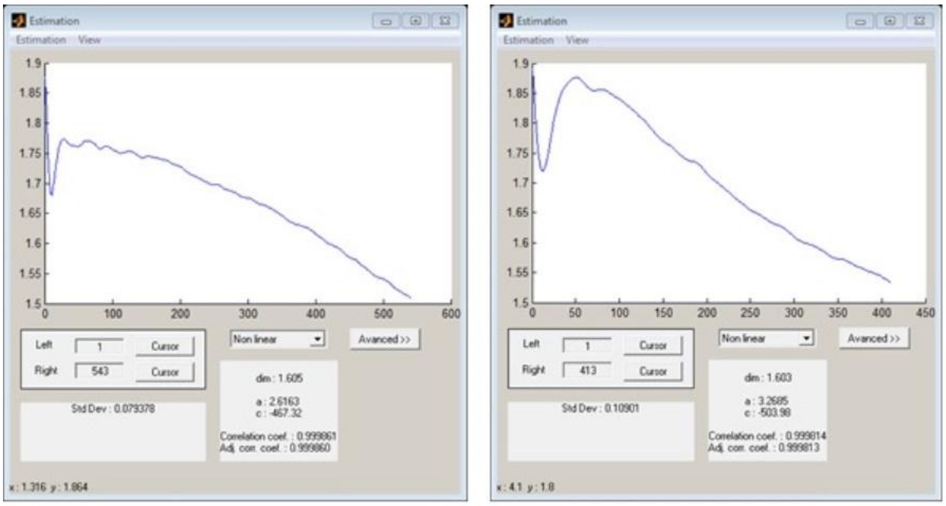

Figure 7 The Graphic image of the scaling behaviour obtained as a result of the spatial correlation analysis for the years 1990 and 2010, Pantelimon, Ilfov county.

A homogeneous perimeter of analysis, identified as the one towards which a first stage manifests itself (the Drumul Garii Street on the West and on the South, and on the East, the emergence of open areas) reveals a value D = 1, 948 and a value of the correlation coefficient equaling to 0, 999997. These values correspond to a compact urban fabric, with no important interstitial spaces between points, points which have a similar distribution, with no clear hierarchy between them.

A secondly identified perimeter, through a second stage in the previous analysis, reveals a dimension of D = 1, 72 and a correlation coefficient of 0, 999843. This fact is explained by the engulfment within the analysis perimeter of the open area, presently situated between the Livezilor and Rascoalei Streets, but also by the military installments with a particular spatial distribution. In 2010, on the scale of the entire constructed assembly, the value D = 1, 605 and that of the correlation coefficient is that of 0, 999861.

In what concerns the identified stages, in the first perimeter the value D = 1, 864 has been registered, along with a correlation coefficient of 0, 999975 (image 5). These values show that the urban fabric grafted to the initial hearth (the area between the Livezilor and Tractorului Streets), compared to the existing situation in 1990, presents a relatively larger diversity regarding the aggregates distribution, even if it belongs to the same compact trend. This can be explained through the fact that, even if the area has been projected for expansion, in strong connection with the urban morphology of the year 1990, the abrogation of the laws with restrictive character has given room for negotiation and deviation from these strict regulations.

The perimeter defined by the second stage, the fractal dimension has the value D = 1, 756, and the correlation coefficient equals to 0, 999938, because, in the case of the perimeter defined by the third stage, D needs to have the 1, 706 value and the correlation coefficient, 0, 999910.

A more detailed look upon certain randomly selected areas in the urban fabric developed after 1990 offers completely different values to these indicators, influenced by the existence of the initial hearth in question. Thus, in the residential perimeter which emerged between the Cernica Forest, the bypass and the Biruintei Boulevard, the value of D is that of 0, 6997, with a coefficient of 0, 998253. In other words, we are discussing aggregates situated at great distances one from the other, separated by important open areas.

In the more developed area beween the Biruintei Boulevard, the Cernica roadway and the bypass, D = 1, 658, with a correlation coefficient of 0, 999951, which reveals a much less structured distribution of the elements in space in connection with the existent situation in the settlement's hearth.

The similar tendencies of the scaling behavior for the years 1990 and 2010 (Figure 6), with sudden drops in the central area, followed by relative stabilizations, can be explained through the existence of collective buildings in the town's centre, surrounded by streets and co-owned areas. In addition, the descendent trend of the indicators in question suggests the emergence of open spaces within the constructed fabric. A comparison of the two moments - 1990 and 2010 – from the scaling behavior perspective, indicates an acute descending slope in the year 2010, which corresponds with a significant presence of open spaces between the points occupied with buildings, in other words, an "urbanization in holes", a feature of the sprawl type of urban evolution.

The spatial correlation analysis offers, hence, more precise information than the radial analysis. On a micro-urban scale, offering, thus, the possibility of a better understanding of the aggregates distribution on finer levels of analysis than those of the radial analysis. However, the high values of the correlation coefficient necessary for the entire validation of the values in question become obstacles in applying this type of analysis in optimum conditions.

Conclusions

The methods of fractal analysis that have been used, compared to the density indicators frequently used, which require a homogeneous elements distribution on an area unit, allow an analysis of elements distribution on an individual level, in connection with the spatial reality.

Using the dilation method, the radial analysis or the correlation one, provides complementary information over the number of clusters, the border length, the elements distribution according to a centre or the distribution of those aggregates inside a certain perimeter, and, so, using a single analysis becomes insufficient in the urban fabric study.

It needs to be mentioned that the fractal analysis allows the description of the urban morphology and the spatial organization of the urban aggregates. However, this must be backed by an analysis of the spatial reality, through already established methods. The scaling behavior, for instance, allows the identification of certain stages of fraction on the level of mass distribution constructed along the radius, though, for their interpretation, the type of the urban fabric needs to be known, with its specific urban forms, which have determined the emergence of their particular stages.

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