URBAN GREEN SPACE NETWORK EVALUATION AND PLANNING:
OPTIMIZING ACCESSIBILITY BASED ON CONNECTIVITY AND
RASTER GIS ANALYSIS

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Abstract

The main objective of this paper is to establish a methodological framework, with universal use, in order to evaluate and optimize an urban green network in densely built urban areas. GIS functionality and its spatial processes modeling capabilities led us to choose the raster structure for our data analysis, although it is not as commonly used as its vector counterpart. The raster data structure, however, is the most appropriate in cases where there is a plethora of criteria involved and a need for successive layers overlay. Connectivity plays a prominent role in controlling and evaluating the structure of the generated network. This paper is based on the theoretical foundations of the theories of Landscape Ecology, Urban Ecology, Green Networks, Bioclimatology, Landscape Architecture, and the new discipline of Landscape Urbanism, combined with Spatial Analysis and GIS. Furthermore, we argue that the “square meters of green per capita” index is not satisfactory. The methodological framework proposes to take into account the overall effect of new green spaces over the wider region and service of the population, in order to draw conclusions.

Keywords: Urban Green Network, Connectivity, GIS, Least Cost to User, Modeled Raster Analysis, Alpha Index, Gamma Index

1. INTRODUCTION

Growth during the twentieth century (Heilbroner, 2000) and rapid urbanization caused serious problems (Romero-Lankao & Dodman, 2011) placing the way land-use distributes at the epicenter of urban planning and related research (Wang et al., 2012). Serious environmental damage, climate change (Harlan & Ruddell, 2011), the effect of urban lifestyle on health, physical, and psychological condition of people living in cities, makes research for open green spaces in urban areas more vital than ever (De Ridde et al., 2004).
Nowadays, sustainable development focuses on the "green network" (Conine et al., 2004) as a main strategic tool. This is for the integration of cultural and recreational uses in the urban fabric, and mainly for the maintenance and protection of nature. In other words, the intention is to achieve “the reallocation of green spaces all over the city, fairly and democratically; thus each citizen has access in this good” (Thompson, 2002).

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

- Which spatial units of existing green spaces are suitable as structural elements of the green network and according to what criteria?
- Which new green spaces will be proposed and according to what criteria?
- Which connection of the green network will be realized and according to what criteria?
- Is the ratio m²/resident satisfactory in order to evaluate each proposal?

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

Based on these questions, a methodological framework is proposed in the present paper, which aims to show how Urban Planning can be organized from a holistic approach based on ecologic, service, and bioclimatic processes. These processes take place along the following three axes. The first is “the initiating evaluation”, which via ecologic criteria (the vegetation type, the area, and the number of birds) 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 of “build a geometric network”, which in turn leads to “the 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 Alpha and Gamma that leads to the upgrading of the urban planning.

The steps of the proposed methodological framework are the following:

i) Definition of a new method for evaluating resident proximity to and accessibility of green spaces (based on their area and distance, normalized by block population density); ii) Formulation of a final cost raster, according to the entire set of criteria (e.g. ecological, environmental, urban planning, bioclimatic), along with the origins-destinations matrix produced by the “least cost path” algorithm. This will lead to the formation of linear links, not only of the major green spaces and green areas connections (existing and proposed), but also of smaller parts. iii) “Building” of a geometrical network from those links, whose structure is validated through the adaptation of the Alpha and Gamma indexes.
The main advantages of the proposed methodological framework are: i. It always selects the optimal path for connecting sources and destinations, instead of creating primary and secondary networks based on suitability. ii. The modeled processes allow many tests, although the methodology uses several criteria, parameters etc. iii. It is a tool for testing scenarios of urban planning in order to include bio-climatic and environmental criteria in planning projects. Of course, in order to be fully operational and utilized as a decision support aid newly updated non-spatial (temperature, humidity, air pollution, etc.) as well as spatial data are required. The next section is devoted to reviewing the basic planning components. The third section presents the proposed Methodological Framework, the necessary data collection, and their organization into geodatabases. In the last section, same thoughts based on the results are presented along with some conclusions related to Urban Planning.

2. THEORETICAL BACKGROUND – (CONCEPTUAL FRAMEWORK)

The basic principles of species and their habitat protection, biodiversity, soil, and aquifer protection as well as the rational allocation of land use in order to prevent its fragmentation are given by Landscape Ecology. This base theory offers the necessary structural elements; mosaic, corridors, and stepping-stones as connection components, and the matrix that contains them. According to Forman (1995, p.136), «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». In other words, it offers the theories and approaches of evolving spatial patterns and the connectivity of these elements (Forman & Gordon, 1986; Turner et al., 2001; Van Dyck & Baguette, 2005; Forman, 2008). Certain methodological steps proposed by Forman are adopted in this paper.

It is also a fact that the contribution of Landscape Architecture is critical since it determines the model processes, in city scale, based on which green spaces are defined and allocated. However, Landscape Architecture does not focus on planning and design of green spaces separately any more, but it is rather established as a large-scale planning and land use organization discipline. It does not deal with the local solution, or the creation of beautiful sceneries, but instead provides 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 planning of public space (Mossop, 2006).

Theories from microclimatology and bioclimatology are contributing to bioclimatic planning at city scale (Papangelis et al., 2012). The main factors that are documented are the existence of a marine forehead (Zerefos, 1984), the planting of trees (Hall et al., 2012), especially across 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 the ratio of street width to building height (Ali-Toudert & Mayer, 2006).

An important role, in the step of decision-making, is evaluating or informing the public about city plans. These constitute Urban Environmental Indicators in
accordance with 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 Green Areas, Proximity of Green Space, 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 the quality of green space.

3. METHODOLOGICAL FRAMEWORK

The proposed methodological framework includes accessibility of residents to large green spaces, in relation to population density of blocks. It is important to identify the blocks that meet the fewer criteria, according to Accessible Natural Greenspace Standards (ANGSt), or those that are most populated and have less access to quality green, with an easy and quick way. At the same time, the output of initial evaluation can directly be used in the next step, as a criterion for the formation of the cost raster. In this way, blocks’ degraded parts 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), will finally lead to the creation of connection paths; not only to the formation of green corridors but also green spaces (existing and new) and of the – necessary – stepping stones and to the interconnected smaller patches.

It must be made clear that through the proposed methodology, the optimal path is always selected, and so it is not necessary to create primary and secondary networks based on suitability (Drazic et al., 2014). Inasmuch as separate sections are created, which are consolidated based on source – destination routing process (and the least cost condition) – and not suitability, the formulated problem of urban green networks «go nowhere and do little, except possibly for real estate prices» (Turner, 1995, p. 269) is solved.

More specifically, the following are 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.
- The creation of the cost raster from each criterion.
- The solution of the least-cost algorithm with an appropriate choice of sources and destinations.
- The building of geometrical network and evaluation of its structure.
- The connectivity evaluation with Alpha and Gamma Indexes.
- Reevaluation of the blocks and comparison of the effect of space intervention.

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

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. The main aim is a pre-evaluation of significance of existing green and open spaces, which probably will be considered as the pattern that must be enhanced and upgraded.

3.2 Data

The minimum data considered necessary are shown in Table 1.

<table>
<thead>
<tr>
<th>Type</th>
<th>Geometry</th>
<th>Attribute</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>Polygon</td>
<td>Population</td>
<td><em>It would be interesting to have the cadastral data and especially the parcels and the property data</em></td>
</tr>
<tr>
<td>Green Spaces</td>
<td>Polygon</td>
<td>Vegetation Form</td>
<td><em>We could use also other quality data, concerning maintenance needs of the green spaces.</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Birds</td>
<td></td>
</tr>
<tr>
<td>Utility Sites</td>
<td>Polygon</td>
<td>Use</td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>Geometry</td>
<td>Attribute</td>
<td>Comments</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------</td>
<td>--------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Buildings</td>
<td>Polygon</td>
<td></td>
<td>It would be interesting to have the cadastral data and especially the height of each building.</td>
</tr>
<tr>
<td>Unstructured Blocks</td>
<td>Polygon</td>
<td></td>
<td>We produce it from the layers “Blocks” and “Buildings” with Select by Location</td>
</tr>
<tr>
<td>Archeological Sites</td>
<td>Point</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road Network</td>
<td>Polyline</td>
<td>Street Name</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Street Category</td>
<td></td>
</tr>
<tr>
<td>Noise Pollution</td>
<td>Polyline</td>
<td>Noise Pollution</td>
<td>Relates with the Polyline layer of Road Network</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range in DB</td>
<td></td>
</tr>
<tr>
<td>Traffic Load</td>
<td>Polyline</td>
<td>Traffic Load</td>
<td>Relates with the Polyline layer of Road Network</td>
</tr>
<tr>
<td>Sites Proposed for Relocation</td>
<td>Polygon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Areas Proposed for Reformation</td>
<td>Polygon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obnoxious Activities Inside the Urban Fabric</td>
<td>Point</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polluting Areas</td>
<td>Polygon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban Neighborhoods</td>
<td>Polygon</td>
<td>Neighborhoods’ Name</td>
<td>The digitization must be done on the lines of the Road Network that separates the neighborhoods between them.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Floor Area Ratio (FAR)</td>
<td></td>
</tr>
<tr>
<td>Protected Areas Boundaries</td>
<td>Polyline</td>
<td></td>
<td>Mountains, forests, reforestation areas etc.</td>
</tr>
<tr>
<td>City Boundaries</td>
<td>Polyline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Streams</td>
<td>Polyline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoreline</td>
<td>Polyline</td>
<td></td>
<td>Of course if there is another important wet element - such as a river or lake – it should be taken under consideration</td>
</tr>
</tbody>
</table>
It is essential to collect data by the relevant agencies and organizations and their digitization if necessary. At the same time, techniques of Remote Sensing could be used. Some of the data must be collected directly from the field, or produced through pre-analytical procedures.

### 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>
<thead>
<tr>
<th>GEODATABASES</th>
<th>FEATURE DATASETS</th>
<th>FEATURE CLASSES</th>
<th>TOOLBOXES</th>
<th>CREATED FILES (used in following steps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd Geodatabase: Analysis</td>
<td>DATA COLLECTION</td>
<td>All data, as they are described in the previous chapter, except BL. &amp; G.S.</td>
<td>TOOLBOX FOR THE CREATION OF COST RASTER &amp; SOURCES &amp; DESTINATIONS</td>
<td>Cost Raster</td>
</tr>
<tr>
<td></td>
<td>SOURCES &amp; DESTINATIONS</td>
<td>Sources: Green Spaces over 12000m², mainly at the boundaries of the municipality.</td>
<td>TOOLBOX FOR THE CREATION OF (GEOMETRICAL) GREEN NETWORK</td>
<td>Sources &amp; Destinations</td>
</tr>
<tr>
<td>GEODATABASES</td>
<td>FEATURE DATASETS</td>
<td>FEATURE CLASSES</td>
<td>TOOLBOXES</td>
<td>CREATED FILES (used in following steps)</td>
</tr>
<tr>
<td>----------------------</td>
<td>------------------</td>
<td>-----------------</td>
<td>-----------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Destinations:</td>
<td></td>
<td>&amp; GREEN SPACES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>i. All the existing green spaces, in order to establish the connection of the <strong>ecological network</strong>, so that the populations can travel and reproduce.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ii. The polluted areas or areas for relocation, or the utility sites. The purpose is to create a green network of <strong>walking service path</strong> for the residences.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GEOMETRICAL</td>
<td>Build Green Network from Cost Raster - Sources &amp; Destinations</td>
<td></td>
<td>Geometrical Network (Evaluation of connectivity using Gamma &amp; Alpha indexes), Points, Lines and Polygons of New G.S.</td>
</tr>
<tr>
<td></td>
<td>NETWORK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The intermediate data will be saved in the Geodatabase but outside the Feature Datasets</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; Geodatabase: Final Evaluation</td>
<td>VECTOR FEATURE CLASSES</td>
<td>New Green Spaces (New G.S.)</td>
<td></td>
<td>Maps, Tables and other Quantitative &amp; Qualitative Measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Any other file that we want to include to the final results for purposes of comparison or digital deliverance</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Synoptically, organization in three geodatabases is proposed:
3.4 Block Initial Evaluation

For the initial evaluation of the distribution of green in the study area, it is recommended to be taken into account the general philosophy of Urban Environmental Indicators (CEROI) on accessibility, environmental protection, and proximity. The only modification is to make use of a combination of Accessible Natural Greenspace Standards and of the blocks’ population density, instead of m² of green per habitant. The Accessible Natural Greenspace Standards (ANGSt) state “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 distance criteria met:

- 20ha site within 2km;
- 100ha site within 5km;
- 500ha site within 10km.

After the conversion of the following geographic data-sets from polygon to raster format, an automated procedure is run through ArcGIS Model Builder, to evaluate the initial blocks:

- Green Spaces [area based];
- Blocks Except for the Green [area based];
- Blocks Except for the Green [primary key based];
- Blocks Except for the Green [population based].

From raster of area-based Green Spaces, regions with an area equal to 20,000 m², 200,000 m², 1,000,000 m², and 5,000,000 m² are selected. In fact, the distance raster from green spaces with area 5,000,000 m² represents the suburban green and the necessary connection to it. Subsequently, Euclidean distances from each cell are calculated and reclassified as follows (Table 3):

<table>
<thead>
<tr>
<th>Value = 1</th>
<th>Value = 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>A = 20,000 m²</td>
<td>D ≤ 300 m</td>
</tr>
<tr>
<td>A = 200,000 m²</td>
<td>D ≤ 2000 m</td>
</tr>
<tr>
<td>A = 1,000,000 m²</td>
<td>D ≤ 5000 m</td>
</tr>
</tbody>
</table>
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.), population density raster 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

<table>
<thead>
<tr>
<th>DISTANCE FROM G.S.</th>
<th>POPULATION DENSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>3 - F</td>
<td>0</td>
</tr>
<tr>
<td>2 - M</td>
<td>0</td>
</tr>
<tr>
<td>1 - C</td>
<td>0</td>
</tr>
</tbody>
</table>

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 for analysis and 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 a proper cell size. Finally, every criterion raster must have the same spatial extent. 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 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, the lower the value on a logical level must be.

To clarify this, we consider the following examples:

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

*Example 2nd.* The overall optimization of residents’ quality of life is a goal. A very important factor is noise pollution. Roads with heavy noise pollution are to be covered with green, so that a physical barrier to the noise can be formed. Therefore, as the values of reported DBs of noise increase, the cost at raster should decrease.

Similar sets of criteria are defined conceptually. These concern:

- Potential new and existing green spaces.
- Ecological improvement and environmental protection.
- City’s bioclimatic performance, its ventilation and decontamination.
- Improvement of quality of life.
- Proximity and types of transportation networks.

Besides the increase of total city green and the connection of green spaces between them, a primary goal is optimization of blocks' status that in the initial evaluation was "judged as badly".

According to the above, every set of criteria will be present and analyzed separately.

### 3.5.1 Criteria: Ecological/Bioclimatic/Service

It should be noted that maps must have the same extent before their addition. This can be easily achieved with if – then – else procedures (e.g. combination of IsNull/Con).

#### i. Criterion of Initial Evaluation:

The output – described in the previous paragraph (3.4) – is a raster showing the initial evaluation of the blocks. The lowest weight will be given to cells exhibiting the worst evaluation, in order to support an inclination for improvement (Fig. 2).

![Figure 2. Blocks’ Improvement](image)
ii. **Criterion Land Use:** 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 into green spaces (Fig. 3). These kinds of areas, characterized “for Relocation”, are Polluted Areas, Unstructured Parcels, and Green Spaces.

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

If Regeneration Areas exist, where there is a serious lack in housing stock, unstructured parcels of these areas must not be preferred, and neither be excluded. Therefore, these areas should participate in this criterion, but with lower weight. Finally, the necessary reclassification of every raster will be on the logic of “Exist – Not Exist”

![Figure 3. Landuse](image-url)
iii. **Criterion of Biodiversity Conservation:** The green spaces’ size, their form, and type of vegetation play a key role in environmental effect and impact (Huber et al., 2012). In this respect, green spaces must cover a minimum area of 10,000 m² and the vegetation should be tall, dense, and irrigated (Fig. 4).

![Figure 4. Vegetation & Biodiversity Conservation](image-url)
iv. **Criterion of Bioclimatic Improvement – Road Air Ventilation:** It is necessary to place tall green vegetation next to roads with intense noise problem as a barrier to sound. An intense air pollution problem is indicated at roads with high average traffic, especially at the layer of air near the ground. On these roads, Greenways and their connection to large patches are crucial for the improvement of the city (Fig. 5). It is most effective if these Greenways are placed on major roads in the direction of prevailing winds.

![Figure 5. Road Ventilation](image)

v. **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 road's ventilation is not proper. The best ratio is 0.5.

In most cases, floor area ratio (FAR) for each neighborhood as well as the building's area is given.

In this case, the buildings will be treated as groups and their height will vary in every urban neighborhood.

\[
H = \frac{(h_1 + h_2)}{2}
\]

In order to estimate the Building Height (H), the following formula can be used:

![Figure 6: General Case of buildings with different heights (H = Arithmetic Mean)](image)
Building Height = \( \frac{100 \times \alpha \times \text{FAR}}{C} \)

C: Coverage
\( \alpha \): average height of every floor (m)
FAR: Floor Area Ratio

**Equation 1:** Building Height (H)

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

Also, the width from building to building and not from one parcel to the other is needed. This might be a continuous value. To overcome this problem, the “aggregate” procedure can be used. Combining Line Statistics and Euclidean Distance procedures, properly parameterized, the road width raster can be calculated with a fine approach.

Finally, the bioclimatic index \( H/W \) has to be calculated (Fig. 7). Through Map Algebra, the two raster datasets have to be divided, and the output reclassified, as mentioned below.

![Figure 7. Index H/W](image)

**vi. Hydrographic Criterion:** The region's hydrographic elements must be taken into account. If rivers or streams exist, Greenways should be created along them; these are called blue-ways by Turner (1995). In the case that the city under examination has a waterfront, or a big lake, the distances from these water elements are calculated.

**vii. Criterion of Travel Networks Use:** The existing travel networks are appropriate to create Greenways along them, with a scalable suitability. The scale used below (Fig. 8) is taken from Lionatou (2008).
viii. **Criterion of Proximity – Service:** It is very important that residents have easy access to green spaces and to connecting nodes, especially to a local level. It is necessary to create a raster of Euclidean Distances from the road network (Fig. 9). The lesser the distance of the green space from the road is, the lower the weight.

ix. **Slope Criterion:** Some of the Planners consider that areas with small slopes are of higher suitability for sitting connectivity Greenways, because they can easily be used as pathways for residents’ movement. At natural banks with steep slopes, the problem of erosion is primary and more important than the movement of inhabitants, so the criterion of suitability should be reversed (Viles & Rosier, 2001, p. 23). Also, Forman (2008, p. 157) states 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. Slope is a very
important factor and may need to be treated case by case. Obviously, if it is a mountainous region, the criterion of the slope must take special care.

### 3.5.2 Ranking

According to Nyerges and Jankowski (2010, p.139), “Ranking is the simplest of all weighting techniques”. Decision Maker starts from criteria arrangement, using the straight importance ranking. Rank Sum is used to compute weights for each criterion as follows:

\[
w_j = \frac{n - r_j + 1}{\sum_{k=1}^{n}(n - r_k + 1)}
\]

**Equation 2: Rank Sum**

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 for each cell at the same location must be added to produce the one and only raster, the cost raster.

### 3.5.4 Geometrical Network

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

There can be two types of destination:

- All existing green spaces for the connection of the ecological network [population movement].
- Polluted areas, or areas “for relocation”, or utility sites [creation of a green network as a service to residents].

### 3.5.5 Least-Cost Path

Landscape representation as a graph, a set of nodes and links, is well established among different disciplines, as well as in Landscape Ecology, and still has much to offer (Urban & Keitt, 2001). As Rudd et al. (2002, p. 368) note, «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 to the destinations with the least possible accumulative cost (Xiang, 1996). Through the Cost Weighted Distance procedure (Verbyla, 2002, pp. 127-133), the algorithm of Shortest Path twice will be used; one for the Ecological Network and one for the Walking Network.

### 3.5.6 Connectivity

At this point, it is necessary to create a modeled procedure to unify these two separate networks automatically, in order to check their overall connectivity, to simplify, and correct (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 Alpha and Gamma indexes (Forman & Gordon, 1986, pp. 417-419; Turner et al., 2001, p. 111) and their formulas are:

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

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

**Equation 3:** Gamma and Alpha indexes

### 3.5.7 Maps, Tables, Alpha, 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 whether the network is Minimum, Medium or Maximum Connected Network (Koutsopoulos, 2006, p. 230). The results can be considered satisfactory if indexes' values 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. Also, a check of blocks’ new condition is performed, concerning the initial evaluation of the “worst” cells, for improvement.

In the following, the steps of the Methodological Framework will be implemented in the municipality of Keratsini, in Greece.

### 3.6 Case Study

We apply the steps of the methodological framework in a real case. Graphically, these steps are shown in Figure 10.
3.6.1 Study Area

The municipality of Keratsini in Greece is selected as a study area, because it is considered a privileged area in terms of place and morphology (i.e. green space per capita is double the average in the Athens area). However, 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.

3.6.2 Data

We collected the data primarily by geo-reference and digitization of the maps of the General Urban Plan of Keratsini and by updating existing data (mainly road network) from the aerial photographs of “KTIMATOLOGIO SA” and “GOOGLE EARTH”. Also, we digitized adequate information from maps of the Athens Urban Transport Organization, namely, pavements, noise data, and traffic data.

3.6.3 Processing

In order to implement the proposed Methodology, we used the software ArcGIS and Autocad. We followed step-by-step the Methodological framework, previously presented, starting with the Blocks’ Initial Evaluation. Then, the mentioned criteria were taken into account, ranked according to Table 5, to create the cost raster (Map 1).

The Shortest Path algorithm is used twice. Two networks are created that connect the sources to the destinations through least-cost path, one Ecological and one Walking network (Map 3).

3.6.4 Case Study Results

The Application results showed obvious improvement. More specifically:

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

It is noteworthy that the new large patch of green (790,000 m²) – sited at the sea front – has a significant contribution in the blocks’ evaluation. This is illustrated in Map 4.

<table>
<thead>
<tr>
<th>Criteria (n)</th>
<th>Hierarchy (ri)</th>
<th>Score (N + 1 - Ni)</th>
<th>Weight (wj)</th>
<th>Weighting (Times)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use</td>
<td>1</td>
<td>10</td>
<td>10/55</td>
<td>0.18</td>
</tr>
<tr>
<td>Green Space Size</td>
<td>2</td>
<td>9</td>
<td>9/55</td>
<td>0.16</td>
</tr>
<tr>
<td>Blocks Initial Evaluation</td>
<td>3</td>
<td>8</td>
<td>8/55</td>
<td>0.15</td>
</tr>
<tr>
<td>Bioclimatic Improvement</td>
<td>4</td>
<td>7</td>
<td>7/55</td>
<td>0.13</td>
</tr>
<tr>
<td>Bioclimatic - Roads</td>
<td>5</td>
<td>6</td>
<td>6/55</td>
<td>0.11</td>
</tr>
<tr>
<td>Type of Vegetation</td>
<td>6</td>
<td>5</td>
<td>5/55</td>
<td>0.09</td>
</tr>
<tr>
<td>Birds Existence</td>
<td>7</td>
<td>4</td>
<td>4/55</td>
<td>0.07</td>
</tr>
<tr>
<td>Hydrographic</td>
<td>8</td>
<td>3</td>
<td>3/55</td>
<td>0.05</td>
</tr>
<tr>
<td>Travel Network</td>
<td>9</td>
<td>2</td>
<td>2/55</td>
<td>0.04</td>
</tr>
<tr>
<td>Transportation Proximity</td>
<td>10</td>
<td>1</td>
<td>1/55</td>
<td>0.02</td>
</tr>
</tbody>
</table>

The Weighted Cost Distance was subsequently created (Map 2).
Map 1. Cost Raster
Map 2. Cost Weighted Distance
Map 3. Shortest Path Algorithm Results
The advantages of locating a unified park with direct access to the coastline are numerous. We can note also that smaller spaces of green are created, either as
stepping stones or as wedge formations, which is a highly positive event that helps the network’s connectivity.

3.7 Conclusions

The objective of this paper is to establish a Methodological Framework, with universal use, in order to evaluate and optimize an urban green network in densely built urban areas. The GIS use and the ability to model procedures make it feasible to choose the raster structure of data for analysis, although it is not as commonly used among users as vector structure. Nevertheless, raster data structure is the most appropriate in cases where there are many criteria involved and continuous overlay of layers. Connectivity will play a prominent role in controlling the structure of the generated network.

This paper is based on the theoretical foundations of Landscape Ecology, Urban Ecology, Green Networks, Bioclimatology, Landscape Architecture, and the new discipline of Landscape Urbanism, combined with Spatial Analysis and GIS. The steps of the Methodological Framework are the following:

- A newly proposed method for evaluating the accessibility of the residents and the accessibility of green spaces (based on area and distance, combined with the population density of the blocks).
- Creating a cost raster, which includes all the criteria (ecological, environmental, urban planning, bioclimatic), along with the appropriate sources and destinations and the use of the algorithm “least cost path”. This will lead to the formation of linear links, not only of the green spaces and green areas connections (existing and proposed), but also of smaller parts and stepping stones.
- The geometrical network is “built” from these links, and its structure is checked by the indexes Alpha and Gamma. This paper claims that the index square meters of green per capita is not satisfactory. The methodological framework proposes to take account of the overall effect of the new green spaces over the wider region and service of the population.

The main advantages of the proposed methodology are:

- Always selects the best possible path for connecting a particular source and destination, instead of creating primary and secondary networks based on suitability.
- The applied processes allow many tests, using several criteria, parameters, etc.
- However, the most important contribution is that it is a tool for testing scenarios of urban planning, which includes bioclimatic and environmental criteria. As a result, its main advantage – outside of modeling – is the use of vector input data, which are created while applying these projects. In order, however, to use it as an instrument of operation and implementation, the unhindered access to updated information (temperature, humidity, air pollution, etc.) as much as to spatial data is a prerequisite. At the same time, Delphi analysis could “fill in the gaps” with experts’ opinions (Eycott, 2011).
• Finally, the proposal of a methodology in the form of modeling procedures of the most 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.

3.8 Further Research

It is crucial to find ways to inform the community about the benefits of green networks (Krummenacher et al., 2008), so that they trust the design, and participate in it actively. Citizens can take part in various stages of design (Sharma et al., 2011) through different ways, including the Internet (WebGIS) (Lwin & Murayama, 2011). This is technologically feasible (Boroushaki & Malczewski, 2010), but much less adapted as a process of participatory decision-making from the corresponding structures of bureaucracy and state structure, as well as in terms of public education in new technologies. However, the most important deficit is in the culture of participation. Programs and processes of learning and educating all citizens in new technologies and GIS are developing in the right direction. Knowledge and understanding of society is the only way to protect the environment and safeguard the future of cities and the whole planet.

REFERENCES


