Applying Ecological Landscape Concepts and Metrics in Urban Landscape Management

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Abstract
Recent studies in landscape ecology, related to metrics of shapes in vegetation patches, have become very useful for identifying areas with preservation potential as well as for characterizing the quality of vegetation fragments. However, this analysis logic is rarely used in urban landscape management. Landscape Ecology aims at analyzing vegetation fragments' structure, changes and functions that characterize the studied environment. To perform these analyzes land cover is spatially decoded as matrix (which prevails in the landscape), patches (fragments dispersed in the matrix, the smaller, individual elements observable in the landscape) and corridors (axes that promote the flow of species and, consequently, biodiversity maintenance). The use of this logic in urban planning allows vegetation fragments' hierarchical classification in order to identify the most important in the promotion of urban ecological corridors. This ranking is the basis for zoning definition in master plans, establishing occupation and protection levels in city zones. To prove the potential of this approach in landscape metrics, the city of São Gonçalo do Rio Abaixo was chosen as a case study because it is undergoing profound transformations stimulated by the development of iron mining exploration in the Quadrilátero Ferrífero (QF) Region (*Iron Quadrangle*) in the State of Minas Gerais, Brazil. The methodological process employed was divided into three stages: 1 - satellite image classification (RapidEye, year 2013) for land use and land cover mapping; 2 - application of landscape metrics in land cover mapping in vector format (area, perimeter, distance to nearest neighbor, core area and e shape index); 3 - integration of metrics using multicriteria analysis (MCA) in order to classify vegetation fragments by their level of environmental importance. The classification of each fragment is presented as the results, indicating those that must be defined as full-preservation, those that must be considered for sustainable use, and fragments that should be the target of restoration strategies such as plant recovery since they have a strategic role and position in the system. Fragments with a larger core area, with rounded morphology, and near to other fragments so as to form an interconnected network were selected as the most important in the system, but others were identified as important components in the system. Fragment characterization and ranking allowed identification of their vocations in relation to their use: urban activities (parks and recreation); landscape protection (bio-climatic quality and scenic beauty); and environmental protection, because of biodiversity maintenance interests. Selected areas can compromise public and urban regulatory policy proposals that promote vegetation cover maintenance and connection, considering not only those officially sanctioned areas of vegetation cover (parks, protected areas and conservation units), but also propose special rules and policies to include private properties in the studies, in order to stimulate the protection of backyards with forest fragments, because vegetation cover must be understood as a systemic network.
Keywords: Landscape Ecology; Landscape Metrics; Spatial Analysis; Urban landscape.

1. INTRODUCTION AND MOTIVATION

Urban landscapes have always been a way of reflecting collective values in the manner of cohabiting in a territory and produce identity and links to the “space”, which is ranked in the sense of “place” [1]. Due to the breakneck speed of urban occupation, it is necessary to evaluate the pace of transformation and the lack of expression in the city's construction, most especially in the reduction of values associated to the presence of vegetation cover. It's important in a society that has in the urban space its main form of habitation, leaving non-urban territories only as places of production.

In Brazil, we observe a significant loss in the role of vegetation cover in cities, considering cultural and environmental values. There is an environmental loss reflected in temperature, humidity and biodiversity changes in urban areas. However, it is necessary to understand that there is also a loss in cultural values, related to changes in places' essence, to cities' “genius loci”, according to Schulz's definition [2] and, more specifically, to cities in Minas Gerais's territory, where the cities' landscape was always characterized by the balanced juxtaposing of vegetation cover and anthropic occupation.

Green spaces can have different functions in the urban space. They carry out aesthetic quality maintenance and soften feelings of oppression regarding high buildings. They create socialization and leisure possibilities for the population. They can also be important to maintain biodiversity protection, protection against geotechnical problems, aquifer recharge areas and protection of water sources, even without been directly accessed by the population. There are also those areas that carry out environmental balance functions related to climate, humidity, air quality and acoustical management [3,4].

According to Falcón [5], concepts related to green space planning were officially incorporated into urban planning since UNESCO's “Man and Biosphere” conference (MAB), realized in Barcelona in 1988. Basic principles for “urban green” planning in sustainable cities were defined at this congress.

Magalhães [6] defends that the characterization of vegetation cover fragments, according to form, quality and position relative to other fragments, is an important step to adequately plan the role of urban vegetation cover. Each vegetation fragment must be studied according to it's value to functional and aesthetic qualities to the environment. From this characterization, the uses can be defined, such as biodiversity protection, leisure and socialization areas, aesthetic effects, environmental quality (noise, temperature, air quality, humidity) and safety (protection from geotechnical risk areas and for water resources).

The use of geotechnologies can favor the recognition of vegetation cover distribution, of vegetation's quality and morphological characteristics, and the measurements of shape, dimensions and distance among vegetation cover areas. Geotechnologies are composed by data gathering, information treatment, and spatial analysis production. It is a collection of methods and techniques that promote a significant progress in the Earth's representation and analysis [7]. In the vegetation cover's case study the techniques applied area satellite image classification processes, geographic information systems (GIS) presenting fragments' representation and alphanumerical tables of attributes with the main characteristics of the elements, and application of spatial analysis models.

The collection of geotechnologies compromises a complex potential for the use of software, methods and models. Facing the myriad possibilities presented to a researcher, the key is to make an adequate methodological choice in light of the objectives to be reached. Planning the processes to be used is fundamental due to the labyrinth of possibilities the researcher faces. It is important to make the steps clear to the agents involved, give different users a clear view and, in this way, gain their interest in participating.

1.1 Geodesign and Landscape Ecology Concepts in Urban Landscape Planning

Geodesign aims to promote a contextualized landscape's occupation, respecting natural and cultural conditions. In brief, it is to project “with” the territory and “for” the territory [8]. As a concept, Geodesign's objective is the sustainable integration of anthropic activities into the natural environment, respecting cultural peculiarities and making a democratic decision-making process possible. [8,9,10,11]. In practice, it is a systematic methodological planning to the territory, based on GIS tools, choosing specific tools, which are being developed by researchers in the field, presenting steps in a proposed framework.

In 1938, geographer Carl Troll introduced the Landscape Ecology concept into scientific terminology in the article called *Landschaftökologie*. The term came from his studies on the interpretation of aerial photographs in geographic space research [13]. According to Troll [13], only an aerial image is capable of transmitting place's different conditions. It promotes visualization of the association among plants, geomorphological units, waterways, localization of urban centers and other land cover, and through it's possible to infer some relationships among landscape factors, which should be complemented by land recognizance. Landscape Ecology is a subject that has been generating greater knowledge for more effective environmental and urban planning actions, since its main focus is the study of the interrelations among the biotic and abiotic aspects in heterogeneous landscapes, while observing anthropic interference.

The concepts instituted by Forman and Godron [14] in Landscape Ecology's scope understands the landscape presenting a structure formed by three elements: Matrix, Patch and Corridor. The study of the spatial relationship between these elements constitutes a central research theme in Landscape Ecology.

Lang and Blaschke [15] presented a collection of methods called “landscape structure measures”, developed for a landscape's structure's analytical evaluation, which guide their methodological procedures towards the prospective scientific tendency and a large quantitative orientation. According to Metzger [16], land use and land cover maps represent a data source for quantifying landscape structure using landscape metrics and, in this way, making possible ecological research by spatial patterns.

In this context, this study has as its objective the application of landscape metrics to characterize and evaluate urban and periurban forest fragments, identifing their vocation related to the diverse types of use: social activities (parks and recreation), landscape protection (bio-climatic quality and scenic beauty), environmental protection (biodiversity maintenance) and safety (geotechnical risk control and water source protection).

2 MATERIALS AND METHODS

2.1 Study Area

The São Gonçalo do Rio Abaixo municipality is located in the Quadrilátero Ferrífero *(Iron Quadrangle)* mineral province, in the central region in Minas Gerais state, southeastern Brazil, that has great mineral commodity reserves, most especially of iron ore and gold, that are very important to Brazilian economy. The São Gonçalo do Rio Abaixo territory (Figure 2) had as its occupation vector guided by the use of fertile lands for agriculture as well as the search for gold, both along Santa Bárbara river's, in the XVIII century [17, 18]. Starting from the first half of the XX century, when industrial iron ore production was effectively developed, and until today, the mineral exploration constitutes the municipality's most important economic activity.

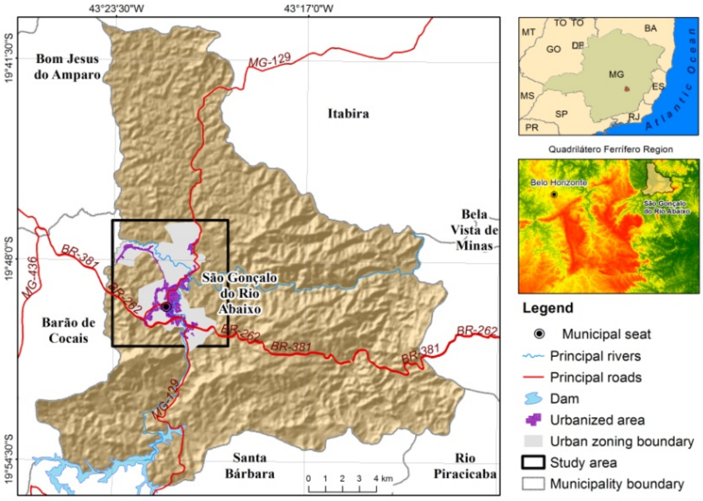


Figure 2 – Localization of the São Gonçalo do Rio Abaixo municipality - MG

2.2 Methods

Analysis presented in this topic were structured according to the Geodesign framework as proposed by Steinitz [7].

2.2.1 Representation Model – Automatic Classification of Images and Cartographic Maps

Orthorectified images with a spatial resolution of 5 meters taken by the RapidEye sensor were acquired from the São Gonçalo do Rio Abaixo municipality's Environmental Secretariat in 2013. Digital processing was carried out in the SPRING 5.2.1 software, beginning with a radiometric correction among the three scenes used. Later, a mosaic of the scenes was constructed, applying a contrast enhancement. After the scenes' pre-processing and the construction of the image mosaic, it was promoted the visual interpretation in order to compose the interpretation key, based on which the automatic classification was developed.

It was used the Maximum Likelihood (MAXVER) supervised classification algorithm, based on pixel by pixel analyzes. This algorithm uses each pixel's spectral information to identify homogenous regions, considering the influence of distances among classes' average, using statistical parameters. The minimum defined value to accept collected pixels samples' general performance in the classification process was 95%. After this first classification it was executed a post-classification, a process in which some "noises" in the images are eliminated. In other words, mistakenly classified areas were corrected using matrix editing, available in the SPRING 5.2.1 software. The matrix classified in raster format was exported to vector format (shapefile).

The cartographic map in shapefile format of the municipal urban zoning was used. It contains information on urban parameters in occupancy rates, permeability rates and use coefficients. It was also used a shapefile of points with the localization of new approved projects to be finished until the year 2020.

2.2.2 Process Model - Calculating Landscape Metrics

ArcGIS 10.2's free V-LATE (Vector-based Landscape Analysis Tools Extension) extension was used to calculate metrics. In order to do so, the raster format classified image was converted to a vector format (shapefile) representing polygons of dense vegetation cover. Landscape ecology indexes applied were: area, perimeter, core area, shape index and distance to nearest neighbor.

The metric "core area" represents the respective internal area in the fragment, that I less affected by external factors (edge effects). In this internal area it's observed vegetation conditions of stability, mainly for species sensitive to the disturbing effects of the edges, which is valid for biotic and abiotic processes, most especially due to each fragment's lateral and functional relationships [15]. In the study the core area metric was set using a 100 hundred meter buffering zone from the edge inwards.

The metric of "form index" was proposed by Forman and Gordon [13] to analyze the vegetation fragment's shape complexity in relation to a standard feature, which is circular. According to the formula, in which ***p*** is the fragment's perimeter and ***a*** is its area, the more the patch deviates from a round morphology, the greater is this non-dimensional index's value:

$$SI = \frac{p}{2\sqrt{\pi . a}} \tag{1}$$

For a quantitative analysis on remaining forest in relation to urban zones, it was used the normalized remaining vegetation index (NRVI) proposed by Bonnet et. al. [19].

$$NRVI = \frac{rv - aa}{rv + aa} \tag{2}$$

in which ***rv*** corresponds to natural remaining vegetation by urban zone and ***aa*** represents anthropic areas by urban zone that correspond to the land's anthropic uses.

2.2.3 Evaluation

The multicriteria analysis procedure is widely used to create a synthesis or variable integration based on criteria or variables weighing. In this work, MCA is based on the weighted average supported by knowledge-driven evaluation. In this case, weight is given by experts on phenomenons in the study area as well as analyzed variables [6, 20, 21].

Using multicriteria analysis, it was promoted a combination of core area, shape index and distance to nearest neighbor metrics. It produced a qualitative analysis of each fragments, composing a multiple correspondence analysis (MCA). It was considered that the fragments with the best quality and harmonic relationship with urban areas are those that have the largest core area, a shape index that indicates a stabler morphology in relation to the study area's characteristics, and smallest distance to the nearest vegetation fragment. To promote the analysis the values in each metric were normalized, and each of these metrics got the same weight, of 33%.

Later, a combinatorial analysis between MCA (multiple correspondence analysis) results and NRVI (normalized remaining vegetation index) results was done by combining MCA (less than 0.6 – low values, more than 0.6 – high values) and NRVI (-1 to 0, low values and 0 to 1, high values), as exemplified in Table 1. As a result, it was possible to identify highly significant environmental urban areas, which are areas with high quality and high quantity of vegetation fragments.

Table 1. Combinatorial Analysis between vegetation quality (MCA) and quantity (NRVI) by urban zone.

	NRVI (Quantity)	Low Values	High Values
MCA (Quality)	Combinatorial Values	0 (-1 to 0)	1 (0 to 1)
Low Values	0 (< 0.6)	**0**	**1**
High Values	2(>0.6)	**2**	**3**

Legend: 0 – Low quality, low quantity. 1 – Low quality, high quantity. 2 – High quality, low quantity. 3 – High quality, high quantity.

2.2.4 Change, Impacts and Decision

An impact potential analysis was done considering the spatial concentration of new projects approved by the municipal administration, which are being executed and have the year 2020 as their deadline for installation. It was applied the kernel density estimator based on points of new projects registered by the public administration. It was done a combinatorial analysis, presented on Table 2, relating the new projects concentration map with the environmental significance map.

Table 2. Combinatorial analysis between environmental significance and concentration of new projects.

	Concentration of Appoved Projects	Low Values	High Values
Environmental Significance	Combinatorial Values	0	1
Low Values	0	**0 (0)**	**1**
High Values	2	**2** (2 and 3)	**3**

Legend: 0 – Low concentration of projects, low environmental significance. 1 - High concentration of projects, low environmental significance. 2 - Low concentration of projects, high environmental significance. 3 – High concentration of projects, high environmental significance.

3. RESULTS AND DISCUSSION

3.1 Representation and Process

The study area is characterized by the balance between grazing (matrix) and dense vegetation areas as presented in Table 2.

Table 3. Quantification of land use and cover classes

Land Use/Land Cover	**Area (ha)**	**%**
Water body	30.39	0.59
Urbanized area	193.47	3.77
Rupestrian Field (rock fields vegetation)	12.08	0.24
Forest (Dense Vegetation)	2137.74	41.62
Degraded Pasture/Grazing	2317.36	45.12
Reforestationwith Eucalyptus	351.74	6.85
Exposed soil	93.04	1.81
Total	**5135.82**	**100.00**

Landscape metrics were applied to the forest class (dense vegetation) that presents an average distance to the nearest neighbor of 39 meters, indicating a relative connectivity among fragments; an average shape index of 2, indicating fragments with morphologies out of the circular morphological pattern, being more susceptible to edge effects; a 10 thousand m² average core area. The three analyzed metrics were calculated by vegetation fragment as presented in Figure 5.

Urban zones with the smallest quantities of remaining forests (values -1 and -0.9), represented in red and orange, correspond to areas destined for mixed use (residential and commercial) and industrial use, respectively (Figure 6). It is important to highlight that more than 50% of urban zones, which have already been urbanized, present a balance of anthropic areas and areas with remaining forests with NRVI (normalized remaining vegetation index) values near 0, from an index that goes from -1 to +1, but in the case study presented values from -1 to 0.6, what means that the conditions of NRVI are medium-to-high quality.

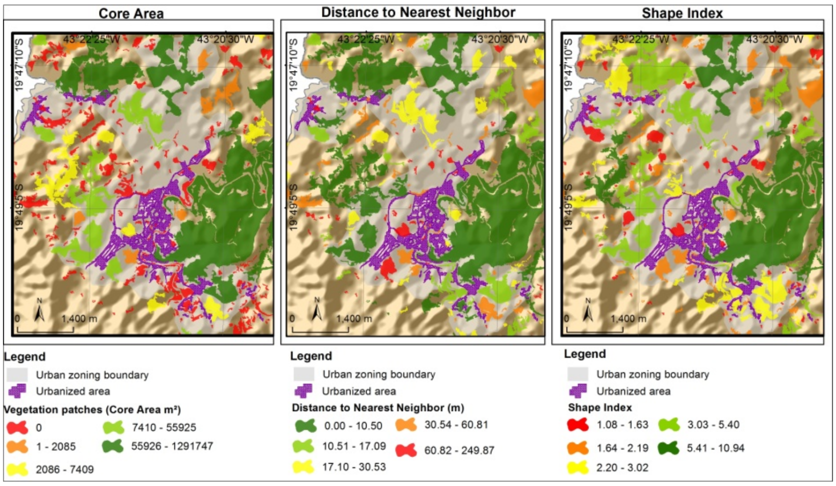


Figure 5. Analyzed landscape metrics.

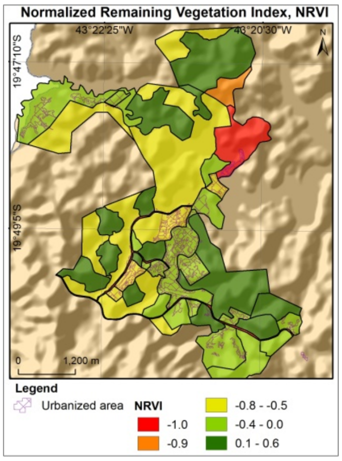
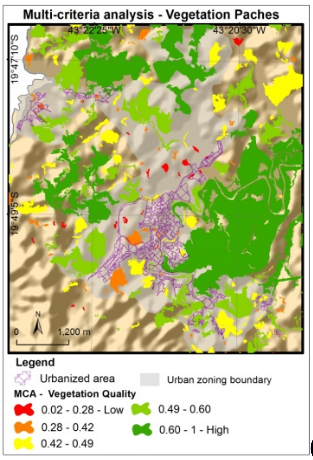


Figure 6. Remaining vegetation index by urban zone

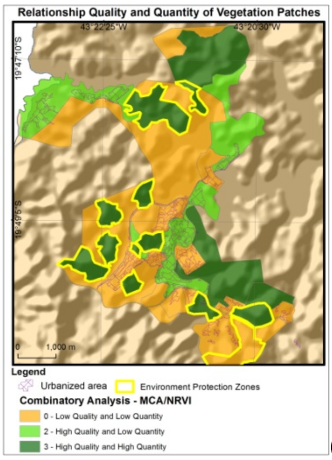
Yellow areas correspond to urban zones that have little remaining forest and are classified by urban zoning as urban interest zones. In other words, they are areas destined for immediate urban expansion. Dark green areas with a larger quantity of remaining forests correspond to urban environmental protection zones and environmental interest areas. The urban zone with the greatest amount of remaining forest (east area of the territory) is an environmental interest area. In it, there is pharmacology research being done as well as studies for the creation of a municipal park. The second largest urban zone with the greatest quantity of remaining forests is a residential area with 1000 m² tracts.

3.2 Evaluation

Fragments classified as low quality correspond to vegetation patches and present a small or nonexistent core area. They are isolated and have low possibility of building corridors with other patches (Figure 7a). However, these fragments are important as they are a natural resistance among denser urban areas. In the urbanized area as well as in the legally urban area (urban zone limits), vegetation fragments are important for bio-climatic quality maintenance due to the 3°C to 4°C drop in temperature in urban zones under vegetation patches [22].



(a)



(b)

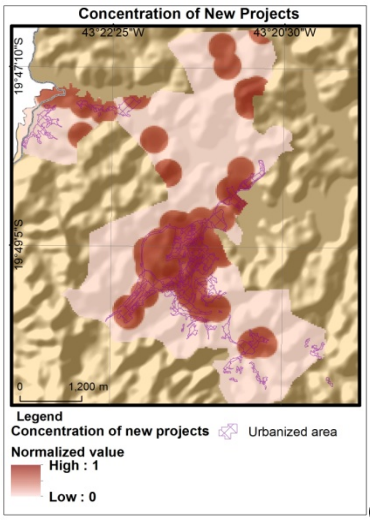
Figure 7. Result of multicriteria analysis by vegetation fragment (a), result of the combinatorial analysis between MCA and NRVI, compared to protected existing areas (b).

Combination between MCA and NRVI resulted in the urban zone's environmental significance map seen in Figure 7b. This relationship showed that urban zoning environmental protection areas (areas with yellow edges) present high quality and high quantity of vegetation with the exception of only one environmental protection area to the south of the municipal urban area. This area should be targeted for forest recovery.

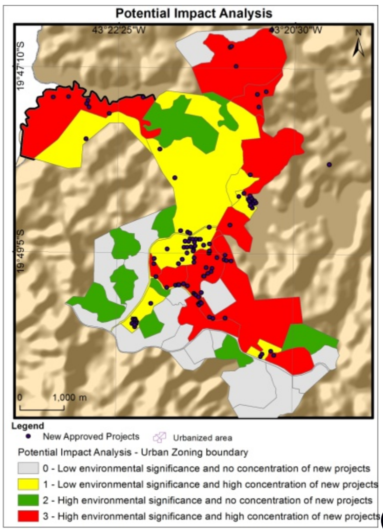
Zones that have high quality and low vegetation quantity and coincide with already urbanized areas should be targeted by specific regulation striving to maintain existing vegetation. The smallest vegetation fragments are in these zones and are therefore more susceptible to anthropic action. However, they are vegetation patches important for maintaining urban bio-climatic quality.

3.4 Change, Impact and Decision

Changes forecast to happen until 2020 correspond to new projects that have been approved by the municipal administration. Many of these projects are already being executed such as hospitals, health centers, commercial and residential buildings, paving of side roads, bridges and the new municipal administrative center. It's possible to observe a spatial tendency of concentrating these projects in areas surrounding the areas that are already urbanized, as seen in Figure 8a. Zones with a higher concentration of new projects serve as catalysts to urban landscape transformation and constitute vectors of pressure on vegetation patches.



(a)



(b)

Figure 7. Concentration of new projects (a), impact potential by urban zone (b).

Combinatorial analysis, between the map of environmental significance and the map of concentration of new projects, resulted in the map of potential impact, seen in Figure 8b. Urban zones with potential of impact, shown in red, have high environmental significance and high concentration of new projects. It's recommend to propose specific urban parameters and legal regulation use to reduce possible impacts on existing vegetation fragments and to recover or increase vegetation parcels.

Zones in yellow in Figure 8b have low environmental significance and high concentration of new projects. In this areas it's recommend specific regulations for neighborhood impact studies, promoting environmental compensation policies and vegetation recovery. An interesting proposal would be a change in the Master Plan to broaden the minimum area necessary for institutional green areas on tracts undergoing land subdivision or new urban occupations.

4. CONCLUSIONS

Analyzes based on landscape ecology concepts and metrics, associated to multicriteria analyzes in a GIS environment, provided vegetation fragments' characterization and classification in the context of urban zones. Associating the vegetation fragments' qualitative and quantitative analyzes, presented for each urban zone, it was possible to verify the suitability of uses and parameters proposed to the urban zoning, and give conditions to review the proposals according to arboreal vegetation's preservation possibilities.
It's was observed that the municipality's urban zoning is coherent in relation to areas destined for environmental protection and environmental interest areas, because just one environmental protection area proposed by the master plan presented low significance.

Therefore, the great challenge is to manage urban expansion and its reflexes on environmental processes, and to face the need to preserve urban green areas so as to maintain the quality of life. In this context, it's defended that Geodesign framework and concepts may contribute to an integrated management of the urban landscape.

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