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CHANGES IN LANDSCAPE STRUCTURE INDUCED BY TRANSPORTATION PROJECTS IN CLUJ-NAPOCA PERIURBAN AREA USING GIS

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Abstract: The infrastructure development projects planned and partly implemented around some major Romanian cities have significantly changed the characteristics of the natural landscape. Based on the landscape metrics, we analyzed the state of landscape fragmentation in the urban and periurban area of the municipality of Cluj-Napoca before and after the implementation of the projected road network. In this respect, we used a combination of ArcGIS functions and interpolation methods (Calculate Geometry function, Topogrid and IDW interpolations), as well as Patch Analyst extension. The statistical analysis was applied to a territory of almost 60000 ha and the total length of proposed transportation projects is 96 km. The results showed higher values for Number of Patches, Total Edge, Edge Density after the transportation projects implementation, while Mean Patch Size values decreased. In order to gain expressivity, three sites with high concentration of proposed roads were selected to be analyzed comparatively, significant changes being identified in land-use structure within the categories arable lands (Number of Patches increasing with 13 up to 54 and Mean Patch Size decreasing with 4.21 up to 4.94 ha) and roads (Number of Patches increasing with 1 up to 3 and Mean Patch Size decreasing with 1.86 up to 6.60 ha). In the eastern part of the region, due to multiple crossings of the Someşul Mic River, important differences were pointed out within the flowing water category (Number of Patches increasing from 4 to 18 and Edge Density from 28.26 to 31.86, while Mean Patch Size decreased from 6.72 to 1.49 ha). The applied methodology could constitute an effective tool to be used in the Strategic Environmental Assessment of transportation projects to complete those commonly applied that approach mainly subjective aspects as landscape aesthetics.

Keywords: mobility management, landscape assessment, landscape metrics, topogrid interpolation, idw interpolation, landscape categories

1. INTRODUCTION

The development of metropolitan areas imposes significant demands for transportation infrastructure to support social and economic activities and to enhance territorial connections between the component localities. This is a premise to the fulfillment of a fundamental objective that all metropolitan areas should follow – the development of an *integrated mobility management*. Mobility management is a concept to promote sustainable transportation and manage the demand for car use by changing travellers' attitude and behavior through good communication and information, organizing services and coordinating activities (soft measures) with the purpose to enhance the effectiveness of the hard measures (construction of new transportation infrastructure). It is largely accepted that transportation provides economic growth, welfare, accessibility or social cohesion, but at the same time, it also induces negative effects related particularly to energy consumption and degradation of the urban environment through lowered air quality, increased temperatures, increased noise and landscape fragmentation. The present article analyzes some quantitative changes in landscape structure induced by the projection and construction of periurban roads, as part of a larger strategy meant to increase connectivity and improve mobility in Cluj-Napoca Metropolitan Area. With the purpose to express landscape quantitative changes, we approached some indicators widely used in the field of landscape assessment, such as *the statistical indicators in landscape metrics* (McGarigal & Marks, 1995, Elkie et al., 1999, Herzog et al., 2001). At international level, landscape metrics indices, respectively the relation between road network and land cover dynamics, has been widely explored. The link between road network development, its connectivity and the induced change in land cover was analyzed in Lop Buri Province, Thailand, through correlation analysis and Wilcoxon matched pair test (Patarasuk, 2013). Roadless Volume Index (RV) was used to calculate road's network disturbance effect on landscape pattern (Fu et al., 2010). Landscape indices as the probability of connectivity (PC) and the equivalent connected area (ECA) were employed to assess landscape connectivity trends in the European forests through network analysis (Saura et al., 2011). Complex landscape indices, as the aggregation indices, have been analyzed in relation to built up areas, soil erosion change or simply to quantify fragmentation for planning purposes (Szabo et al., 2012). Some methods to describe and quantify landscape metrics were discussed by Turner et al. in 2001. They explored from the ecological point of view some of the commonly used metrics within three broad categories: metrics of landscape composition; measures of spatial configuration, including contagion and patch-based metrics; fractals (Turner et al., 2001). In Romania, landscape metrics analyses were undertaken with reference to particular territorial units, such as the Transylvanian Plain (Schreiber et al., 2003), the Buzău Subcarpathians (Niculae & Pătroescu, 2011) or Prahova Valley (Pătru-Stupariu et al., 2009), but in all cases the analysis revealed landscape structure at a given moment and did not relate it to urbanization or road construction.

The study area is located in the north-western region of Romania, in the historical province of Transylvania, being developed along the corridor of Someșul Mic River that separates the Feleacu Hills in the south and the Someş Plateau in the north. In this territory, the extension of the built-up area, including the transportation infrastructure, is restricted by morphology and the friable deposits of clay, shale and sand. During the last decade, road infrastructure projects totalizing a length of 96 km were initiated by central administration units (Romanian National Company of Motorways and National Roads - RNCMNR) in Cluj-Napoca area, a few of them being now under various construction stages. The main purpose of these projects was to provide the city with road rings that contribute to urban traffic decongestion or to facilitate an efficient east-west crossing of the town taking into account that the corridor morphology of the city determines increased traffic flows along that direction. The increased number of proposed road projects is also explained by the need to connect the most important roads in North-western Romania (Transylvania highway, E60, E81 and E576), providing the city of Cluj-Napoca with accessibility towards them. The land cover categories that are intersected the most by proposed road ways are arable lands, forests and orchards.

Thus, by approaching landscape assessment in road construction, the paper will provide with scientific basis for appropriate landscape assessments associated to further expansion of the Romanian urban areas, respectively for landscape-driven projects that take into consideration sensitive locations, local landscape pattern, constraints and opportunities.

2. MATERIALS AND METHODS

Landscapes are characterized by three main elements: *structure* (the spatial configuration of landscape elements), *ecological function* (how ecological processes operate within that structure) and *dynamics* (evolution in time). Understanding and predicting landscape changes is a rather challenging attempt. Disturbance usually produces patches (distinct areas with environmental conditions that are different from surrounding areas). Landscape fragmentation is the result of the interaction of past disturbance and the heterogeneity of the abiotic environment, while monitoring change at the patch-based level of spatial pattern is an important way to assess landscape change (Gergel & Turner, 2002).

In order to express the relationship between transportation network and landscape fragmentation, a spatial analysis method applied to landscape units was applied. On the other hand, for pointing out the impact of network transportation on landscape structure, some statistical indicators in landscape metrics were used applied through Patch Analyst ArcGIS Extension.

The input database consisted of orthophotoplans, edition 2004-2005. On these orthophotoplans, homogeneous territorial units were identified and digitized (Fig. 1). We considered this is the most accurate way to express landscape structure, taking into account that the analyzed territory is an urbanized area in which landscape is affected by consistent human interventions and, on the other hand, the orthophotoplans resolution (and the field survey) allowed us a precise delineation of borders and of the transition areas (e.g. orchard-arable land, pasture-forest).

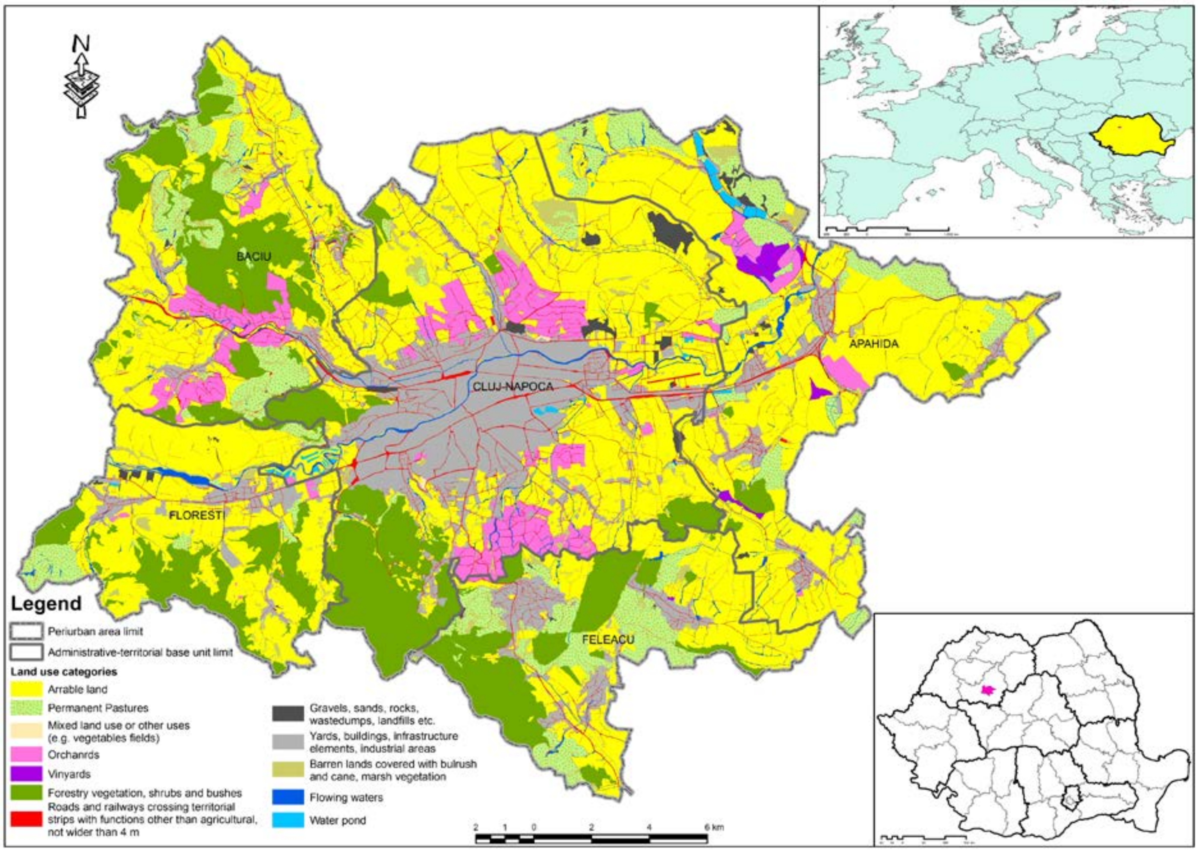

Figure 1. Land use types in Cluj-Napoca periurban area (digitized on 2004-2005 aerial images).

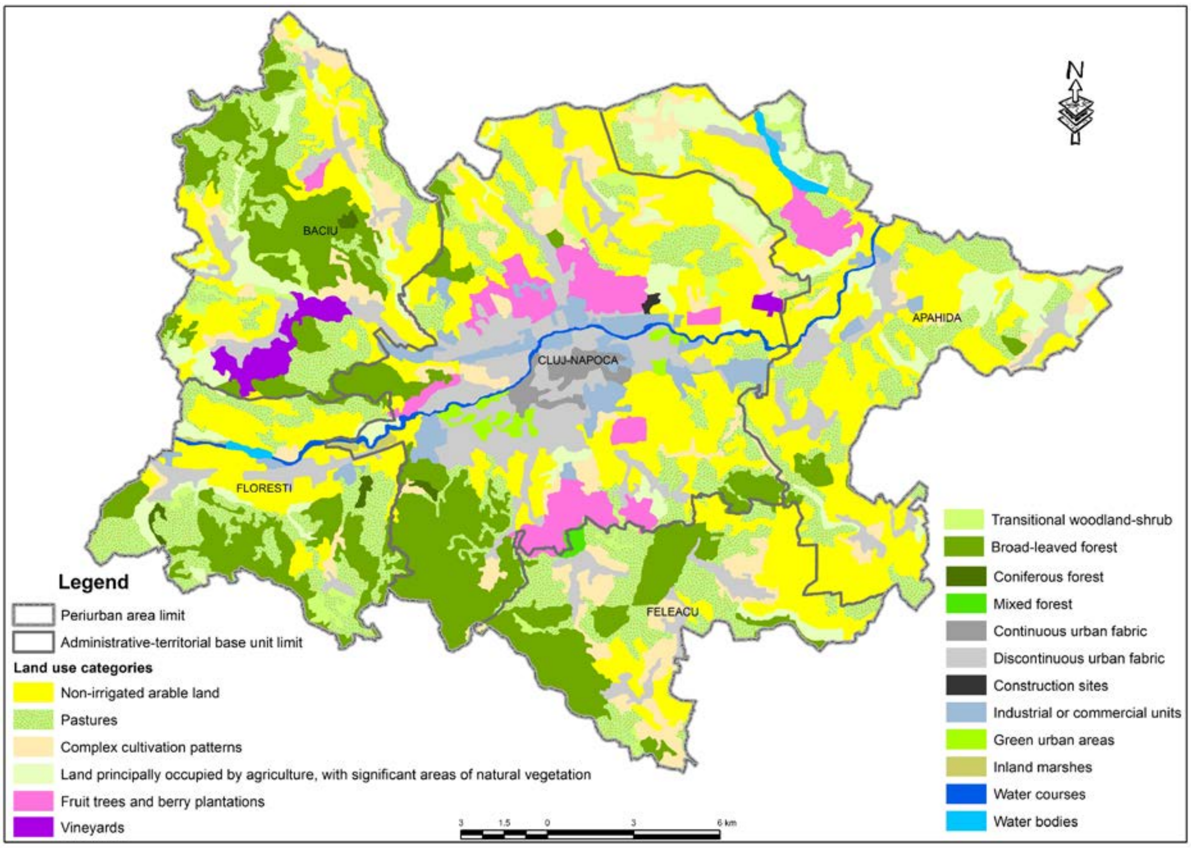

Figure 2. Land use types in Cluj-Napoca periurban area (after Corine Land Cover 2000).

Additionally, an update of the field structure was achieved through field surveys, in order to compensate the lack of newer orthophotoplans. The vector polygons we obtained follow in general the limits of the parcels set by the Romanian Agency for Payments and Intervention in Agriculture (APIA in Romanian), defined as territorial units used for agricultural purposes by one or more farmers, delineated by natural or artificial linear borders and including one or more agricultural parcels (APIA, 2006).

Searching for the most appropriate way to express the landscape structure, the identification of landscape units through the combination between morphological features – DEM derived from 1:50000 topographic maps - and land use cover provided by Corine Land Cover 2000 (CLC 2000) (Schreiber et al., 2003) was also approached in the study. As the method relates the variety of landcover types to morphology, the output expresses better the territorial reality. In spite of this potential advantage, in our study, as well as in all urbanized areas, with high density of land patches, this method proved to offer a rather poor particularization of the land use cover, as long as in CLC 2000 land units were identified on satellite images with lower resolution than orthophotoplans, parcels under 1 hectar being ignored (Fig. 2).

Aiming to surpass this technical gap, the territorial units derived from orthophotoplans could replace in the combination the CLC 2000 land units. But for our study area, the good resolution of the orthophotoplans allowed us to identify very small landscape patches, homogeneous from the morphological point of view, thus we considered that such a combination could bring any significant increase in the number of patches, so we decided to use as input data only the patches identified on the orthophotoplans.

Table 1. Proposed ringroads projects in Cluj-Napoca area (RNCMNR)

Stage	RNCMNR project name	Length
Projection phase	Cluj Nord - ringroad	33 km
	Cluj South – highway regime	40 km
Execution phase	Cluj East - ringroad	23 km

In order to point out how transportation projects affect landscape, a polyline layer was created, the route being taken from the feasibility studies elaborated for these projects (Table 1). Thus, by intersecting this polyline layer with the homogeneous functional units, the landscape structure after the implementation of these infrastructure projects was calculated.

The territory under analysis was delineated following the territorial-administrative borders of the localities intersected by the route of the proposed roads: the city of Cluj-Napoca and the communes of Apahida, Feleacu, Florești and Baciu (Fig. 3). The identified land-use categories are shown in table 2 and figure 4.

Table 2. Land use categories in the periurban area of Cluj-Napoca

APIA Abbrev.	Type	Surface (ha)
TA	Arable land	23386.07
PP	Permanent Pastures	4369.16
CP	Orchards	2431.45
MX	Mixed land use or other uses (e.g. vegetables fields)	11.34
VI	Vineyards	184.83
PA	Forestry vegetation, shrubs and bushes	8009.50
DR	Roads and railways crossing territorial strips with functions other than agricultural, not wider than 4 m	1391.33
PN	Gravels, sands, rocks, waste dumps, landfills etc.	467.49
CC	Yards, buildings, infrastructure elements, industrial areas	6697.93
HN	Barren lands covered with bulrush and cane, marsh vegetation	1475.02
HR	Flowing waters	795.95
HB	Water pond	170.72

Figure 3. Transportation projects in Cluj-Napoca periurban area (ringroads and connections).

In order to proceed to the spatial analysis of landscape fragmentation, the territory was divided into cells of 1 sqkm, the edge length between the landscape units being calculated for each cell using Calculate Geometry ArcGIS function. The computed values were attributed to the centroids of each cell and were further used in interpolations made through methods as Topo to Raster and Inverse Distance Weighting (Figs. 5 and 6). The output of these procedures is represented by grid maps that point out landscape fragmentation in km/sqkm.

Then, for the statistical analysis of landscape structure, we employed Patch Analyst (PA), an ArcGIS extension that facilitates the spatial analysis of landscape patches and the modeling of attributes associated with patches.

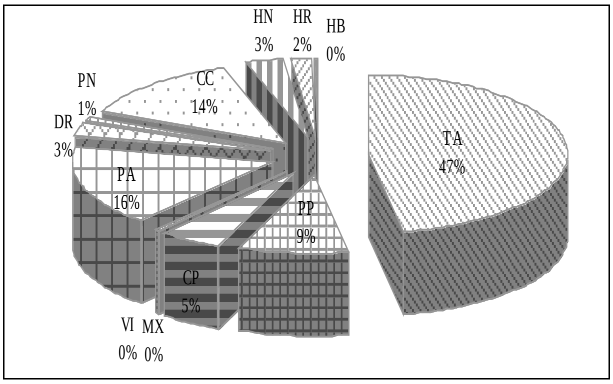

Figure 4. Shares of land use categories

The program includes capabilities to characterize patch pattern and the ability to assign patch values based on combination of patch attributes. Among the 15 indicators that PA generates, we selected 5, namely Number of Patches, Mean Patch Size, Total Edge, Edge Density and Mean Shape Index, that we considered to be relevant for the analysis as they mirror the most serious transformations induced by transportation projects in landscape structure and, at the same time, provides with an expressive and easy access to the variety of changes (Table 3).

NumP (Number of Patches) measures the total number of patches of a specified land use or land cover class. When NumP is too high, it indicates that the patch class is highly fragmented. The **total number of patches** in a landscape results from first defining connected areas of each cover type *i* (Gergel & Turner, 2002).

Patch density and size metrics (Mean Patch Size). Mean Patch Size (MPS) is an indicator representing the average size of patches of a particular class level or of the whole landscape. According to McGarigal & Marks (1995), patch area is one of the most important and useful information that can be obtained in a landscape analysis.

Mean patch size is often used when assessing landscape undergoing transformation induced by urban or transportation sprawl. MPS at the class level equals sum of the area of the patches across all patches of the corresponding type divided by the total number of patches of the same type, being calculated through the following formula (Leitao et al., 2006):

$$\text{MPS} = \frac{\sum_{j=1}^{n} a_{ij}}{n_i} \qquad (1)$$

a_{ij} = area of the patch (m^2) and n_i = number of patches in the landscape of patch type.

Edge Metrics (Total edge, Edge Density). Edge calculations provide a useful measure of how dissected a spatial pattern is and can be calculated in a variety of ways. An edge is shared by two grid cells of different cover types when a side of one cell is adjacent to a side of the other cell. The total number of edges in a landscape can be calculated by counting the edges between different cover types for the entire landscape, every edge being counted only once (Gergel & Turner, 2002).

Table 3. Landscape metrics indicators for the study area

Class	MSI	MSI	TE	TE	ED	ED	MPS	MPS	NumP	NumP
CC	1.50	1.60	1818122.8	1822859.8	30.7	30.8	2.84	2.79	2515.00	2564.00
TA	1.90	2.80	3836345.8	3974440.3	64.8	67.1	12.1	10.1	2321.00	2786.00
MX	1.74	1.74	2934.08	2934.08	0.05	0.05	5.67	5.67	2.00	2.00
DR	5.08	5.08	3086270.0	3101148.9	52.1	52.4	0.66	0.60	2352.00	2595.00
VI	1.53	1.65	25813.45	27203.92	0.44	0.46	12.3	10.2	15.00	18.00
HN	2.32	2.93	954886.22	962230.34	16.1	16.2	1.17	1.09	1502.00	1611.00
HR	3.70	4.49	1007998.3	1013540.3	17.0	17.1	1.18	1.03	813.00	932.00
PP	3.77	3.69	789562.41	800889.10	13.3	13.5	18.1	16.7	376.00	408.00
CP	1.76	9.54	383262.55	404665.07	6.48	6.84	9.20	5.15	270.00	482.00
PA	14.21	17.3	613224.15	645329.41	10.3	10.9	76.3	23.1	122.00	402.00
PN	1.72	1.73	100812.69	103176.81	1.70	1.74	4.22	3.75	111.00	125.00
HB	1.64	1.61	42125.35	42349.73	0.71	0.72	4.05	3.73	47.00	51.00

white – before transportation projects; light grey – after transportation projects

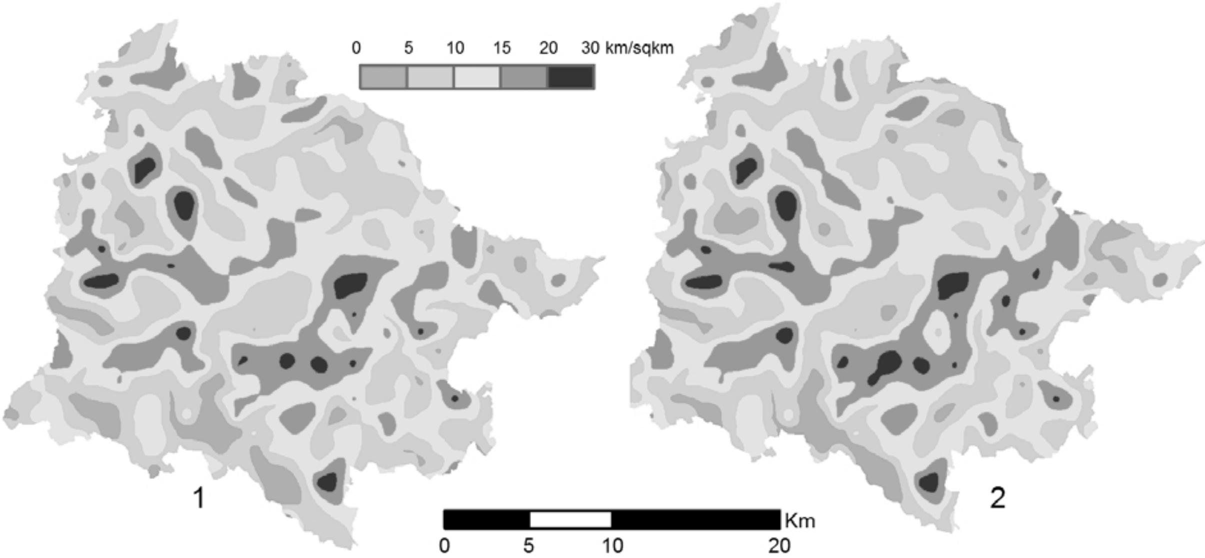

Figure 5. Landscape fragmentation density before (left) and after (right) transportation projects implementation

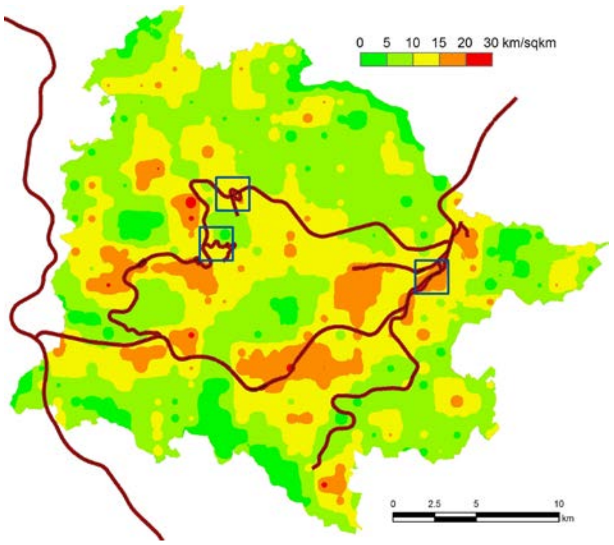

Figure 6. Landscape fragmentation density (IDW interpolation) after transportation projects implementation and site selection.

Edge density (in m/ha) equals the length (in m) of all borders between different patch types (classes) in a reference area divided by the total area of the reference unit. The index is calculated as:

$$ED = \frac{E}{A} \qquad (3)$$

E = total edge (m)
A = total landscape area (ha)

Mean shape index (MSI) is given by the sum of the patch perimeter divided by the square root of patch area for each patch in landscape, adjusted by a constant for a square standard divided by the number of patches (Howard, 2005). In other words, MSI equals the average shape index of patches in the landscape. Mathematically, it is given by the following formula (Howard, 2005):

$$MSI = \frac{\sum_{i=l}^{m}\sum_{j=l}^{n}\left(\frac{0.25 p_{ij}}{\sqrt{a_{ij}}}\right)}{NP} \qquad (2)$$

where p_{ij} *is the perimeter of patch ij in meters,* a_{ij} *is the area of patch ij, i = 1...,m is the number of patch types, j = 1...,n is the number of patches and NP is the total number of patches in the landscape.*

MSI has values greater or equal to 1, value 1 being met when all patches in the landscape are square and increases gradually when shapes become more irregular.

3. RESULTS AND DISCUSSIONS

The analysis of the maps indicating the density of landscape fragmentation before and after the implementation of the suburban transportation projects (Fig. 5) emphasizes that they overlaps territories with already high values of landscape fragmentation (with orange, in Fig. 6). Changes are seen as a general extension of the high fragmented surfaces. This result is shown in figure 5 as a conjunction of high fragmented areas (dark grey) and, on the contrary, an isolation of the less fragmented ones (light grey).

Taking into account that the statistical analysis was applied to a territory of 59161.63 ha and the total length of proposed transportation projects is 96 km, the variation in indicators' values was rather poor, thus, in order to gain expressivity, we selected three relevant sites with high concentration of projected roads. In figure 6, site 1 is delineated by the top-left quadrat, site 2 by the bottom-left quadrat and site 3 with the quadrat in the right. In figure 7, site 1 is in the left, site 2 in the center and site 3 in the right. The

3 sites were analyzed through the same statistical method, the obtained results being thus much more relevant (Tables 4, 5 and 6).

The indicators calculated for the entire territory highlight that the most important changes appeared within the categories CP, PA, TA (orchards, forests, arable lands), the last two categories being in fact the ones with the largest spatial expansion; as regarding the orchards, in spite of their lower extension within the area, they are very much intersected by the projected bypass routes (the southern and northern ring roads). Thus, the Number of Patches indicator increased from 270 to 482, while the Mean Patch Size decreased from 9.20 to 5.15 ha.

As regarding the 3 mentioned sites in figure 7, the major differences were found in the categories TA and DR (arable land and road areas), and for the third site, also in the HR category (flowing waters), due to the multiple crossings of the Someşul Mic River planned in order to assure connection between Cluj South, Cluj East and Cluj North.

Figure 7. The landscape patches (red) in detail and transportation projects (green) fragmentation.

Table 4. Landscape metrics indicators for site 1

Class	MSI	MSI	TE	TE	ED	ED	MPS	MPS	NumP	NumP
CC	1.50	1.50	9253.07	9664.43	23.13	24.16	0.99	0.86	21	24
DR	12.71	11.62	26729.00	26985.55	66.82	67.46	5.57	3.71	2	3
HN	1.92	1.86	6032.71	6055.59	15.08	15.14	0.93	0.85	12	13
HR	3.50	2.63	14023.78	14534.81	35.06	36.34	1.32	0.73	10	18
PA	2.21	2.21	3917.83	3917.83	9.79	9.79	25.01	25.01	1	1
PP	2.40	2.40	3095.53	3095.53	7.74	7.74	13.21	13.21	1	1
TA	1.65	1.63	47092.53	56180.06	117.73	140.45	11.32	7.11	27	43

Table 5. Landscape metrics indicators for site 2

Class	MSI	MSI	TE	TE	ED	ED	MPS	MPS	NumP	NumP
CC	1.38	1.37	4432.00	4529.31	11.08	11.32	1.38	1.25	10	11
DR	19.43	10.24	20430.61	21660.45	51.08	54.15	8.80	2.20	1	4
HN	2.00	1.91	3944.74	4376.35	9.86	10.94	0.32	0.20	10	16
HR	2.05	2.05	935.71	935.71	2.34	2.34	0.46	0.46	2	2
PA	2.11	1.84	7667.33	11273.73	19.17	28.18	52.56	21.02	2	5
TA	1.49	1.62	35759.01	40205.67	89.40	100.51	12.19	7.66	22	35

Table 6. Landscape metrics indicators for site 3

Class	MSI	MSI	TE	TE	ED	ED	MPS	MPS	NumP	NumP
CC	1.85	1.84	28676.39	29200.97	71.69	73.00	2.39	2.06	37	43
DR	14.46	10.51	38294.13	38871.79	95.74	97.18	12.21	6.11	2	4
HB	1.31	1.26	1691.23	1795.05	4.23	4.49	1.49	1.12	3	4
HN	1.87	1.62	2604.53	3186.47	6.51	7.97	0.87	0.44	5	10
HR	3.80	2.35	11303.37	12742.34	28.26	31.86	6.72	1.49	4	18
PA	1.59	1.59	267.68	267.68	0.67	0.67	0.23	0.23	1	1
PN	1.52	1.72	4599.09	6397.44	11.50	15.99	2.23	1.03	6	13
PP	1.49	1.49	1435.63	1435.63	3.59	3.59	7.39	7.39	1	1
TA	1.58	1.49	40492.90	49717.07	101.23	124.29	7.68	2.74	30	84

white – before transportation projects; light grey – after transportation projects

The Edge Metrics indicators express more accurately the impacts of transportation projects on small areas (for each site), while the Patch Density and Size Metrics indicators highlight similar differences in the analysis of both the entire territory and the selected sites.

The composite indicator Mean Shape Index represents the ratio between the perimeter and the surface of patches and it does not highlight major changes for the majority of land classes at the level of the whole surveyed territory. This is determined by the fact that landscape fragmentation generated by transportation projects sets, most of times, limits without significant inflections. An exception was pointed out in the case of CP and PA categories, which form rather compact surfaces and are intersected to a high extent by the projected roads, many new irregular limits being thus generated. In these cases, Mean Shape Index has significantly increased, from 1.76 to 9.54 within CP category and from 14.21 to 17.37 within PA. There are also some increases in this indicator in road interchange areas, where the shape of the new limits is more inflected.

The results obtained through the methods used in the paper are fundamentally related to the accuracy of the input data: resolution and date of flight in the case of orthophotoplans, proper interpretation in the case of CLC database. In order to improve the results, we compensated the rather old orthophotoplans (2004-2005) with field surveys, taking into account the rather small territory under study.

We consider that these methods could be applied with success in the monitoring of the some development plans implementation, as well as in the analysis of alternatives within the Strategic Environmental Assessment procedure for plans and programs.

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