Analytical model of green-blue connectivity in the metropolitan area of Bucharest

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Abstract: Planning for a green-blue infrastructure contributes to protecting nature and improving the quality of urban life by supporting the ecological, economic and social functions of urban areas. The European Commission states that there is no need for legislation designed exclusively to enforce implementing the concept of green-blue infrastructure in European countries and calls instead for using existing legislation, policy instruments and funding mechanisms. For the effective conservation of biodiversity, territorial planning at any spatial level must be an indispensable tool, especially for a country like Romania, where nature conservation yields almost always to economic development. Therefore, the main objective of our study is developing and implementing an innovative methodology for delimiting green-blue areas and ecological corridors in Bucharest metropolitan area and its integration into national policies and strategies. The methodology for developing the green-blue infrastructure plan is based on European, local and regional data, GIS tools, and urban planning solutions. The results of this study represent a realistic connectivity analysis, which contributes to planning for the green-blue infrastructure within the Urban Plan of Bucharest. As the main conclusion, we mention the need to protect the metropolitan territory of big cities from the intensity and dispersion of urban development.

1. Introduction

The inevitable fragmentation of urban green areas causes a decrease in biodiversity and reduces ecosystem services. Habitat fragmentation and isolation is one of the greatest threats to species survival, resulting into biodiversity loss (Alvey, 2006; Pullinger and Johnson, 2010; Petrișor et al., 2021, 2022). A major challenge for urban planners is to ensure sustainable development, which must integrate economic growth, social well-being and environmental conservation, especially at the urban/rural border, through coherent development policies (Gopinath and Jackson, 2010; Drăghia, 2023). Green infrastructure generally differs from conventional approaches to land conservation and resource protection because it contributes to their conservation through urbanization and human infrastructure planning. Unlike other conservation methods taken independently or opposing urbanization, green infrastructure planning recognizes the need for places where people can live, work, purchase goods, and enjoy nature. Thus, it facilitates development that optimizes land use to meet the needs of people and nature (Benedict and McMahon, 2006; Meneguetti, 2009).
Formal strategies such as green belts, green wedges and greenways can counteract spatial fragmentation by providing green spaces and open spaces close to residents and connecting to rural areas (Laforțezza et al., 2013). Green belt is the best-known model of green space for its connection with the idea of garden city and spread throughout the 20th century. The main function of a green belt is to control urban sprawl. Over time, green belts have become multifunctional, providing people with opportunities for recreation and outdoor sports near urban areas, improving the health of urban populations by protecting air quality, ensuring the protection of agricultural land. Green "wedges", linked by narrower green corridors, provide an interconnected network of accessible and managed green space throughout the city (Stan, 2022). Providing areas for recreation, education, sports, storm water management, air quality improvement and eco-commuting (Sanghamitra and Bharati, 2023), this network includes most of the city's remaining sites of ecological interest outside the specially designated local and national nature reserves in surrounding areas (Petrișor and Petrișor, 2021; Crăciun and Gârjoabă, 2022; Legutko-Kobus et al., 2023). This network helps improving the life quality of residents and provides an attractive framework for new investments (Menenguetti and di Oliveira, 2021). Regarding its relation with the territory, the greenway idea is often linked to protecting rivers and other sensitive natural areas (Fábos, 2004; Quattrone et al., 2017; Krummenacher et al., 2008) and its ability to connect and protect local resources (Palmisano et al., 2016; Dal Sasso and Ottolino, 2011). In terms of the size of greenways and green corridors, narrow corridors configured by waterways or other landscape features are the only space left, and greenways may be the only choice to provide open spaces in high-cost urban land, as they require more less physical space than traditional ones and may include areas with lower real estate value (Smith and Hellmund, 1993). However, corridor width is crucial to enable connectivity and thereby support wildlife, plant life, and hydrology of rivers and streams (Schafer et al., 2000).

The development of green networks is an ambitious initiative that connects green space, road systems and river networks as main components of built urban areas. Planning and design of green networks is a multidisciplinary or even transdisciplinary endeavor, involving a wide range of ecological public and recreational open spaces within the city. Its implementation requires the cooperation of different disciplines and fields, e.g., landscape architecture, urban planning, forestry, nature conservation, environmental management, etc. (Tzoulas et al., 2007). The European Commission (2013) defines green infrastructure as a strategically planned network of natural and semi-natural areas that includes all its ecological characteristics and is designed and managed in a way that provides a wide range of ecosystem benefits. According to the European Commission, local authorities tend to have the main responsibility for implementing the green infrastructure in Europe due to their role in planning and investing in urban infrastructure. They influence the renewal of nature and expansion of infrastructure and have the capacity to promote greener and more sustainable urban centers. The concept has a number of key components: connectivity (e.g. between green areas, undeveloped land and water), and multifunctionality (e.g. areas that have multiple social functions and values). Understanding multifunctionality is central to the green infrastructure approach to land use and spatial planning. Whereas land has many functions, it provides a greater range of social, environmental and economic benefits than could otherwise be provided (Niedźwiecka-Filipiak et al., 2019; Rusu et al., 2020). Landscape connectivity is a crucial feature of green infrastructure (Popescu et al., 2022). Connectivity affects the flow of energy, matter, nutrients, species and people in landscapes.

In Romania, peri-urban landscapes are under great pressure despite their particular importance in introducing effective cooperation methods, common green spaces, green infrastructure planning tools for municipalities and increasing public participation (Iojă et. al., 2020; Petrișor et al., 2020; Nowak et al., 2022). Underestimating the value of goods and services provided by natural areas has been recognized as a major cause of
failing to protect and manage nature in a sustainable way. Not only the easily quantifiable costs and benefits of nature should be considered in decision-making procedures regarding the use of natural resources, but also its intangible costs and benefits (Lette and de Boo, 2002).

Various green-blue infrastructure planning methodologies exist in the European Union and worldwide. These methodologies are based in particular on analyses of management plans for natural and cultural landscapes of national and local importance. However, there are many divergences in the assessment of studied landscapes and GIS methods that are not dedicated to such analyses. For this reason, the assessment of landscape was based on the history and traditions of the area, but also on the analysis carried out by urban specialists drafting the General Urban Plan.

The aim of our project is to develop an innovative method of creating a green-blue infrastructure plan for Bucharest metropolitan area, as an essential part of the urban master plan (General Urban Plan), including an IT component, which represents an innovative and original model in the European Union.

2. Materials and methods

Land use accounts in the study area for the characteristic values of landscape in several categories: zero, low, moderate, high, and very high. In order to evaluate the characteristics of landscape in the studied area, we took into account the biodiversity value, socio-economic value, connectivity aspects and type of ecosystem services offered. For a more accurate assessment of landscape, we used data from the National Agency for Cadastre and Real Estate, European CORINE 2018 data, topographic elevation of Bucharest, and data from the Urban Atlas. A first result was a list of cartographic features and a quick assessment of the landscape of the studied area, their economic and social values described using a landscape feature assessment form. To define the permeability of land occupation area in the study area, we developed an IT solution based on the ARCGIS tool - Gnarly Landscape Utilities. This GIS tool allows for an exact definition of a raster corresponding to areas with high connectivity and areas that constitute barriers in developing the green-blue infrastructure structure. In order to define the connections of areas with high landscape characteristics, we developed an IT solution for assessing the surface of green-blue infrastructure and connections of different green elements, using the ARCGIS - Linkage Mapper tool. In the first phase we obtained the first version of a green-blue surface of the pilot area. For a realistic delimitation we overlaid the green infrastructure raster (study area with green infrastructure mapped in the first phase) with property data (raster purchased from the National Agency for Cadastre and Real Estate Advertising). Thus, we defined as few connections crossing private properties as possible, taking into account the difficulty of planning for privately owned areas. The last version, which is also the realistic one, was obtained by overlaying the second version rater with satellite images (Copernicus).

The green infrastructure analysis model for Bucharest is designed so that it can be used with input data for different scales, since necessary input data are available at different qualities. The quality of results is based on the homogeneity and quality of input data. The ultimate objective is to see natural and agricultural areas forming a single territorial ecological matrix, ensuring sustainability and biodiversity (Stan and Cortel, 2022).

In accordance with current scientific approaches, we decided that the main components of green infrastructure used in this study are landscape units labeled as central areas (core areas), dispersion connections, matrices and corridors. Core areas are part of green areas and have the highest values of recreation, nature and culture. They have a wide range of cultural values, great biodiversity and variability, which ensure good conditions for the reproduction and spread of animals and plants (RPN, 2010). Dispersion connections are narrow sections in continuous green wedges. These parts are essential for linking core areas to provide recreational pathways, create access
to greater walking areas and maintain ecological dispersion (RPN, 2010). Green corridors are linear open spaces, including green parks, agricultural land or natural or semi-natural areas existing inside or outside urban areas for environmental and landscape protection. Matrices are landscape units whose biodiversity and land cover are not as varied as those of core areas.

One of the most difficult problems for delimiting and managing the green-blue infrastructure of large cities, affecting the preservation of connectivity and identification of landscape types, is the collection of data and assessment of their quality for a correct assessment, but also the ability to manage large amounts of data. For this reason we identified data sources for the land cover of studied area consistent with CORINE and the Urban Atlas (Petrişor and Petrişor, 2015; Petrişor, 2015). In this regard, land cover data on Bucharest metropolitan area includes data from the National Agency for Cadastre and Real Estate, data on the hydrographic cadastre from the database of “Apele Române” company, and proposals of radial roads of A0 belt, currently under construction and modernization.

For the urban area of Bucharest, we used the topographical support of Bucharest Urban Plan and completed the database with information taken from the Green Cadastre of Bucharest and information on the hydrographic network of Bucharest. The connectivity analysis methodology is based on data processing, in accordance with the characteristic values of landscape on several categories and requirements of Gnarly_Landscape_Utilities and considering the capability of GIS Linkage Mapper tool and correct choice of basic core areas in the identifying ecological corridors of connectivity. The methodology schematics are displayed in Figure 1.

**Figure 1.** Schematics of the green-blue infrastructure planning methodology for Bucharest metropolitan area. Source: Created by the authors.

The first level of data collection and processing relates to land cover in Bucharest metropolitan area. Data was processed at a regional level - Bucharest metropolitan area, and at a local level - Bucharest, transformed into geodata, and then into two rasters that were processed using Gnarly Landscape Utilities. The two rasters were named Rrsland (land cover raster) and Rraces (transport infrastructure raster). The weights of land cover and transport infrastructure data were determined based on many discussions with specialists in urban planning, landscaping, ecology, geography, urban engineering. The data of the two rasters, according to the requirements of Gnarly Landscape Utilities, is presented in Table 1.
It is noted, according to the methodology, that natural watercourses are considered ecological corridors. Also, in order to have an overview of connectivity needs for the studied area, we compared data sources from the past (military topographic maps 1:25000 from 1950s-1960s, topographic maps scale 1:50000, 1:10000) with the sources of current data. Thus, the green core areas corresponding to proposed connectivity analysis were identified. In this regard, we transposed into GIS the radial roads of Bucharest A0 belt proposed by the agreement signed by the Ministry of Transport and Bucharest Metropolitan Area Intercommunity Development Association. This road network will more efficiently connect local communities around Bucharest and eliminate congestion in the capital.

Table 1. The weights of the two raster values (Rrland and Rraccess) according to the analyses carried out with the specialists and requirements of Gnarly Landscape Utilities.

<table>
<thead>
<tr>
<th>Data Layer</th>
<th>ID</th>
<th>Class Description</th>
<th>Resistance</th>
</tr>
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<tr>
<td>rracces</td>
<td>1</td>
<td>Streets</td>
<td>30</td>
</tr>
<tr>
<td>rracces</td>
<td>2</td>
<td>Streets with over 1000 vehicles</td>
<td>50</td>
</tr>
<tr>
<td>rracces</td>
<td>3</td>
<td>Railways</td>
<td>60</td>
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<tr>
<td>rracces</td>
<td>4</td>
<td>Highways</td>
<td>90</td>
</tr>
<tr>
<td>rracces</td>
<td>5</td>
<td>Engineered roads</td>
<td>20</td>
</tr>
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<td>1</td>
<td>Isolated constructions</td>
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</tr>
<tr>
<td>rrland</td>
<td>2</td>
<td>Constructions with very low density</td>
<td>60</td>
</tr>
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<td>Low density constructions</td>
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<td>rrland</td>
<td>6</td>
<td>Constructions with very high density</td>
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<td>7</td>
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<td>0</td>
</tr>
<tr>
<td>rrland</td>
<td>8</td>
<td>Green areas and leisure facilities</td>
<td>5</td>
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<td>9</td>
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<td>20</td>
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<td>rrland</td>
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<td>Complex cultivation patterns</td>
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<td>25</td>
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<td>Medium lakes</td>
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<td>rrland</td>
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<td>Lakes with area &gt; 0.7 ha</td>
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</table>

3. Results

According to the methodology, the two rasters were combined with the GIS tool - Gnarly Landscape Utilities in order to obtain the movement resistance raster through each landscape element in the Bucharest metropolitan area (Figure 2). As it can be seen, the lower the value of the landscape element, the easier is the ability to move through the landscape element. We can say that areas colored in yellow are green areas (core areas) where connectivity is very high, green areas are areas with medium connectivity
(matrix), and blue areas are areas with low connectivity, i.e., areas with many constructions.

According to the methodological scheme, the connectivity analysis was carried out both at the regional level (metropolitan) and at the local level (Bucharest).

For the regional connectivity analysis, we used the entire set of geodata representing core areas. The purpose of this analysis was to identify the basic elements of green infrastructure, namely: green belts, green edges and ecological corridors and paths.

Both regional analysis and local connectivity analysis were developed using Linkage Mapper, a dedicated GIS tool supporting connectivity analyses of wildlife habitats. After implementing the GIS tool and assessing connectivity, we overlaid the raster purchased from the National Agency of Cadastre and Real Estate Advertising on the property type in order to change the routes of the ecological corridors, so that they intersect as few privately-owned lands as possible. Finally, for a realistic evaluation of the green-blue connectivity in Bucharest metropolitan area, we overlaid the updated raster with high-resolution satellite images obtained through the Copernicus program.

![Figure 2. Resistance raster regarding the ability to move through each landscape element. Source: Created by the authors.](image)

Following this overlay, we modified the green connections, using data derived from field observations, obtaining a very precise connectivity analysis (Figure 3).

The connections of core areas are dark green ecological corridors. Based on these ecological corridors, we identified the route of two green belts (yellow dots); one around the ring road (orange color) and one around the future A0 motorway. Unfortunately, the green belt around the ring road cannot be closed in the south-west part, because we could not define core areas in that area. According to the connections obtained using the Linkage Mapper tool, we were also able to define three green wedges (green-white triangles) along the new radial roads of the A0 belt proposed for construction and
modernization. The greening of rivers and lakes and development of banks by planting a varied palette of plant species is essential for the green-blue infrastructure of the Bucharest metropolitan area. These areas must become open recreational spaces for population.

In the case of local connectivity analysis, within Bucharest, we used qualitative data regarding the topographic elevation of Bucharest, a data set on the Green Cadastre of Bucharest and sets of geodata on the transport infrastructure and hydrological network. All these data sets were processed together with the Urban Atlas. Also, we used as core areas all green areas in Bucharest larger than 5000 m² and all core areas represented especially by the existing forests at the edge of city core. As in the case of regional connectivity, we used Linkage Mapper, the difference being the degree of detail for the components of the two rasters - land use and transport infrastructure. The results are presented in Figure 4. From the connectivity analysis carried out in GIS, we identified some compact areas (green shaded), where the green infrastructure is well represented, but still fragmented. At the same time, we have large areas with a deficit of green infrastructure, especially in the north-west, south and partly in the east of the city. Due to the very high density of buildings, the connections (orange color) appear along major boulevards or traffic arteries. That is why it is necessary to rethink the development of the road infrastructure in the city by widening the large boulevards and highways and planting some indigenous species of street trees. Another important aspect is the need for greening and landscaping the railway routes that cross Bucharest.

![Figure 3](image-url)
4. Discussion

The proposed methodology is innovative through the use of very precise GIS tools, under the conditions of using correct data sets. The results obtained are very valuable given that Bucharest is one of the most polluted metropolises of Europe and has an average area of green space per inhabitant below 10 m², while the European Union recommends 26 m² per inhabitant. The results are a primer for planning the green-blue infrastructure of metropolitan areas, taking into account that Romania has assumed the objectives of the European Green Pact, which require urgent measures to curb climate change effects and increase biodiversity (Cocheci and Petrișor, 2022).

![Connectivity analysis of the green-blue infrastructure within Bucharest. Source: Created by the authors.](image)

The use of correct data sets, compatible with the European environmental databases – Corine CLC and the Urban Atlas, constitutes a favorable premise for connectivity analysis and green-blue infrastructure planning for metropolitan areas of large cities. An essential element for defining the connectivity analysis is the spatial and temporal scale of the connectivity assessment of green-blue infrastructure. In this regard, data was processed both for the regional level (metropolitan area), and local level (Bucharest). Robust connectivity design with modern methods and application of the best scientific tools Gnarly Landscape Utilities and Linkage Mapper ensure successful connectivity analysis and green-blue infrastructure design. The overlap of results with the property raster (public or private) and high-resolution satellite images constitute essential elements for a real connectivity analysis and implicitly correct design of the green-blue network.
The results of this study represent a realistic connectivity analysis, which contributes to planning for the green-blue infrastructure within the Urban Plan of Bucharest and a necessary document for implementing the Urban Policy of Romania for 2022-2035. The proposed methodology is consistent with European green-blue infrastructure design techniques, but simplified by using the two GIS tools. It is true that this methodology requires both qualitative and quantitative data and also a good knowledge of the two tools. The resulting connectivity analysis is very precise and creates the possibility of developing different scenarios for green-blue infrastructure planning. From this perspective, the study underlines the importance of using local data, especially related to property, in the planning process in order to improve local sustainability (Crespo and Rajabifard, 2022; Alonso Frank and Mattioli, 2023) and obtain realistic solutions. The solution presented in this study was proposed as part of the new Master Plan for Bucharest.

For this reason, the study carried out has certain limitations in terms of green-blue infrastructure planning, since we did not address all possible scenarios and did not consult a critical mass of specialists required in related fields to determine the most correct option. Also, the lack of local data does not allow us analyzing the sectors of Bucharest, where innovative green solutions are needed to contribute to urban regeneration.

5. Conclusions

Green-blue infrastructure is essential in achieving the objectives of the European Green Deal, in terms of climate change, biodiversity, social conditions and economic development. The implementation of green-blue infrastructure is even more important in Romania, where green spaces have substantially reduced their area in contradiction with the expansion of built surfaces, often uncontrolled, which has led to air and soil pollution, decrease of urban water quality and poor waste management.

Designing green-blue infrastructure requires a very large volume of data at different spatial scales. Data collection and processing is essential for the correctness of results and the most thorough activity within our methodology. These data must be processed for implementation in GIS, using European spatial databases for the environment – CORINE and Urban Atlas. Connectivity analyses require accurate GIS tools to assess the connectivity of green core areas. In our methodology, we used two GIS tools – Gnarly Landscape Utilities and Linkage Mapper, dedicated to regional and local connectivity analyses. For a real connectivity analysis we overlaid the connectivity raster with the property (private or public) raster and high-resolution satellite imagery. Based on the connectivity analysis, different green-blue infrastructure planning scenarios can be proposed.

One of the main objectives of the Green-Blue Infrastructure Strategy is to integrate its goals and related objectives into as many policy areas as possible. Policy areas particularly highlighted as suitable for integration are: climate, water, nature conservation, especially through the EU Biodiversity Strategy, regional policy, land and soil. As the main conclusion, we mention the need to protect the metropolitan territory of big cities from the intensity and dispersion of urban development by integrating green-blue infrastructure and sustainable dedication in urban and territorial planning.

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