CO-440

A METHODOLOGICAL FRAMEWORK FOR EVALUATING AND OPTIMIZING URBAN GREEN NETWORKS USING GIS

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1 INTRODUCTION

Growth during the 20th century (Heilbroner, 2000) and the rapid urbanization has caused serious problems that placed the distribution of land uses in the epicenter of urban planning. The serious environmental damage, the climate change, the effect of urban life style on the health, the physical and psychological condition of the people living in cities; make the research for open green spaces in the urban areas more vital than ever.

Nowadays sustainable development is focused on the green network as a main strategic tool for the integration of cultural and recreational uses in the urban web and mainly in the maintenance and protection of nature. In other words, the intention is "the reallocation of green spaces all over the city, fairly and democratically, thus each citizen have access in this good" (Thompson, 2002).

Therefore in order to approach and analyze the urban planning process, there is a need to examine the following questions:

• Which spatial units of the existing green spaces are suitable as structural elements of the green network and by which criteria?

• Which new green spaces will be proposed and by which criteria?

• Which connection of the green network will be realized and by which criteria?

• Are the ratio m2/ resident satisfactory in order to evaluate each proposal?

From the literature review, it appears that the each of these questions have been examined, some of them in the context of Urban Planning, and most of them in the context of Landscape Ecology.

Based on these, a methodological framework (Fig. 1) is presented which show how urban planning is organized within a holistic approach, which is based on an ecologic, a service and a bioclimatic process. These processes take place along the following three axes: The first is the initiating evaluation which via ecologic criteria (the type of vegetation, the area and the bird's number) along with service criteria (the land use and the infrastructure network and the bioclimatic criteria (Anthropogenic intensity and morphology), provides the process of least cost that in turn leads to the weighting of the initial study. This is one of the three basic urban planning components. In a similar manner, the second axis, the connectivity through biodiversity conservation criteria, the walking paths and the Geometry via the new green areas, corridors and their connections, provides the process built geometric network which in turn leads to optimization of space. Finally, the third axis, the green network, via connections between important spaces (Ecological network), Pedestrian network, Ventilation, Shading and Dew provides the process of map, tables and indexes Alfa and Gamma that leads to the upgrading of the urban planning.

In order to accomplish this goal the next section is devoted to review the basic planning components. The third section is aimed to present the proposed Methodological Framework, the necessary data collection and their organization into geodatabases and finally, in the last section, same thoughts based on the results are presented along with some conclusion related to the urban planning.

2 THEORETICAL APPROACHES

The Landscape Ecology gives the basic principles of species and their habitats protection, of biodiversity, soil and aquifer protection as well as the rational allocation of land use in order to prevent its fragmentation. As a basic theory offers the necessary structure elements such as mosaic, corridors and step-stones as connecting components and the matrix that contains all the above. In other words, it offers the theories and the approaches of the evolving spatial patterns and the connectivity of those elements (Forman & Gordon, 1986; Forman, 1995; Turner et al., 2001; Forman, 2008).

Certain methodological steps proposed by Forman are used in this paper. «We may hypothesize that an optimum landscape has large patches of natural vegetation, supplemented with small patches scattered throughout the matrix. Alternatively, most of the small-patch functions can be provided by small corridors in the matrix» (Forman, 1995, p.136).

It is fact also that the contribution of Architecture of Landscapes is decisive after it determines the models processes, in city scale, it decides and selects the green spaces. Landscape Architecture does not plan and draw, separately, green spaces any more, but is established in the large-scale planning and the organization of land use. It does not deal with the local solution, the creation of beautiful scenes etc, but gives solutions to the problems of urbanization and environmental degradation (Waldheim, 2006). However, an interesting approach offers the hybrid science of Landscape Urbanism which establishes the importance of infrastructures, concerning the landscape that surrounds them, for the growth of modern cities and the planning of public space (Mossop, 2006).

Theories from microclimatology and bioclimatology are fulfilling an effort of bioclimatic planning at city scale. As a main factors are documented the existence of marine forehead (Zerefos, 1984), planting trees across the main roads that follow the direction of prevailing winds. In this way, green corridors are used as filters of pollutant substances. An important bioclimatic factor that must be reviewed is of street width to building height (Chronopoulou-Sereli, 1990).

2.1 Indicators

Important role, in the step of decision making, evaluating or informing the public about the city plans, constitutes the urban Environmental Indicators which is in according to the Cities Environmental Report on the Web (CEROI) and the United Nations Environment Report (UNEP). The main environmental indicators that are proposed for the sustainable operation and development of a city area are: the Green Areas, the Proximity of Green Space, the Accessibility/Public Access to Green Space, Availability of public Open Areas, Urban Renewal Areas and Protected Areas as a Percent of Total Area.

Additionally, there are English Accessible Natural Greenspace Standards (English Nature, 2003) to express both accessibility and proximity with quality of greenspace.

3 METHODOLOGICAL FRAMEWORK

The proposed methodological framework includes the accessibility of the residents to large green spaces, in relation with the population density of the blocks. It is eligible that with an easy and quick way to identify the blocks that meet the fewer criterions, according to ANGTs, or those that are most populated and has less access to quality green. At the same time, this initial evaluation output can directly be used to the next step, as a criterion to the formation of the cost raster. In that way, the degraded parts of the blocks can be improved from the green corridors.

The formation of a cost raster, which will include the whole number of the criteria (ecological, environmental, urban and bioclimatic), finally will lead to the creation of the connection paths not only to the green corridors but also the green spaces (existing and new) and the - so necessary - stepping stones and interconnecting smaller patches.

It must be illustrated that through the proposed methodology it is always been chosen the optimal path and so it is not necessary to create primary and secondary networks based to suitability. The fact that are created separate sections which are consolidated base on the source – destination routing (and the least cost condition) and not based to suitability, solves the formulated problem of urban green networks «go nowhere and do little, except possibly for real estate prices» (Turner, 1995, p. 269).

More specifically there are going to be referred to:

- The necessary data collection and their organization into geodatabases
- the model of the initial evaluation of the blocks based on the population density and the accessibility / proximity to the large green spaces according to ANGSt
- creation of the cost raster from each criterion
- the solution of least-cost algorithm with an appropriate choice of sources and destinations
- the built of geometrical network and the evaluation of its structure
- the connectivity evaluation with Alfa and Gamma Indexes
- re-evaluation of the blocks and compare the effect of space intervention

According to our approach a new methodological framework is proposed and the following diagram (Fig. 1) illustrates its basic steps which are further analyzed in the following paragraphs.

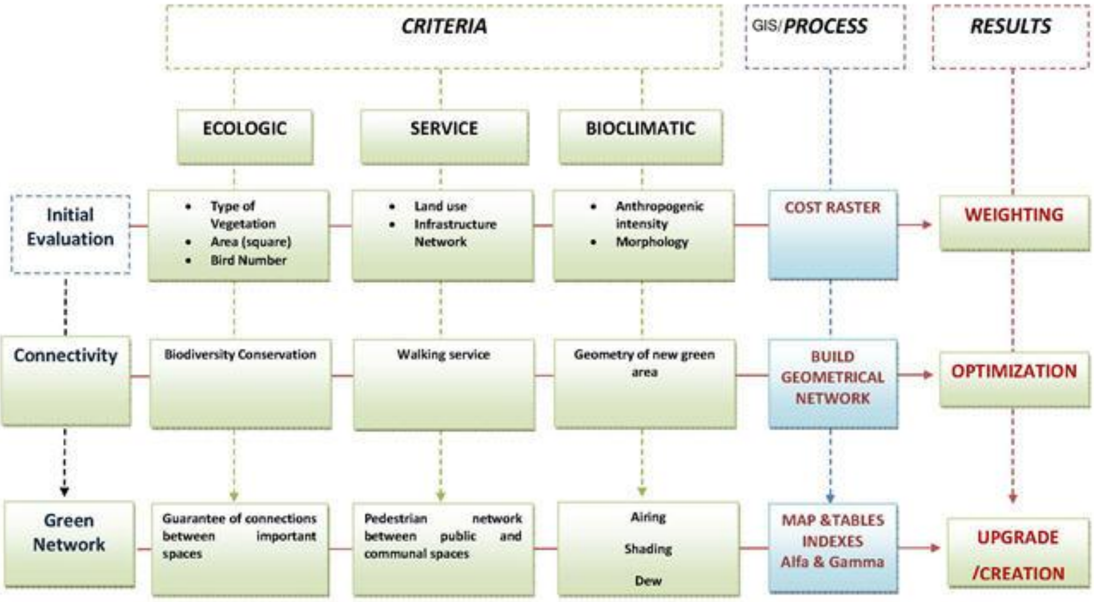


Fig.1: METHODOLOGICAL FRAMEWORK OF URBAN GREEN NETWORKS

3.1 Study area

The study area's overall institutional framework must be known as well as additional data such as, population growth and activities, employment rates and land use percentages. This mainly aims to a pre-evaluation of the significance of existing green and open spaces that will probably be considered as the pattern that must be enhanced and upgraded.

3.2 Data

The minimum data considered necessary are the following:

Table 1: Data Collection

Type	Geometry	Attribute	*Comments*
Blocks	Polygon	Population	*It would be interesting to have the cadastral data and especially the parcels and the property data*
Green Spaces	Polygon	Vegetation Form Birds	*We could use also other quality data, concerning maintenances needs of the green spaces.*
Utility Sites	Polygon	Use	
Buildings	Polygon		*It would be interesting to have the cadastral data and especially the height of each building.*
Unstructured Blocks	Polygon		*We produce it from the layers "Blocks" and "Buildings" with Select by Location*
Archeological Sites	Point		
Road Network	PolyLine	Street Name Street Category	
Noise Pollution	PolyLine	Noise Pollution Range in DB	*Relates with the Polyline layer of Road Network*
Traffic Load	PolyLine	Traffic Load	*Relates with the Polyline layer of Road Network*
Sites Proposed for Relocation	Polygon		
Areas Proposed for Reformation	Polygon		
Disturbing Jobs Inside the Urban Network	Point		
Polluting Areas	Polygon		
Urban Neighborhoods	Polygon	Neighborhoods Name Floor Area Ratio (FAR)	*The digitization must be done on the lines of the Road Network that separates the neighborhoods among them.*
Protected Areas Boundaries	PolyLine		*Mountains, forests, reforestation areas etc.*
City Boundaries	PolyLine		
Streams	PolyLine		
Shoreline	PolyLine		*Off course if there is another important wet element - such as river or lack – it should be taken under consideration*

3.3 Geo-Spatial Data

Respective files, data and tools must be organized in different spatial databases (GeoDatabases) each of which in our case will focus on the successive methodological steps of our framework (Table 2):

Table 2: Database Organization

GEODATABASES	FEATURE DATASETS	FEATURE CLASSES	TOOLBOXES	CREATED FILES (used in following steps)
1η Geodatabase: Initial Evaluation	VECTOR FEATURE CLASSES	i. Blocks (BL.) ii. Green Spaces (G.S.) iii. BL. – G.S. (erase) iv. BL. & G.S. (union)	TOOLBOX FOR THE INITIAL EVALUATION OF BL.	i. Initial Evaluation BL. Raster ii. BL. Raster based on the population
2η Geodatabase: Analysis	DATA COLLECTION	All the data, as they are described at the previous chapter, except BL. & G.S.	TOOLBOX FOR THE CREATION OF COST RASTER & TOOLBOX FOR THE CREATION OF (GEOMETRICAL) GREEN NETWORK & ΤΩΝ GREEN SPACES	Cost Raster
	SOURCES & DESTINATIONS	Sources: Green Spaces over 12000m^2, mainly at the boundaries of the municipality.		Sources & Destinations
		Destinations: i. All the existing green spaces, in order to establish the connection of the ecological network, so that the populations can travel and reproduce. ii. The polluted areas or the areas for relocation, or the utility sites. The purpose is to create a green network of walking service path for the residences.		
	GEOMETRICAL NETWORK	Build Green Network from Cost Raster - Sources & Destinations		Geometrical Network (Evaluation of connectivity using Gamma & Alfa indexes), Points, Lines and Polygons of New G.S.
	The intermediate data will be saved in the Geodatabase but outside the Feature Datasets			
3η Geodatabase: Final Evaluation	VECTOR FEATURE CLASSES	New Green Spaces (New G.S.) Any other file that we want to include to the final results for purposes of comparison or digital deliverance		
Maps, Tables and other Quantitative & Qualitative Measurements				

3.4 Block Initial Evaluation

For the initial evaluation of the distribution of green in the study area it is recommended to take into account the general philosophy of Urban Environmental Indicators (CEROI) on accessibility, environmental protection and proximity. The only modification being is to utilize a combination of Accessible Natural Greenspace Standards and blocks' population density instead of m2 of green per habitant. The Accessible Natural Greenspace Standards (ANGSt) states that "No person should live more than 300m from their nearest area of natural green space” and that there should be at least one of the following site types and distances criteria met:

• 20ha site within 2km;

• 100ha site within 5km;

• 500ha site within 10km.

After converting from polygon to raster the following geographic data sets, an automated procedure is run in ArcGIS Model Builder to evaluate the initial blocks:

• Green Spaces [area based];

• Blocks Except from the Green [area based];

• Blocks Except from the Green [primary key based]

• Blocks Except from the Green [population based].

From the raster of area– based Green Spaces, regions are selected with areas equal to 20.000 m2, 200.000 m2, 1.000.000 m2 and 5.000.000 m2. In fact, the distance raster from green spaces with area 5.000.000 m2 represents the suburban green and the necessary connection with it. Afterwards, Euclidean distances from each cell are calculated and reclassified as follows (table 3):

Table 3: Greenspace Area / Block Distance Reclassification

	Value = 1	Value = 0
A = 20.000 m^2	D ≤ 300 m	D > 300
A = 200.000 m^2	D ≤ 2000 m	D > 2000
A = 1.000.000 m^2	D ≤ 5000 m	D > 5000

The final values will eventually be 1, 2 and 3 counting how many criteria are met. At the same time a raster for each non green block is depicted with values for the population density and a respective Location Quotient is formulated. This technique compares the local variables to a reference region, in a process attempting to identify local specializations.

Using the appropriate sequence of Map Algebra operations (Divisions, Multiplications etc.) the raster of the population density is produced. The results are shown in Table 4:

The used scale is 1-9 with:

• 1: best value

• 9: worst value

Table 4: Initial Evaluation Score Table

	POPULATION DENSITY			
DISTANCE FROM G.S.	0	1 - D	2 - M	3 - S
3 - F	0	1	2	3
2 - M	0	7	6	4
1 - C	0	9	8	5

The produced raster datasets of Distances from the Green Spaces and Blocks’ Population Density will also be combined through Map Algebra rules and functions and the above values will be assigned to the new raster.

Applying this evaluation method the result is visualized, the created raster is ready to be further exploited in the analysis and in order to optimize the worst parts (cells) of the blocks. Vector input data are also needed, which can be obtained from respective professionals and institutions.

3.5 Cost Raster

Analysis through raster model data structure is proposed mainly due to the large number of overlaying layers and the mixture of discrete values (e.g. road network), continuous fields (e.g. bioclimatic influence and air pollution) as well as the large number of relative distance data (Verbyla, 2002, p. 119). Initially, all layers are converted to raster using the proper cell size. Finally, every criterion raster must have the same spatial extend. Moreover, all criteria have to be reclassified to the same scale and a weight must be assigned to them.

The Cost Raster will define the routes that will be drawn from the source to the destinations and backwards, after a cell by cell examination choosing each time the least possible cost to "walk that line". In our case however, the cost is simultaneously examined from the point of view of the user and the environment. That is, the higher the value on a physical level is the lower the value on a logical level must be.

To illustrate this we consider the following examples:

Example 1o: If there is a large patch of green space, with rich flora and fauna, it would be certainly a goal its protection and conservation. The relative distance from this green space it would be an important criterion. The cells that are closer to that patch would have had less cost than others and that cost would increase gradually.

Example 2o: It is a goal the overall optimization of habitants' quality of life. A very important factor is noise pollution. It is wanted that roads with heavy noise pollution would be covered with green, so that it can be formed a physical barrier to the noise. So, as the values of reported noise dbs increase the cost at the raster should decrease.

A conceptually similar set of criteria is defined, that concerns:

• The potential new and existing green spaces
• The ecological improvement and the environmental protection
• The city bioclimatic performance, it's ventilation and decontamination
• The improvement of the quality of life
• The proximity and the type of the transportation networks

Beside from the increase of the total city green and the connection of the green spaces between them, primary goal is the optimization of the status of the blocks that at the initial evaluation were "judged as bad".

According to the above, every set of criteria will be presented and analyzed separately. It should be noted that, before their addition, maps must have the same extend, which can be easily achieved with if – then – else procedures (e.g. combination of IsNull/Con).

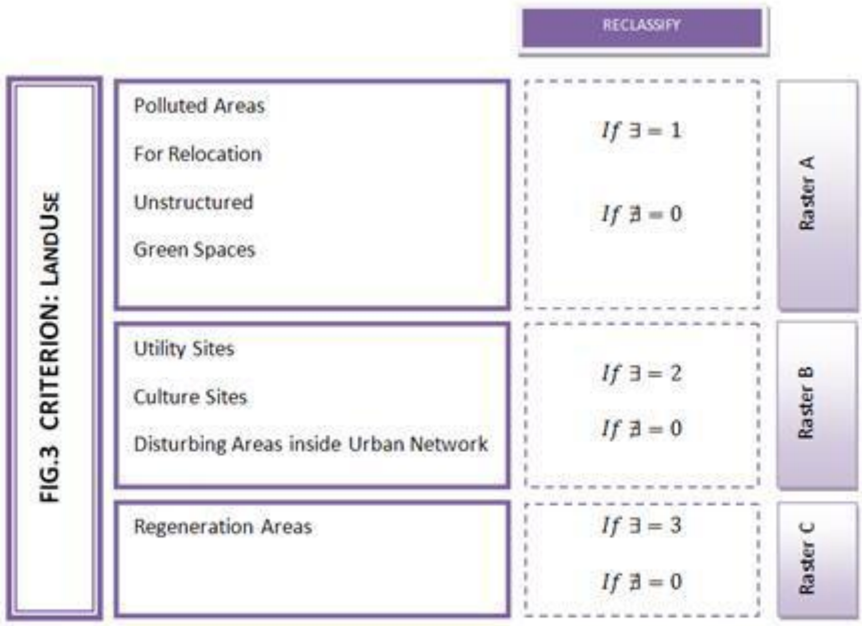
3.5.1 Criteria: Ecological / Bioclimatic / Service

Criterion of Initial Evaluation (Fig. 2): The output - described in the previous paragraph (3.4) - is a raster showing the initial evaluation of the blocks. To the cell exhibiting the worst evaluation will be given the lowest weight, in order to support an inclination of improvement.

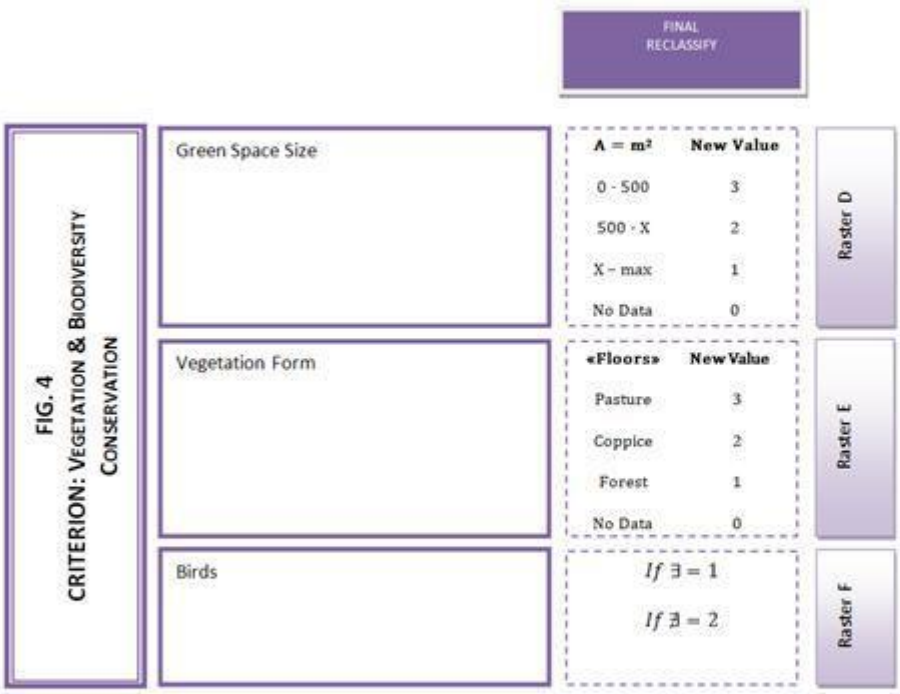
Criterion Land Use (Fig. 3): Initial selections and conversions from vector to raster must be performed in order to produce the dataset. The first step is the formulation of a land use mosaic, with large or medium patches or greenways defining areas that may potentially be transformed to green spaces. This kind of areas characterized "for Relocation", are Polluted Areas, Unstructured Parcels and Green Spaces.

From a different point of view, and with significantly lower importance, is the aim for connection with public utilities (e.g. schools) and cultural areas (e.g. archeological sites) which undoubtedly is a way to improve the city, as well as the daily life of citizens and the promotion of cultural heritage.

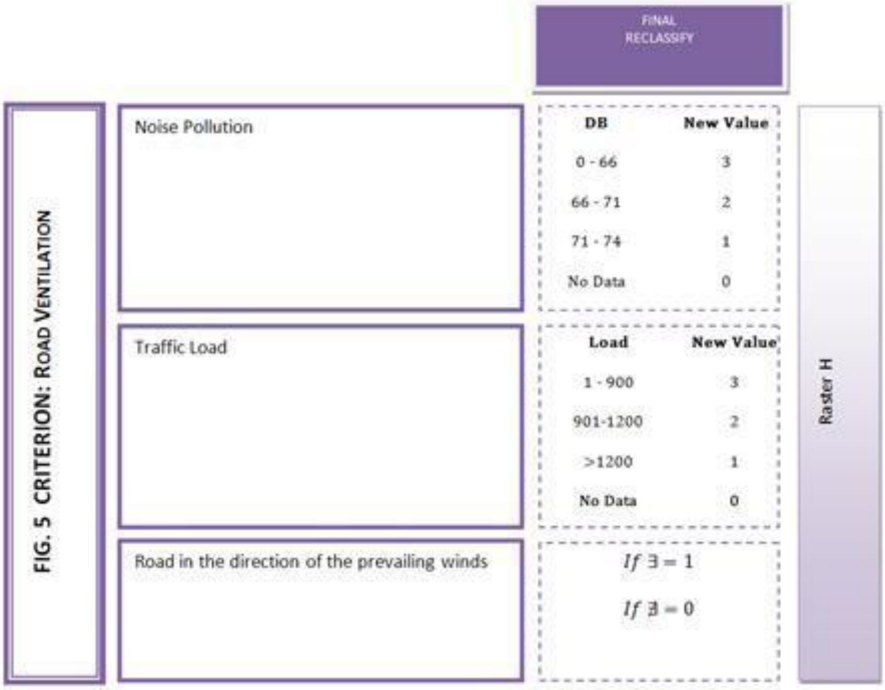
If there are Regeneration Areas, where there is serious lack in housing stock, the unstructured parcels of those areas must not be preferred but neither been excluded. Therefore those areas must participate to the criterion, but with lower weight. Finally, the necessary reclassification of every raster will be on the logic of "Exist – Not Exist"



Criterion of Biodiversity Conservation (Fig. 4): The green spaces' size, their formation and the type of vegetation play a key role to the environmental effect and impact. In this respect, the green space must cover an area of 10.000 m2 and the vegetation tall, dense and irrigated.



Criterion of Bioclimatic Improvement – Road Air Ventilation (Fig. 5): It is necessary to place tall green vegetation to roads with intense noise problem as a barrier to sound. Intense air pollution problem is indicated at roads with high average traffic, especially at the layer of air near the ground. At those roads the greenways and their connection with large patches are crucial for the improvement of the city. It would be most effective if those greenways were placed at major roads in the direction of prevailing winds.



Criterion Ratio Building Height / Road Width (H/W): A very important bioclimatic index is the ratio Building Height / Road Width (H/W). When this ratio is 1, the ventilation of the rods is not proper. The best ratio is 0.5.

Building Height (H): In most cases, the floor area ratio (FAR) for each neighborhood and the building area are given. In that case the buildings are going to be treated as groups and their height will be differentiating on every urban neighborhood.

In order to estimate the Building Height it can be used the following formula:

$$H = \frac{(h1 + h2)}{2}$$

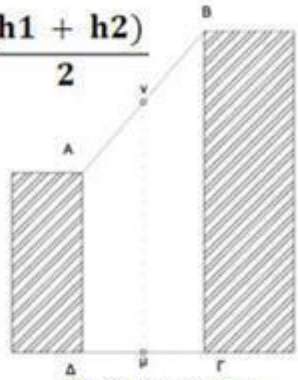


FIG. 6: Mean Height

$$\text{Building Height} = \frac{100 \times \alpha \times FAR}{C}$$

C: Coverage

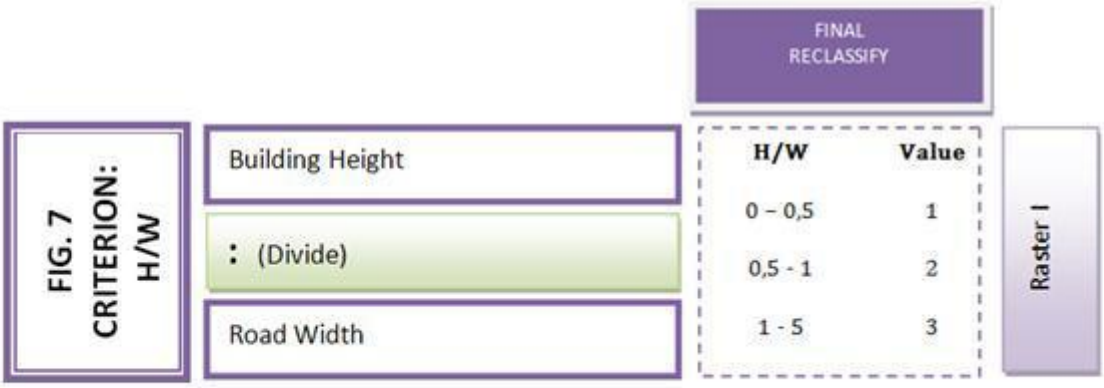
a: average height of every floor (m)

FAR: Floor Area Ratio

Through Map Algebra and specifically Line Statistics, it is possible to produce a raster that represents the height of the buildings.

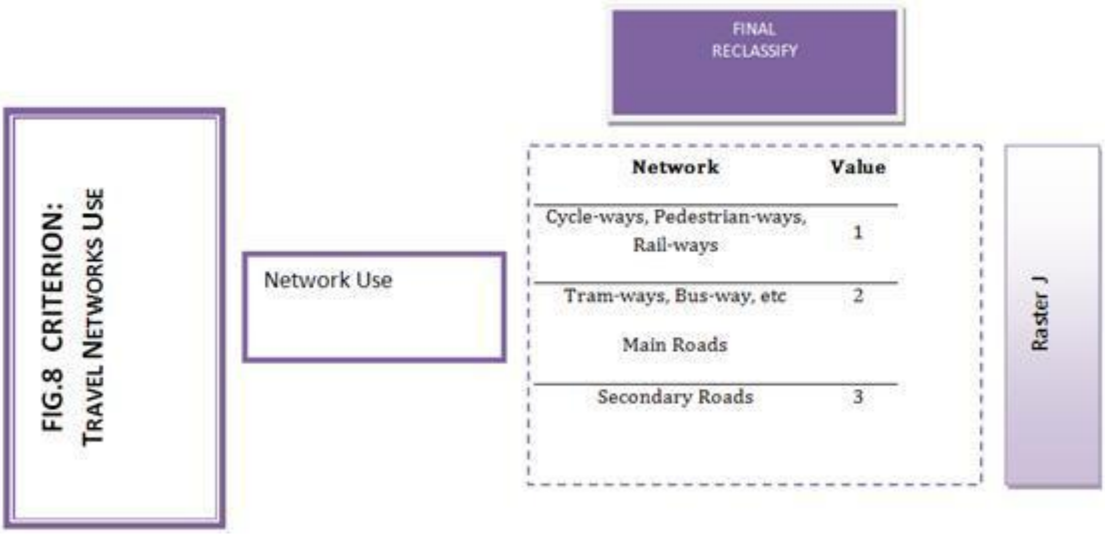
Road Width: It is needed the width from building to building and not from one parcel to the other. This is may be a continuously changing value. To overcome this problem it can be used the aggregate procedure. Combining Line Statistics and Euclidean Distance procedures, properly parameterized, the road width raster can be calculated with a fine approach.

Bioclimatic index H/W (Fig. 7): All it has to be done is to divide, through Map Algebra, the two raster datasets and reclassify as mentioned.



Hydrographic Criterion: The hydrographic elements of the region must be taken into account. If rivers or streams exist, greenways must be created along them, named blue-ways by Turner (1995). If the city under examination has a waterfront, or a big lake, the distances from those water elements are calculated.

Criterion of Travel Networks Use (Fig. 8): The existing travel networks are appropriate to create greenways along them, with escalated suitability of course. The one used below is been taken from Lionatou (2008).



Criterion of Proximity – Service (Fig. 9): It is very important that the residents have easy access to the green spaces and to the connecting nodes, especially to local level. It is necessary to create a raster of Euclidean Distances from the road network. The lesser the distance of the green space from the road is, the lower the weight.

Slope Criterion: Some Planners consider the areas with small slopes of higher suitability for siting connectivity greenways, to be easily used as pathways for the movement of the residents. To natural banks with steep slopes the problem of erosion is primer and more important than the movement of inhabitants, so the criterion of suitability must be reversed (Viles & Rosier, 2001, p. 23). Also Forman (2008, p. 157) says that «more than half of the cities with nearby hill-slopes or mountain-slopes facing the city have 90 – 100 % natural vegetation cover on the slopes» which obviously must be protected. At the same point

Forman (2008, p. 157) notes that «cities with more surrounding city-facing slopes generally have a greater percentage cover of natural vegetation on them, whereas few nearby slopes near a city tend to be much built up». The natural vegetation there needs to be protected and enhanced, to stop the urban sprawl. This theoretical controversy predisposes to further research. The slope is a very important factor and maybe it needs to be treated case by case. Obviously if it is a mountainous region, the criterion of slope must take special care.

3.5.2 Ranking

According to Nyerges & Jankowski (2010, p.139) "Ranking is the simplest of all weighting techniques". The Decision Maker starts arranging criteria, by using the straight importance ranking. Rank Sum is used to compute the weights for each criterion as follows:

$$wj = \frac{n - rj + 1}{\sum_{k=1}^{n}(n - rk + 1)}$$

Where:

w_j: Normalized weight for the criterion j, ranging in value from 0 to 1

n: The number of criteria under consideration

r_j: The rank position of the criterion

3.5.3 Create Cost Raster

Finally, the weighted cost values of every cell at the same location must be added to produce one and only raster, the cost raster.

3.6 Geometrical Network

The first step in the analysis based on least cost is to determine to areas of sources and destinations (Kong et al. 2010, p.4). Patches of green with area over 12.000m2, mostly at the border of the city, can be used to build an ecologic green network.

There can be two types of destinations:

• All the existing green spaces, for the connection of the ecological network [population movement].

• The polluted areas, or the areas "for relocation", or utility sites [creation of a green network as a service to residents].

3.6.1 Least Cost Path

The landscape representation as a graph, a set of nodes and links, is well established among other disciplines and in Landscape Ecology too, and still has a lot to offer (Urban & Keitt, 2001). As Rudd et al. (2002, p. 368) say «connectivity has been an accepted goal in ecological restoration of wilderness areas for some time, but it is a relatively new approach in urban areas».

The aim is to connect the sources with the destinations with the least possible accumulative cost. Through the procedure of Cost Weighted Distance (Verbyla, 2002, p. 127-133), it will be used the algorithm of Shortest Path twice, one for the Ecological Network and one for the Walking Network.

3.6.2 Connectivity

At this point, it is necessary to create a modeled procedure to automatically unify the two separate networks, in order to check there overall connectivity, simplify and repair their geometry. The outputs of this model will be the simplified connection lines and the polygon feature of final Greenspace areas.

As long as the network is built, its structure and connectivity must be evaluated through the utilization of The Alfa and Gamma indexes (Forman & Gordon, 1986, pp. 417-419; Turner et al., 2001, p. 111) and their formulas are:

$$\gamma = \frac{actual\ number\ of\ links}{\max.\ number\ of\ links} = \frac{\sigma}{\sigma_{\max}} = \frac{\sigma}{3(\kappa - 2)}$$

$$\alpha = \frac{actual\ number\ of\ circuits}{\max.\ number\ of\ circuits} = \frac{\sigma - \kappa + 1}{2\kappa - 5}$$

3.7 Maps, Tables, Alfa and Gamma Indexes

The importance of connectivity has already been mentioned, so it will be the first and the most important factor to be evaluated. Comparing the results with the range of values, we can identify if the network is Minimum, Medium or Maximum Connected Network (Koutsopoulos 2006, p. 230). The results can be considered satisfactory the indexes are close to the upper limit of the range of Medium Connected Network, or close to the lower limit of the range of Maximum Connected Network.

Measurements that concern the m2 green/habitant would be useful (for purposes of comparison with other studies and statistics), and of course a check of the new condition of the blocks and if the status of the "worst" cells of the initial evaluation is improved.

4 Results and Conclusions

The municipality of Keratsini in Greece was selected as a study area. It was chosen because it can be considered as privileged area in terms of its location and morphology (i.e. green space per capita is double than the average in the Athens area). The fact, however is that the green areas of the municipality are inappropriate, spatially dispersed and isolated. Thus Keratsini is an appropriate study area for checking the proposed methodological framework.

The Application results showed obvious improvement. More specifically:

i. The network structure as shown by the connectivity (indices is desirable given that their values are) with index as shown below:

Alpha Index: 47.6%

Gamma Index: 65.08%

ii. The green per capita increased from 24.37m2 to 32.71m2

iii. All the areas with the worst score in the initiating evaluation, in the proposed methodological framework are located close to the new large area of green (within 300m).

The main advantages of the proposed methodological framework are:

i. Always selects the optimal path for connecting a particular source and destination, instead of creating primary and secondary networks based on suitability.

ii. The applied processes allow many tests, using several criteria, parameters etc.

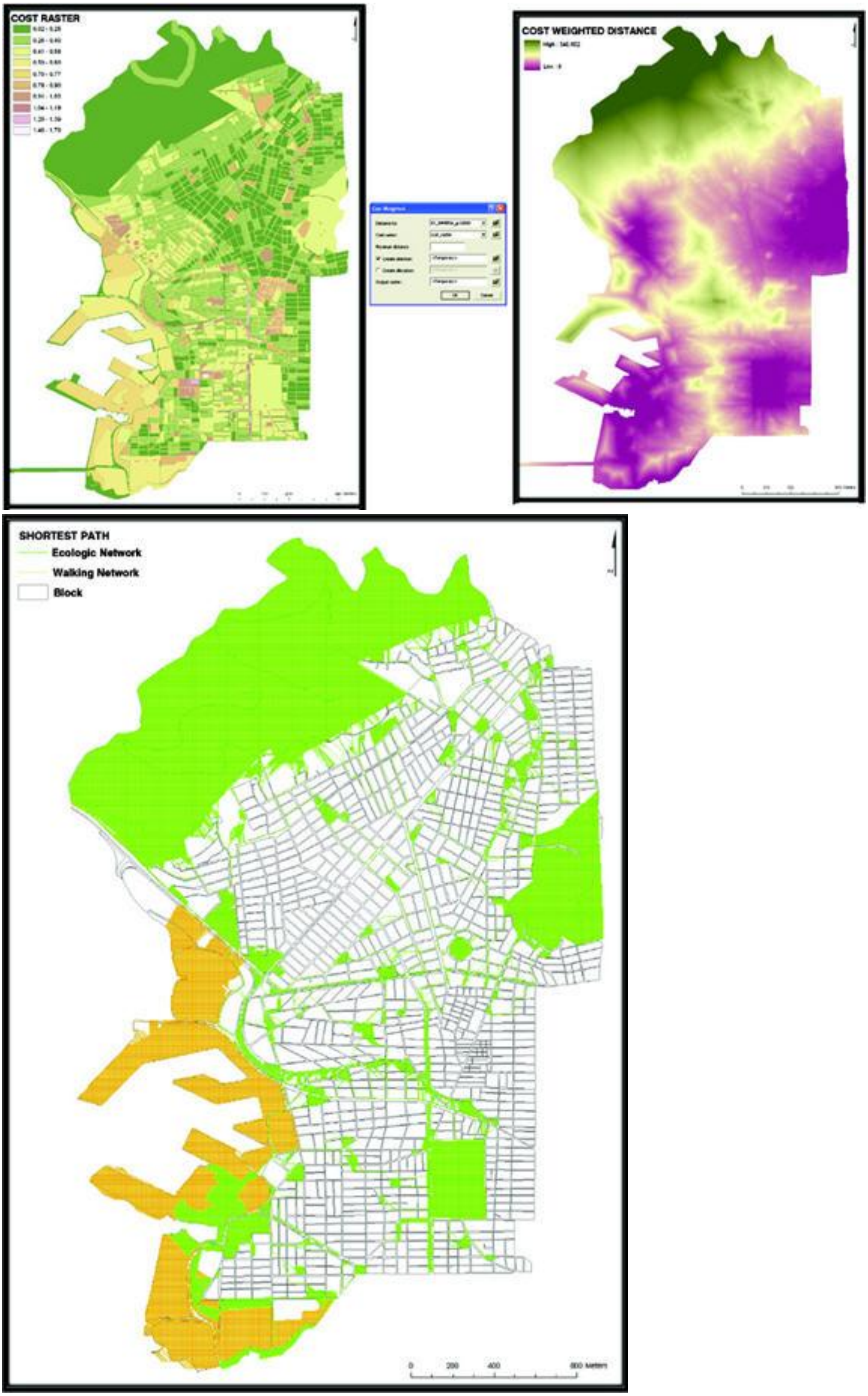
The most important contribution however, is that is a tool for testing scenarios of urban planning which includes bioclimatic and environmental criteria. As result its main advantage - outside of modeling – is that vector data are used as input - that are anyway created during the application of these projects. In order however to be used as an instrument of operation and implementation, the unhindered access to updated information (temperature, humidity, air pollution etc.) and spatial data is a prerequisite.

Finally, the fact that this methodology is been proposed in the form of modeling procedures of a very common GIS software, enables specialists (landscape architects, planners, etc) and non-specialists (residents, clerks, etc) to control the proposed solutions and to document proposals more effectively.

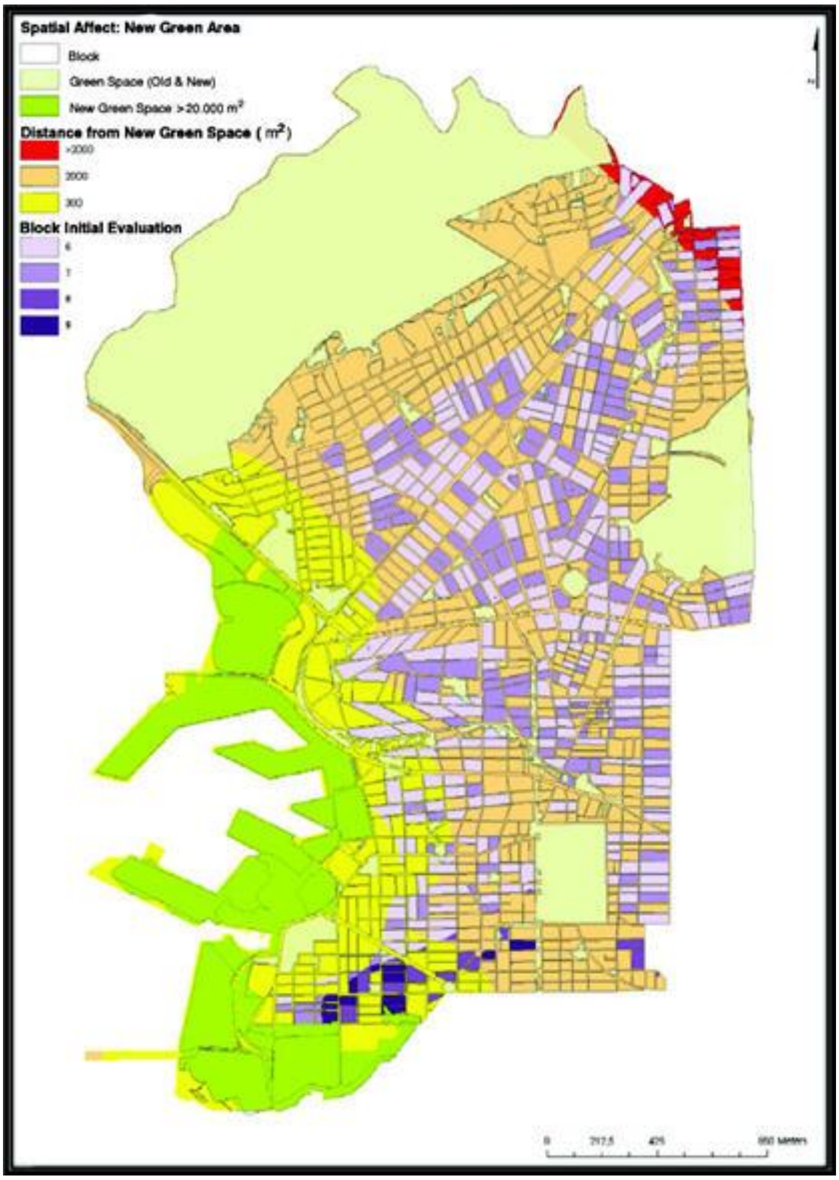
It is known that green areas change their geometry over time. This change modifies their properties and the correlations with the surrounding environment. The study of these changes and of the appropriate data structure, are of great research interest.

The proposed approach in modeling and implementing a spatio-temporal database system will be based on a model of an entity-oriented, spatio-temporal database with emphasis on changes of its geometries over time, whether they change in discrete steps or continuously (Pigaki M.,Koutsopoulos, K., 2009)

The application of such a model requires a more detailed research. That is, in terms of the construction of the database, this incorporates not only the spatial but also the time dimension (i.e. plant growth).



COST RASTER
COST WEIGHTED DISTANCE
SHORTEST PATH
Ecologic Network
Walking Network
Block
0
200
400
800 Meters



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