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Assessing the fragmentation of the green infrastructure in Romanian cities using fractal models and numerical taxonomy

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Abstract

As the share of urban population increases globally each year, man-dominated systems tend to sprawl over the natural ones, substituting and fragmenting them. Urban sprawl is the main cause of many environmental issues, in tight connection with pollution and loss of biodiversity. One of the main consequences is a decrease of the ecosystem services provided by the urban green infrastructure. However, the extent of urban sprawl is spatially uneven due to the spatial structure of human settlements. Among the methods used to pinpoint sprawl, fractal analyses have a good potential for analyzing fragmentation, especially if used in conjunction with statistical methods. This study aimed to assess, in an exploratory perspective, the level of fragmentation in the Romanian cities covered by the Urban Atlas data, and determine its correlation with parameters related to their demographical and physical characteristics. In addition, taxonomical analyses were used to find whether cities or specific components of the green infrastructure can be grouped. The results did not reveal a general trend, although it seems that the green infrastructure consisted of agricultural/ semi-natural/ wetland areas, forests, green areas, sports and leisure facilities and water bodies in all of them, in different shares; with respect to their distribution, the numerical taxonomy analysis indicated that they form classes matching the types of 'nature in the city' previously described by ecologists, despite the particular historical evolution of each city and its particular influence on urban planning. The correlation analysis revealed that the population and its density and the share of the green infrastructure within the total area are significantly correlated

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with most fractal parameters. Similarly, the fractal dimension of the area, computed using Interactive Quantitative Morphology, seems to correlate with most morphological parameters. However, the taxonomical analysis of cities did not find very relevant groups due to the fact that many large Romanian cities lack Urban Atlas data. The results suggest that the degree of urban fragmentation is correlated especially with the population of cities and its density, reclaiming planning measures aimed at controlling the densification processes (sprawl, gentrification, location of specific activities etc.)

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Keywords: urban sprawl; ecosystem services; biodiversity; homogeneity; planning; fractal dimension; lacunarity

1. Introduction

Emerged some 50 years after the foundation of ecology by Ernest Haeckel as one of its branches, urban ecology had its own parallel evolution, trying to answer questions focused on three directions: ecology *in* the city, ecology *of* the city, and sustainability of the city 1. Disregarded by ecologists in the beginning, cities became an important object of study when ecologists realized there importance; cities host nowadays most of the world's population, with a constant increase of its share 2. The concentration of human population and activities determines numerous impacts against the environment 34, affecting the global resilience 5; cities are responsible for the 'global changes', term introduced in 2011 by Dale *et al*. 6 to coin climate changes, land cover and use changes, and alterations of the energy flows, phenomena which are intrinsically related 57.

The process of urbanization is an underlying cause of land cover and use changes 28 which in their turn are connected to climate changes and the alteration of energy flows. Previous studies have found that urban sprawl causes the conversion and fragmentation of natural systems 91011121314 even to a greater extent than agriculture 10, and is the main threat to non-urbanized areas 15 resulting into the loss of biodiversity 141617 and influencing species and biogeochemical cycles 18. As a consequence of sprawl, urban ecological systems are characterized by the connectivity of natural patches, succession and invasion 519, consisting of fragmented green spaces isolated from the natural systems 20, embedding also natural corridors 921.

Urban sprawl has two consequences; fragmentation refers to a patched or leap-frog land development, while dispersion refers to the expansion of a city from its core 22. Morphologically, fragmentation increases the number of patches and their perimeter, altering their functions (including the provision of ecosystem services) and reducing biodiversity 23, but decreases in the mean patch size 15 and increases the perimeter 2.

In relationship to biodiversity, the size of patches is a good predictor of species richness 9, and edge effects could also play an important role 9, because the isolated patches are more exposed to anthropogenic impacts 1016. While urban sprawl reduces species richness, as fragmentation reduces the areal of natural species 24, influencing the composition of specific assemblages, such as arthropods 16, the abundances of some species might peak due to edge effects 2. In general, biodiversity depends on the spatial structure (size of habitats and distance between them) 12.

The nature of cities has been included in four categories: remains of the natural systems, extension of natural systems, landscaped or managed areas, and spontaneous, invasive or ruderal species 2526. Previous studies have showed that maintaining nearly-natural habitats in cities allows even for the presence of rare and threatened species 1927; the quality of habitats seems to be more important than their connectivity 28. In addition to the greenways, which connect different habitats, penetrating the urban areas 28, urban agriculture can play an important role for food security 2930.

In order to coin all the natural or semi-natural systems within the urban areas, the term ‘green infrastructure’ was introduced as a concept useful for both planners and practitioners 31 to encompass ecological corridors, urban areas, industrial parks, suburban areas, sustainable drain systems, and coastal areas 233233. The green infrastructure provides and maintains ecological services 213435, such as flood control, safe drinking water 11, which sustain clean air, water, and natural resources and enrich their citizens’ quality of life 11, have a significant potential for adapting cities to climate changes 3132, can contribute to human and ecosystem health 3336, preserve the biodiversity 33 and increase the resilience 34.

A relatively new concept, ecosystem services are the benefits offered by spatially distributed ecological systems 37 to the human society: supply, regulation, cultural, and support 3839404142. The quality of ecosystem services reflects their normal functioning, as yield depends on the carrying capacity 43. Ecosystems services were not studied in cities as much as in the natural ecosystems (e.g., wetlands) 44. While ecosystem services depend on biodiversity 20, they may be used to reduce the effects of urban environmental issues 41, reduce global pollution and help adapting to the effects of climate change 1544, or help reconnecting cities and people to the biosphere 4445, and have biophysical, health, environmental justice 44, economic, social, cultural, and insurance value 44.

From a planning perspective, previous studies have showed that conservation should protect networks instead of parcels 23, as linking protected areas or parks by creating corridors and greenways 19 or buffering natural areas 10 can counter habitat fragmentation 11 and help maintaining ecosystem services 2037. The inclusion of urban green infrastructure in planning and management can increase urban sustainability 38, especially if a special strategy is created for it 23. Proper planning and management of urban areas could offer lessons for living in harmony with the nature 9 and ensure sustainability 344647. Prudence is also recommended; planners must take a slow pace, especially in eliminating brownfields 28.

Urbanization and its control, the green infrastructure and ecosystem services create a theoretical framework with a significant relevance for planning, presented in Fig. 1. The image displays two circles; the vicious circle shows a continuous degradation of the environment due to the negative impacts of an unwise planning or the lack of planning; sound planning can turn the vicious circle into a virtuous one, enhancing environmental and life quality, as well as human welfare. In more details, the following conceptual model can be derived from the literature: if sprawl is not controlled for, it results into the fragmentation of the green infrastructure and its simplification. Fragmentation reduces the biodiversity and alters ecosystem services. In response, wise planning, accounting for the maintenance of a well-connected green infrastructure by avoiding sprawl, increases its biodiversity and enhances the level of ecosystem services, resulting into better living standards of the human communities.

Different approaches were used to assess the impact of sprawl; previous studies have indicated that spatial metrics, including the number of patches, edge density, largest patch index, nearest neighbor distance, area weighted mean patch fractal dimension 48 patch density, density of built-up land, population density 22, or edge, fractal dimension, and patch diversity 49 are critical in evaluating urban changes 48. The methods used mostly were the gradient and landscape pattern analyses, developed in conjunction with spatial tools 18. Fragmentation was assessed using parameters like the patch density, mean patch size, or mean perimeter-to-area ratio 50. Fractal measures were not reliable for assessing changes 18, but were used to compare ecologically equivalent areas 51. Sprawl can be measured using density 52, and fragmentation is correlated to sprawl 52. In addition, studies aimed at mapping the green infrastructure required the use of GIS techniques to overlay several spatial layers 53.

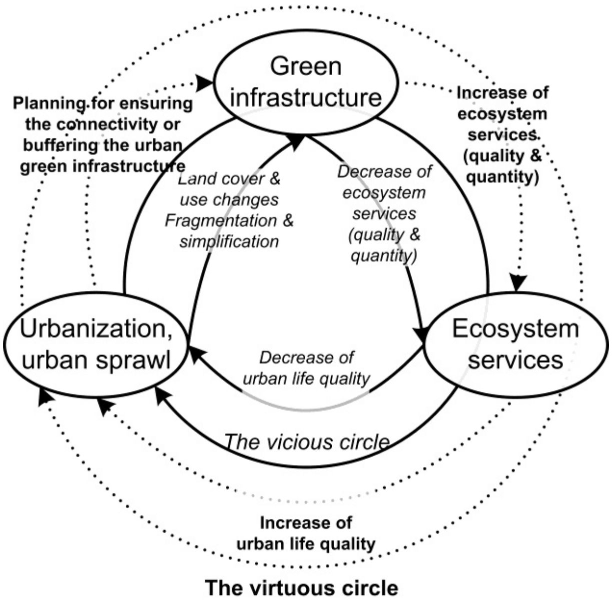

Fig. 1. Conceptual model of the relationship between urban sprawl, green infrastructure, and ecosystem services. The image shows to circles; the vicious circle corresponds to the lack of planning or unwise planning, resulting into increasing environmental and social impacts. The virtuous circle is a consequence of adequate planning, and determines an increase of environmental and life quality, and welfare.

The patterns of sprawl differ substantially across the world; a worldwide comparative study found that the patch dynamics for two of the groups, frantic- and high-growth cities, showed evidence of increased fragmentation, while both expansive- and low-growth cities followed a trend towards infilling (or decreased fragmentation), indicated by the rates of change in patch number for the fringe, periphery and hinterland areas 22. In Europe, sprawl was influenced by the historical structure of cities 14; the change of economic activities led to a homogenization and fragmentation of its rural landscapes 54. Previous studies carried out in Romania found out that the true extent of urban sprawl, masked by the spatial resolution of CORINE data and reduced total urban area, can be revealed if the growth is compared with the total urban area 13.

This study aims to assess the fragmentation of the green infrastructure in several Romanian cities covered by high resolution data provided by the Urban Atlas using spatial metrics from an exploratory perspective, correlating it with several demographic and environmental characteristics, hypothesizing that cities with a higher urban pressure (measured by population and its density) would have a greater level of fragmentation. The ultimate goal is to be able to identify some clusters with similar characteristics using numerical taxonomy.

2. Methodology

The original data, are provided free of charge by the European Environment Agency through the Urban Atlas program, via the Internet (http://www.eea.europa.eu/data-and-maps/data/urban-atlas). The data are a snapshot from 2005-2007 covering cities with a population over 100,000 participating in the Urban Audit at a high resolution: a minimum mapping unit of 25 hectare and a minimum width of linear elements of 100 meters 55, useful for assessing fragmentation 56. The data covered 14 cities (Fig. 2):

Alba Iulia (68,570 people in 2010), Arad (164,665), Bacău (175,546), Brăila (210,245), Bucharest (1,942,254), Călăraşi (73,005), Cluj-Napoca (305,636), Craiova (298,740), Giurgiu (67,510), Oradea (204,625), Piatra Neamţ (106,611), Sibiu (154,220), Târgu Mureş (143,939), and Timişoara (311,428). Original data, covering the peri-urban area in addition to the city, were clipped by the official administrative boundaries using ArcView GIS 3.X. Based on the classification scheme, all the elements of the green infrastructure – (a) agricultural and semi-natural areas and wetlands, (b) forests, (c) green areas, (d) sport and leisure areas, and (e) water bodies (11, 23, 32, 33) were identified (Fig. 2 – blue), and mapped all together as black and white images (with black corresponding to the green infrastructure components). Images were analyzed using fractal and numerical taxonomy approaches in conjunction with statistical methods.

Fig. 2. Position of the study sites. The limits of the fourteen Romanian Urban Atlas cities with a population over 100,000 included in the study are displayed in red, and the green infrastructure in blue.

2.1. Fractal and statistical analysis

Fractal analysis used two open-source programs: ImageJ 1.49t 57 and IQM 3.2 58. ImageJ is an open source image processing software package, developed by Wayne Rasband (National Institutes of Health, Bethesda, Maryland, USA) designed for scientific multidimensional images. ImageJ is highly extensible, with thousands of plug-ins and macros for performing a wide variety of tasks, and a strong, established user base. ImageJ was used to turn the images in a binary format and extract perimeters. Its FracLac 2015Mar6206 plug-in was used to compute the lacunarity, using the following settings: Box-counting Fractal and Lacunarity Analysis, default set background automatically for binary images 61. The perimeter contour was extracted and resized to a standard dimension and converted to a single pixel outline (ImageJ – Process – Binary – Outline) to determine the fractal dimension of perimeters. IQM (Interactive Quantitative Morphology) is an image and signal analysis software framework written in Java, developed by Helmut Ahammer (Medical University of Graz, Austria) 58. It is mainly built around the Java JAI library and incorporates the functionality of the popular ImageJ image processing software. IQM was used to determine the fractal dimension (settings: default, box number: 10) and Sengupta & Vonoy lacunarity (settings: default, gliding box, maximal epsilon 10). The results of fractal analysis consist of the following parameters:

(a) Fractal dimension: represents a measure of complexity, of how much does the fractal 'fill in' the space, quantifying the irregularity or fragmentation of an object. The fractal dimension results from its division into parts. The fractal dimension is determined, for areas or perimeters, via box-counting (58, 59, 60, 61, 62, 63, 64). The method consists of determining the number of cells N (l) required to cover the structure to be measured, based on their side. For different values of the sides of cell 1, the cells covering it are counted and represented in logarithmic coordinates log N=f (log l). The slope is the fractal dimension. The computation formula is:

$$D_{b-c} = \lim_{\varepsilon \to 0} \left(\frac{\log N_{\varepsilon}}{\log \frac{1}{\varepsilon}} \right) \quad [1],$$

where D_{b-c} is the box-counting fractal dimension ε the side length of the box, and N (ε) the smallest number of contiguous and non-overlapping boxes of side ε required to cover (57, 60). As the zero limit cannot be applied to geographical images, D was estimated by means of the equation:

$$D_{b-c} = d \quad [2],$$

where d is the slope of the graph of log[N(ε)] against log(1/ε) 60. In semi-natural ecosystems, the fractal dimension ranges between 0 (when there is only one surface, equivalent to one pixel) and 2 (when the surface has a perfect geometric shape and is fully occupied by the fractal).

(b) The lacunarity of the area covered by the green infrastructure (Λ) was obtained using IQM 3.2 65. Lacunarity measures the size and frequency of lacks within images, describing the texture of fractals, which reflects their invariance to scaling. Lacunarity is usually defined from the mass-related distribution. In the box-counting method, the D-dimensional measure in each box of side r can always be written in the form 66:

$$M(r) = A(r) r^{D} \quad [3],$$

with the restriction: log A/ log r →0. In equation [3], A(r), is in general a function of r and M (r) is the mass in a box of size r. Lacunarity can be quantitatively defined as the fluctuations of mass-distributions over its mean, and given by the equation:

$$\Lambda_{(r)} = \frac{B\left[M^{2}_{(r)}\right]}{B^{2}[M(r)]} \quad [4],$$

where E (x) = Expectation(x). If this formula is used, high values of lacunarity indicate heterogeneity (varied distribution of pixels), and low values indicate homogeneity. In this case, lacunarity ranges from 1 (maximum homogeneity) to 2 (maximum heterogeneity).

FracLac (ImageJ) implements a different formula for computing lacunarity, aimed at determining the level of heterogeneity through the variation of the pixel distribution (area occupied by the fractal) 61:

$$\Lambda = \left(CV_{\Lambda}\right)^{2} \quad [5],$$

where CV is the coefficient of variation 61.

The two parameters, fractal dimension and lacunarity, were computed in reference to the area and perimeter. Along with other morphological parameters (number and density of parcels, % of the image covered, area occupied by the green infrastructure and its share from the total area), they were used in correlation analysis and analyses of covariance (ANACOVA) looking at the relationship between any of them and physical and demographic characteristics of the cities (area, population, density, elevation, biogeographical and ecological region), obtained from the Romanian Statistical Yearbook 67.

More exactly, the ANACOVA model included, for each of the four fractal parameters computed four each city, socio-demographic and physical characteristics of the cities (the area of the city, its population, the density of population, the biogeographical region where the city was situated, the ecological region where the city was situated, the average elevation of the city), and morphological parameters of the green infrastructure (the number of parcels corresponding to the green infrastructure, the area occupied by the green infrastructure, its share from the city area, and density of parcels, computed as area of parcels divided by their number).

2.2. Numerical taxonomy analysis

ArcView GIS 3.2 and its X-Tools extension were used to compute the area covered by each component of the green infrastructure within every city. The results were analyzed from a double perspective (aimed at finding clusters of green infrastructure elements and clusters of cities) using the software Buser 68, freely available on the web at http://projects.bioinformatics.ro/taxonomy/BUSER.zip or http://app.inthelrom.ro/histo/BUSER.zip. The program provides classification trees using the following measures, called homogeneities (68, 69, 70, 71):

(a) Buser's hI homogeneity (for binary tables)
(b) Dragomirescu's h* homogeneity (for binary tables)
(c) Dragomirescu's H* homogeneity (for tables containing positive values)
(d) p(chi2) – p-value associated with a χ^2 test for contingency tables
(e) Dragomirescu's M1 homogeneity (for tables containing positive values)
(f) Dragomirescu's M2 homogeneity (for tables containing positive values)

In all cases, the program provides a unique solution (classification tree). The program was applied for comparing the methods, but also the components of the green infrastructure based on the share of each component in the total area of the green infrastructure; in order to avoid biased results due to the different total sizes of each component correlated to the size of the city, they were expressed as percentages of the total area. For each of the two analyses in this study, in some situations no classification tree could be produced due to the nature of data (cases a and b), and all other trees were identical. Therefore, each analysis resulted into a unique classification tree.

3. Results and Discussion

The first set of analyses was aimed to detect possible correlations between morphological and fractal parameters of the green infrastructure in Romanian cities and their environmental and demographic characteristics. Table 1 presents the results of the correlation analysis, underlining significant correlations ($p\leq0.05$) by bold values and marginally significant correlations ($0.05<p\leq0.1$) by italic values.

The results indicate the existence of significant correlations despite the reduced sample size. Elevation was the only variable which does not seem to be correlated with any of the others. At the opposite extreme, a simple measure – the share of the green infrastructure area from the total image area – seems to be correlated with most parameters of the cities, especially the demographic ones (population and its density), morphological parameters of the green infrastructure (area and share of the total area), and fractal parameters. The demographic parameters (population and its density) seem to correlate with two of the fractal parameters (IQM – area Segupta-Vinoy index), and density only with the lacunarity (FracLac). Overall, the results supported the underlining hypothesis, indicating that the fractal parameters are correlated with socio-demographic parameters and can be used to assess the fragmentation induced by sprawl, although previous studies indicated that they are not useful for assessing changes 18.

From a practical perspective, the influence of population and its density, as a predictor of urbanization, on the fractal parameters, measuring the fragmentation, bring additional evidence on the consequences of human activities and, from an urban management perspective, reclaim measures for controlling population density and sprawl, aimed at reducing their environmental impact.

Table 1. Correlations between morphological and fractal parameters of the green infrastructure in Romanian cities and their environmental and demographic characteristics. The table presents the value of the correlation coefficient (above) and corresponding p-value. Significant correlations (p≤0.05) are indicated by bold values, and marginally significant correlations (0.05<p≤0.1) by italic values.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10	(11)	(12)	(13)
Area (1)	1.00	**0.56**	0.04	-0.05	**0.85**	**0.85**	0.15	-0.45	0.11	0.06	0.06	-0.24	0.15
	–	**0.04**	0.90	0.86	**<.05**	**0.00**	0.60	0.10	0.71	0.84	0.84	0.40	0.62
Population (2)	**0.56**	1.00	**0.77**	-0.18	**0.73**	0.04	**-0.58**	0.00	**-0.56**	0.44	**0.54**	0.20	**-0.56**
	0.04	–	**0.00**	0.54	**0.00**	0.89	**0.03**	1.00	**0.04**	0.12	**0.05**	0.49	**0.04**
Density (3)	0.04	**0.77**	1.00	-0.28	0.31	-0.45	**-0.94**	0.34	**-0.87**	0.42	**0.74**	**0.63**	**-0.88**
	0.90	**0.00**	–	0.33	0.29	0.10	**<.05**	0.24	**<.05**	0.14	**0.00**	**0.02**	**<.05**
Elevation (4)	-0.05	-0.18	-0.28	1.00	-0.04	0.10	0.41	0.01	0.37	-0.12	-0.42	-0.43	0.27
	0.86	0.54	0.33	–	0.89	0.73	0.15	0.97	0.20	0.67	0.14	0.13	0.35
No. parcels (5)	**0.85**	**0.73**	0.31	-0.04	1.00	**0.56**	-0.15	0.02	-0.26	0.38	0.25	-0.03	-0.27
	<.05	**0.00**	0.29	0.89	–	**0.04**	0.60	0.96	0.36	0.19	0.40	0.91	0.36
Green infrastructure (area) (6)	**0.85**	0.04	-0.45	0.10	**0.56**	1.00	**0.59**	**-0.57**	*0.52*	-0.26	-0.31	-0.46	**0.57**
	0.00	0.89	0.10	0.73	**0.04**	–	**0.03**	**0.04**	*0.06*	0.37	0.29	0.10	**0.04**
Green infrastructure (%) (7)	0.15	**-0.58**	**-0.94**	0.41	-0.15	**0.59**	1.00	*-0.51*	**0.93**	*-0.50*	**-0.76**	**-0.74**	**0.93**
	0.60	**0.03**	**<.05**	0.15	0.60	**0.03**	–	*0.06*	**<.05**	*0.07*	**0.00**	**0.00**	**<.05**
Parcel density (8)	-0.45	0.00	0.34	0.01	0.02	**-0.57**	*-0.51*	1.00	**-0.68**	0.37	0.27	*0.47*	**-0.67**
	0.10	1.00	0.24	0.97	0.96	**0.04**	*0.06*	–	**0.01**	0.20	0.36	*0.09*	**0.01**
IQM (area) (9)	0.11	**-0.56**	**-0.87**	0.37	-0.26	*0.52*	**0.93**	**-0.68**	1.00	-0.38	**-0.71**	**-0.77**	**0.94**
	0.71	**0.04**	**<.05**	0.20	0.36	*0.06*	**<.05**	**0.01**	–	0.19	**0.00**	**0.00**	**<.05**
IQM (perimeter) (10)	0.06	0.44	0.42	-0.12	0.38	-0.26	*-0.50*	0.37	-0.38	1.00	0.18	-0.03	**-0.54**
	0.84	0.12	0.14	0.67	0.19	0.37	*0.07*	0.20	0.19	–	0.53	0.92	**0.05**
Segupta & Vinoy (IQM) (11)	0.06	**0.54**	**0.74**	-0.42	0.25	-0.31	**-0.76**	0.27	**-0.71**	0.18	1.00	**0.83**	**-0.73**
	0.84	**0.05**	**0.00**	0.14	0.40	0.29	**0.00**	0.36	**0.00**	0.53	–	**0.00**	**0.00**
FracLac (ImageJ) (12)	-0.24	0.20	**0.63**	-0.43	-0.03	-0.46	**-0.74**	*0.47*	**-0.77**	-0.03	**0.83**	1.00	**-0.71**
	0.40	0.49	**0.02**	0.13	0.91	0.10	**0.00**	*0.09*	**0.00**	0.92	**0.00**	–	**0.01**
% of image (13)	0.15	**-0.56**	**-0.88**	0.27	-0.27	**0.57**	**0.93**	**-0.67**	**0.94**	**-0.54**	**-0.73**	**-0.71**	1.00
	0.62	**0.04**	**<.05**	0.35	0.36	**0.04**	**<.05**	**0.01**	**<.05**	**0.05**	**0.00**	**0.01**	–

Despite the correlations identified, the analyses of covariance did not provide any significant result, meaning that the 14 cities offered insufficient data to show that any of the parameters taken into account (the area of the city, its population, the density of population, the biogeographical region where the city was situated, the ecological region where the city was situated, the average elevation of the city, the number of parcels corresponding to the green infrastructure, the area occupied by the green infrastructure, its share from the city area, and density of parcels) have an influence over each fractal parameter when included in the model all together.

The results of the numerical taxonomy analyses are displayed in Fig. 3 and Fig. 4. Fig. 3 shows a classification of the green infrastructure components with respect to their share in each city, and Fig. 4 compares the cities based on the numerical distribution of the green infrastructure components. In addition, the results indicated that in all the 14 cities included in the study the green infrastructure consisted of the same five components: (a) agricultural/ semi-natural/ wetland areas, (b) forests, (c) green areas, (d) sports and leisure facilities, and (e) water bodies, although their share varied from one city to the other.

The taxonomical analysis of the green infrastructure components (Fig. 4) distinguished three groups; one of them is represented by the agricultural landscape, characterizing in general the fringes of cities, as a transitional ‘ecotone’ to the adjacent agricultural areas (13, 72). The second group consists of the vegetated area (urban and adjacent forests and urban green spaces), and the third one includes landscaped areas – sport and leisure facilities and urban water courses and lakes, corresponding to the categories identified by Qureshi and Breuste 26 and Breuste *et al.* 25. Ecologically, it is relevant to see that the results of numerical taxonomy analysis identified, based on the similarities of their spatial distribution (and fragmentation), the categories identified by the urban ecologists.

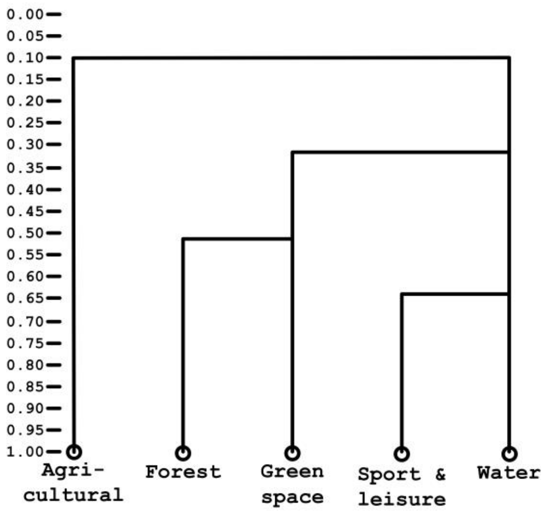

Fig. 3. Taxonomical classification of the green infrastructure components. The analysis is based on the similarities of the share of components within the 14 large Romanian cities included in then study.

The analysis distinguished five groups of cities; understanding the common elements of each group can only be done considering the history of each city, particularly the planning consequences of each historical change, and especially those affecting the relationship with the adjacent or embedded natural and semi-natural systems. The five groups are:

(a) Former medieval citadels – Alba Iulia, Arad and Piatra Neamţ; the first two cities have a prominent Vauban citadel still visible in the form of the city. The citadel in Alba Iulia is a notorious example of successful urban regeneration, as it has been restored and included in the contemporary life.

(b) Regional frontier centers – Galaţi (Danube border), Cluj-Napoca and Oradea (Hungarian border). Although Cluj-Napoca has now a central position, at some point it used to have a position similar to the other ones (largest urban center close to the border).
(c) Regional borderline centers – Bacău (Ukrainian border), Craiova (Danube border) and Giurgiu (Danube border). All of them are historically important centers of their region, although the importance expands over a smaller area than in the previous case.
(d) Cultural and populated centers – Brăila, Timişoara and Bucharest. While the importance of Timişoara and Bucharest is actual (Bucharest is the capital, and Timişoara the most important center of Banat), Brăila used to have an equal importance in the previous center, as home to the Danube Commission; all cities have also an important cultural life.
(e) Typical Transylvanian cities, with a strong ethnic minority component – Sibiu (German) and Târgu Mureş (Hungarian). These minorities constitute a large share of the local population and their culture has set an important distinct fingerprint on the architecture and spatial organization of these cities.

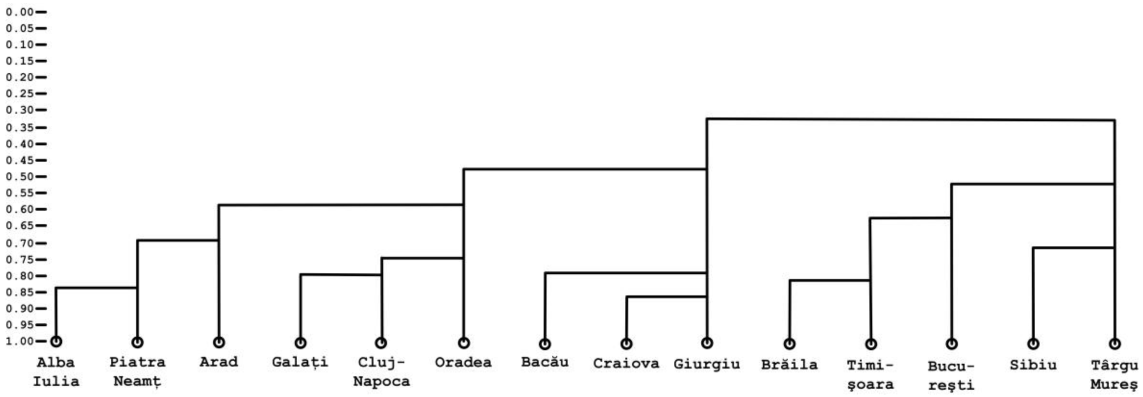

Fig. 4. Taxonomical classification of the studied cities. The analysis is based on the similarities of the share of components within the 14 large Romanian cities included in then study.

3.1. Methodological advantages and limitations

The study employed two unconventional methods – fractal analysis and numerical taxonomy methods. Fractal analysis found during the last five decades numerous applications in biology, medicine, geology, architecture, physics or urban and landscape planning; its added value results from the fact that it brings additional information, complementing classical approaches, and transcends the scale, using a non-Euclidian approach. Its value is increased in this study by its application in conjunction with statistical methods, which add the confirmatory power. Similarly, numerical taxonomy has an epistemic potential for discovery, and found applications in other fields. Green infrastructures have an irregular shape, and are complex, non-linear systems, interrupted and fragmented regardless of the scale of study. Due to these characteristics, they cannot be described by the means of classical Euclidian geometry at local, regional and global levels. The fractal methods help overcoming this inner methodological limitation. The two main fractal parameters used in this study reflect these advantages: fractal dimension measures the irregularity, and lacunarity measures the fragmentation.

There are several important limitations of the study. First of all, the data set contained 14 Romanian cities with a population over 100,000 in 2006 included in the Urban Atlas. Although the choice of cities included in the Urban Atlas by the European Environment Agency is based only on their population size and participation in the Urban Audit 7374, there are other Romanian cities with a population over 100,000 which are not part of the Urban Atlas: Botoşani (114,953), Piteşti (166,954), Braşov (276,914), Buzău (131,377), Constanţa (301,221), Iaşi (309,631), Baia Mare (138,182), Drobeta Turnu-Severin (105,739), Ploieşti (227,194), Satu Mare (111,877), Suceava (117,317) and Râmnicu Vâlcea (110,731) 67. The inclusion of these 13 cities in the analysis would have certainly strengthened the results, as they have several common characteristics with the others already analyzed. More concretely, the inclusion would confer more power to statistical analyses and additional relevance to the taxonomical analyses. It is very likely that an analysis including all the large city would better differentiate groups including densely populated cities (Bucharest, Iași, Constanța, Brașov, Timişoara), ports (Galaţi, Brăila, Constanța), or Transylvanian cities with well-preserved historical structure (Cluj-Napoca, Arad, Oradea, Timişoara). In order to overcome this issue, if data on the missing cities does not become available, future studies should consider enlarging the data set by looking at cities from other countries.

On the same line, a special discussion is needed on the spatial and temporal resolution. The European Union developed two data sets, CORINE data covers the entire territory at a lower resolution than the Urban Atlas and is updated at large intervals, while the Urban Atlas has a better resolution, but covers a unique moment 75. Urban Atlas data would be very useful for assessing land cover and use changes at the urban change if it is updated at an appropriate temporal scale (yearly). For this reason, the present study can be carried only in reference to the 2006 situation.

The inability of ANACOVA to provide additional evidence for the correlations between the fractal parameters, socio-demographic and physical parameters of the cities, and parameters of the green infrastructure is a limitation of the method itself, meaning that relationship between the dependent variable and each independent one cannot be analyzed separately in the analysis of covariance, but only given the presence of the others 76, therefore the individual relationship is masked by other variables. Again, the enlargement of the data set can result into significant results of ANACOVA.

Another issue is the fact that this analysis is diachronic. Available data cover different periods – 2005-2007 for the Urban Atlas Data, 2009 population data (corresponding to the closest census year). Other differences relate to the historical evolution of the cities that were analyzed, with important consequences on planning. For example, although Brăila and Galaţi are Danube ports, situated very close to each other, and with a long tradition of competition, the planning was different. Brăila has a typical plan imposed by its position to the river in a radial way, as a circle sector centered in the Danube 77; the shape was not altered in the communist period, as the only industry of the city was represented by match manufacturing; at the opposite pole, Galaţi was heavily industrialized, focusing on steel processing and chemical industry; consequently, the city was reshaped 78. Future studies can overcome this issue by adding additional variables, with the caveat that the presence of useless ones can actually decrease the significance of statistical tests.

4. Conclusion

Despite the methodological limitations and reduced sample size, if the two classifications are compared, an important conclusion can be drawn. Regardless of the historical evolution (and its consequence on planning), the green infrastructure appears to observe the natural (ecological) laws governing the presence and types of nature found within the man-dominated ecological systems. Moreover, the article showed clear evidence to the relationship between socio-economic and demographic drivers and their pressure on the green infrastructure through fragmentation. From a methodological perspective, the study indicated that fractal analysis, in conjunction with statistics and numerical taxonomy, are useful for assessing changes determined by the anthropogenic factors. Furthermore, the analysis revealed the utility of Urban Atlas data, despite their limitations.

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