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Conceptual Model for Integrating the Green-Blue Infrastructure in Planning Using Geospatial Tools: Case Study of Bucharest, Romania Metropolitan Area

Antonio-Valentin Tache [1,2], Oana-Cătălina Popescu [1,2] and Alexandru-Ionuț Petrișor [1,2,3,4,*]

[1] National Institute for Research and Development in Constructions, Urbanism and Sustainable Spatial Development URBAN-INCERC, 021652 Bucharest, Romania; tonytache62@gmail.com (A.-V.T.); oana_katalina2006@yahoo.com (O.-C.P.)
[2] National Institute for Research and Development in Tourism, 050741 Bucharest, Romania
[3] Doctoral School of Urban Planning, Ion Mincu University of Architecture and Urbanism, 010014 Bucharest, Romania
[4] Department of Architecture, Faculty of Architecture and Urban Planning, Technical University of Moldova, 2004 Chisinau, Moldova
* Correspondence: alexandru_petrisor@yahoo.com; Tel.: +40-213-077-191

Abstract: A green-blue infrastructure is essential for achieving the European Green Deal objectives and can be used to protect large cities and their metropolitan areas against urban sprawl. Green-blue infrastructure is an important research topic, because green-blue planning networks provide solutions for mitigating contemporary growing urban and climate challenges. Our study aims to create an innovative methodology for defining and analyzing the elements of green-blue infrastructure and their connectivity within Bucharest, Romania and its metropolitan area, to serve as a planning model. The methodology consists of merging European geodata sets with metropolitan and local data, using GIS tools, and analyzing the connectivity within the study area. All connections resulted from implementing the Linkage Mapper tool were operationalized, using high-resolution satellite images and correcting obtained connections, so that deviations from reality were minimized. The results consist of a conceptual model for planning the green-blue infrastructure within Bucharest and in its metropolitan area, embedding an analysis of its connectivity. The study contributes to implementing the concept of green infrastructure in urban and spatial planning, providing tools for planning the green-blue infrastructures of large cities and their metropolitan areas and, implicitly, reducing urban sprawl, improving air quality and mitigating environmental threats due to climate change.

Keywords: urban greenery; ecosystem services; urban biodiversity; climate changes; environmental planning; landscape connectivity; geospatial analyses

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1. Introduction

1.1. Green-Blue Infrastructure Approach

Globally, natural landscapes are undergoing drastic changes due to anthropogenic pressures, which include habitat loss and fragmentation [1,2]. Neglecting ecological processes in urban land use decisions can lead to the degradation of the integrity and diversity of landscape structures, the deterioration of ecosystem functions in natural areas and urban green spaces, and fragmentation or even destruction of habitats [3–5]. The long-term effect of increased landscape fragmentation is the decline in biodiversity, ecosystem resilience and ecosystem services [6,7]. As a result, the quality of urban life and sustainability of cities decline.

Europe, as a territorial dimension, is characterized by a fragmented natural landscape, intersected with high human population densities. The need for measures to conserve habitat connectivity is of great importance and urgency as a result of the recognition that

habitat fragmentation can exacerbate the potential impacts of climate change [8]. That is why, in 2013, the European Commission asked European countries to make a special effort to protect their last remaining natural habitat areas. The European Commission considers green-blue infrastructure as infrastructure capable of providing sustainable management of green and blue areas in the context of climate change and providing a wide variety of benefits to society [9]. The European Commission states that there is no need for legislation designed exclusively to enforce the implementation of the green-blue infrastructure concept in European countries and calls instead for the use of existing legislation, policy instruments and financing mechanisms [10]. These needs also call for studies on the green infrastructure, making it an important research topic.

1.2. Theoretical Aspects

The main attributes of green-blue infrastructure are spatial connectivity, multi-functionality, integration with other infrastructures and a multi-scalar approach. Connectivity is a particularly important value for green-blue infrastructure due to its ecological and social benefits [11–14]. Connectivity is the key principle of spatial organization to ensure a better opportunity for the provision of ecosystem services, which can affect urban hydrology, mobility, recreation and cultural assets. In addition, the functional and spatial connectivity of open spaces is essential for maintaining the ecological role of mitigating and adapting to climate change and increasing the value of ecosystem services, including those related to health and recreation [15].

Understanding multifunctionality is central to the green-blue infrastructure approach to land use and spatial planning. Where land serves a range of functions, multifunctionality is the ability of green-blue infrastructure to provide a much greater range of social, environmental and economic benefits than could otherwise be provided [16]. Integration expresses the physical and functional relationships of green-blue infrastructure with other types of infrastructure, and successful planning of green-blue infrastructure naturally requires an integration of different scales of planning and implementation [17].

1.3. Planning Approaches

Formal strategies such as green belts, green wedges and green ways can counteract spatial fragmentation by providing green spaces and open spaces close to residents and connecting to rural areas [18].

The green belt is the best-known model of green space for its connection with the idea of a garden city and its spread throughout the 20th century. The main function of the green belt is to ensure the control of urban sprawl. Over time, green belts have become multifunctional and continue to have a major impact on urban design. The idea of a ring of countryside surrounding an urban area to prevent sprawl emerged in the 1930s and spread to post-war London, being passed into national law in 1955 [19]. Currently, many Western European cities have demarcated and developed green belts with the role of stopping the unplanned expansion of the periphery in the territory and connecting the main areas with tourist and landscape potential.

Green wedges constitute a coherent structure of areas with high recreational, natural and cultural values. They form an amalgamation of green areas and watercourses in relation to built-up urban areas and provide good access to urban nature [20]. This type of green area planning was implemented in the Scandinavian countries, where both historical traditions and the topography of the designed surfaces were taken into account. Green belts and green wedges have in common that they often follow (public) transport corridors, and especially railways [21].

The concept of *greenways* appeared in North America at the beginning of the 20th century. Fabos [22] noted three types of benefits of greenways: ecological, recreational, and historical/cultural. They were created to develop greenway systems that interconnect cities with natural areas or forest areas in metropolitan areas [23,24].

Green corridors were designed as habitat areas for connecting wildlife populations (colonization, migration, etc.), areas that have become fragmented over time by human activities [25]. These corridors can include rural areas, river courses, lake areas, hill areas, natural forests or agricultural areas, being a logistical support for urban development, landscape protection and a healthy urban environment.

1.4. Implementing the Green-Blue Infrastructure

The new concept of green-blue infrastructure offers potential for a more comprehensive analysis and promotion of the connectivity of green and blue spaces and landscape integration. Initially, the concept included an aesthetic vision; it gradually morphed towards a very ecological view and later became a tool for sustainable land use planning [26].

The combination of methods that ensure the connectivity of green-blue infrastructure and its multifunctionality should be recommended, especially for city regions, due to the need to protect nature and biodiversity conservation, on the one hand, and sustainable development with its environmental, social and economic needs, on the other hand [17].

A positive example of green infrastructure implementation is the United Kingdom, which, in its national planning policy, indicates that plans at all levels must be approached strategically to conserve and enhance the network of habitats and green infrastructure [27]. The Good Practice Guide for Natural Environment Planning [28] states that green infrastructure requirements should be considered in the early stages of planning and should be included in drafting development proposals. A good practice example of implementing the concept of green-blue infrastructure is the revised planning legislation in Sweden, which recommends that Swedish cities develop a green infrastructure plan as an essential part of the urban development plan [29]. Thus, green infrastructure was implemented both at the local level (Stockholm city level) and at the regional level—the Regional Development Plan for Stockholm.

Unfortunately, in Eastern European countries, the concept of green-blue infrastructure has been approached to a much lesser extent than in Western European countries. The exceptions are the Czech Republic and Slovakia, which, since 1970–1980, have developed a multi-level ecological network, called the Territorial System of Ecological Stability of the Landscape (TSES) [30].

1.5. Green-Blue Infrastructure Planning Steps

Research shows that the implementation of green-blue infrastructure in European countries has focused on measures to improve ecological networks and preserve green space [31]. Compared to ecosystem services, landscape services take more into account the spatial patterns resulting from human and natural processes, and the social dimension [32]. According to the literature, the methods of planning and evaluating the green-blue infrastructure system in metropolitan areas of large cities include several stages:

− Dividing the planned green-blue infrastructure system into functional landscape units and evaluating them according to the benefits they provide to society and according to the permeability to the movement of species within them;
− Determining a hierarchy of functional landscape units according to biodiversity value, economic and social value, the types of ecosystem services offered and the connectivity aspects of the landscape;
− Elaborating a map of the functional landscape units showing the listed characteristics;
− Developing a synthesis raster of the green-blue infrastructure, using the Geographical Information Systems;
− Promoting integrated spatial planning by identifying multifunctional areas or by incorporating habitat restoration measures and other connectivity elements into different land use plans and policies [33].

However, the boundary between green-blue solutions and existing ones is still unclear. Nesshöver et al. [34] proposed the introduction under this umbrella of green-blue solutions by addressing the following four areas of intervention: (a) maintaining biodiversity, ecolog-

ical functions and/or ecosystem services, where human management interacts with natural processes; (b) restoration of ecosystems affected by human activities; (c) design solutions that address challenges such as climate change or risk management, and (d) sustainable use of nature to mitigate challenges affecting quality of life, including vulnerability, social equity, economy and culture.

Even if the studies recommend using qualitatively different datasets at regional and local levels, they do not take into account the ownership regimes and the overlap of geodata obtained with high-resolution satellite images or obtained using UAVs. The overlay of processed geodata with satellite images creates the prerequisites for developing a much more consistent green connectivity analysis and avoiding, as much as possible, the intersection of green corridors connecting with private land surfaces. At the local level, the resulting green-blue connections can be numerous, many of which are difficult to implement. The choice of viable connections at the local level requires the use of old plans and maps of the city, which provide information on the fragmentation of green-blue areas over time.

1.6. Green-Blue Infrastructure in Romania

Although Romania is one of the first countries to ratify the European Landscape Convention, adopted in Florence on 20 October 2000, it has not taken any measures arising from this convention [35]. Ignoring the issue of landscape as a fundamental element of the national cultural heritage and as an essential mechanism of sustainable development has resulted in the loss of many unique natural areas. In this regard, the landscape represents the integrative tool of policies to protect cultural and natural heritage with development policies. However, its importance has remained until this moment only at the declarative level, as no operationalization mechanisms were provided in the territory [36].

In Romania, since 2001, as required by Law no. 351/2001 on the approval of the National Territorial Development Plan, Section IV—Settlement Network [37], it was necessary that urban plans provide for the establishment of green belts or green areas around the city of Bucharest (the country's capital) and first-class cities. Later, Law 351/2001 was updated by Law no. 190/2019 [38] which provides for the establishment of green belts or green areas also in the case of second-class municipalities. Unfortunately, so far this requirement has not materialized.

In Romania, development strategies and plans are the most important documents for the integration of green-blue infrastructure at local and regional level [39]. But general urban plans and local action plans for the environment offer a rather limited vision in relation to the principles of implementing green solutions, and there is a low degree of implementation in the actions proposed at the level of cities in Romania [40].

The green-blue infrastructure of Bucharest and its dynamic were investigated by Petrişor et al. [14,41], based on Urban Atlas data. According to the aforementioned studies, the green-blue infrastructure of Bucharest consists mainly of agricultural areas (64%), followed by green spaces (20%), forests and natural areas (11%), and leisure areas (5%) [41]. As can be seen, landscaped areas make up one fourth of the green infrastructure. During the two periods covered by Urban Atlas Data (2006–2012 and 2012–2018) Bucharest experienced the fragmentation and loss of its green infrastructure; although some gain occurred in both periods, it was not sufficient to compensate for the loss [14]. For each category of green-blue infrastructure, the loss was proportional to its share.

Bucharest is one of the most polluted cities in Europe, with an average area of green space per inhabitant below 10 square meters, compared to the requirements of the European Union, which recommends 26 square meters of green space per inhabitant, or the World Health Organization, which recommends 50 square meters per inhabitant [42].

1.7. Need for Research

In Bucharest, a study regarding the identification of a green-blue infrastructure plan is absolutely necessary to make green-blue infrastructure an indispensable tool for territorial planning at all levels.

By addressing the previous shortcomings, the purpose of this study is to define an innovative methodology based on GIS tools that leads to the design of green-blue infrastructure both at the local level of a large city and at the regional level of a metropolitan area. Even though GIS tools are mainly used in connectivity analyses of wildlife habitats, they can also have very accurate results in green-blue connectivity analyses, provided that qualitative data is used and realistically processed to identify the resistance raster of moving through the landscape. The key to designing green-blue infrastructure at the local and metropolitan levels is to combine connectivity analysis with the conceptual model of this type of infrastructure. Data on the ownership of the studied areas and the use of high-resolution satellite and UAV images create the prerequisites for correcting the components of the green-blue infrastructure, so that the results are also validated on the field.

The results of this study contribute as a model of good practice, both to the creation of the institutional framework at the national level and to the provision of action models for the conservation of biodiversity and mitigation of climate change within the Urban Policy of Romania 2022–2035, a document to be approved by Government.

2. Materials and Methods

2.1. Principles

Since the lack of management plans for natural and cultural landscapes of national and local importance has led to the degradation of many of those from the metropolitan area of Bucharest, there is a need to develop and implement innovative methods of delimiting the green-blue areas and corridors of habitat. The methodology proposed in this endeavor starts from some basic principles related to the establishment of a functional connectivity both within Bucharest and between it and its peri-urban area.

1. The first important aspect is establishing a balance between the interests of residential development and the use of open space. The key element is preserving the multifunctionality of open space, specifically green-blue areas and habitat corridors that must be secured in order to support ecological functions and benefits for people in terms of social well-being and recreation. Open urban areas remain the most important spaces of social contact for city dwellers despite technological progress and its impact on the social life of the individual (social networks, virtual reality, etc.), so their importance for cities remains undisputed [43]. Urban public spaces represent those places located in cities and which are open (squares, parks, as well as connecting spaces such as sidewalks and streets).
2. Successful green-blue infrastructure planning naturally requires the integration of different planning scales (local/regional level). It is necessary to identify the corridors and blockages in the landscape for the connection of green-blue areas, the movement of species and their mapping.
3. Another important aspect is the need to expand green areas inside and outside the city to improve the microclimate that contributes to lowering the temperature and the urban heat island (UHI) effect, reducing energy consumption in buildings, managing rainwater, increasing the resilience of ecosystems by improving their functional and spatial connectivity.

Starting from these principles, a territorial analysis scheme was created that includes the planning concepts of green-blue infrastructure connecting green space, open areas, road and rail systems and water sources as elementary components in built-up urban areas and in peri-urban areas.

2.2. Input Data

The methodology for identifying the green-blue belt of the Bucharest metropolitan area (Figure 1) was designed so that it can be used with input data at different scales, since necessary input data are available with different quality levels. The quality of results is based on the homogeneity and quality of the input data.



Figure 1. Bucharest metropolitan area (in green): location in spatial relation to the national territory and its neighboring countries.

Data used: For Bucharest, digital data taken from the Bucharest Urban Plan, government sources and digital data from the Urban Atlas were combined, and for the metropolitan area, CORINE 2018 database and data from the National Cadastre Agency were used.

Data processing was based on the authors' experience in ecology and spatial planning and on European research on connectivity and the provision of landscape services.

The evaluation of the green-blue infrastructure connectivity was carried out based on innovative tools of the ARCGIS 10.6 (Figure 2).

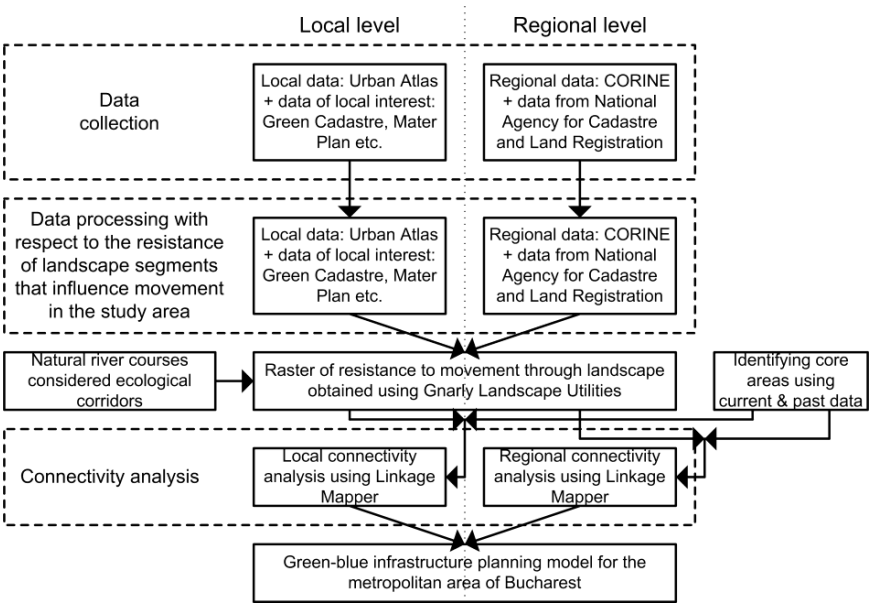


Figure 2. Schematics of the research methodology.

Starting from applying ecological landscape principles and evaluating existing green spaces, the methodology proposes four green wedges and several green corridors from the suburbs to the center of Bucharest (Figure 3). The green wedges were designed along the future radial roads of the A0 belt. The two green belts are intended to protect the belt ring of Bucharest and the future A0 highway from the winds coming during winter from the east. These green belts have the role of stopping urban sprawl and supporting human activities such as walking, cycling and recreation.

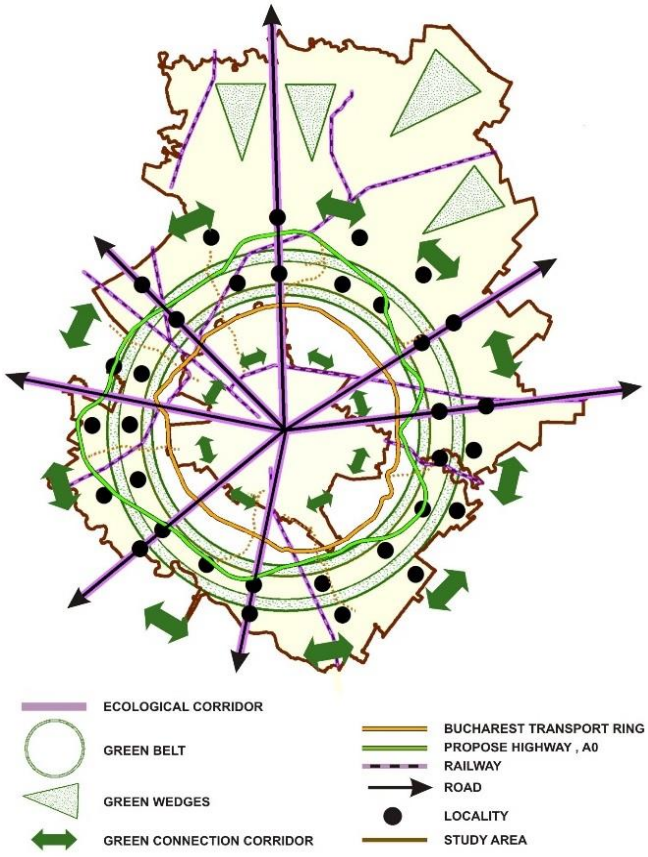


Figure 3. Conceptual diagram of the green-blue infrastructure of Bucharest metropolitan area.

2.2.1. Data Digitization

The proposed methodology combines data sources provided by older or more recent maps with data obtained through new technologies. This was necessary to model the wildlife habitat and connectivity needs driven by impending climate change. Thus, in order to evaluate the existing habitat areas in the past, we used a military map dating from the 1950s. These data were digitized and overlapped with CORINE 2018 database and data from the National Agency for Cadaster and Real Estate Advertising (Figure 4). By digitizing the core areas on this plan, we found that some forests (dark green core areas) no longer exist today, having been transformed into agricultural land. In order to have as many basic elements (core areas) as possible, the analysis carried out at the regional level considered those forest elements that existed 80 years ago, considering that in the future these lands need to be transformed into forests to ensure the connectivity of green areas.

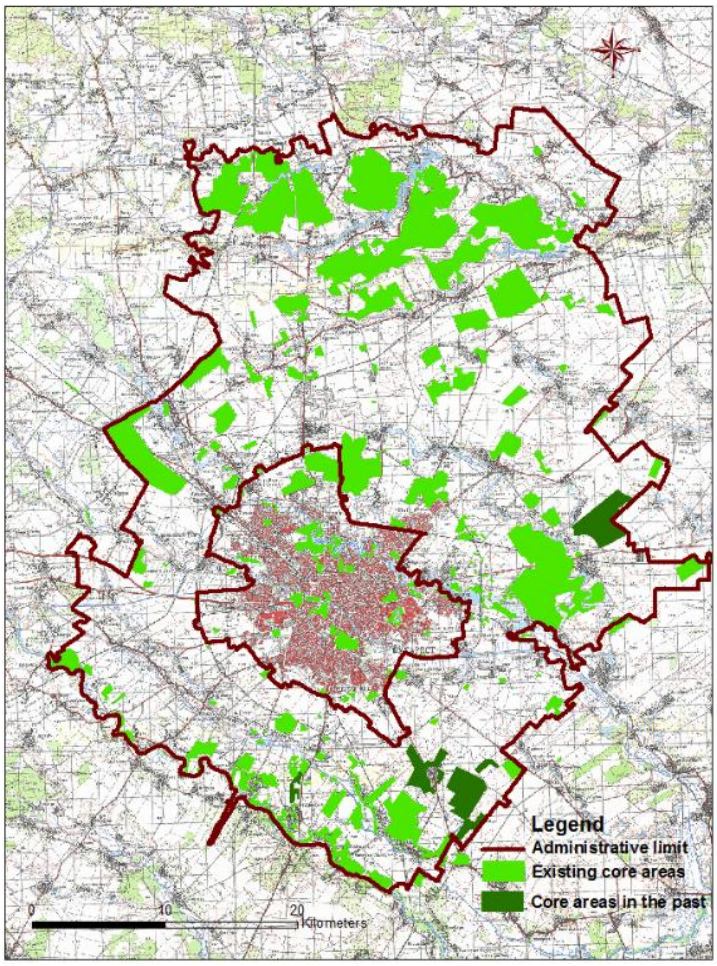


Figure 4. Digitization of core areas in the Bucharest metropolitan area, based on a military map from 1950.

According to the methodology:

− Areas with great biodiversity and multifunctionality represent *core areas*;
− Areas whose biodiversity and multifunctionality are not as varied as the area of basic habitats are called *matrices*;
− Linear open spaces (green parks, agricultural land or natural/semi-natural areas existing inside/outside urban areas for environmental and landscape protection) are considered *green corridors*;
− Natural river courses are considered *ecological corridors*.

As it is necessary to connect green-blue areas through greenways and ecological corridors, the conceptual scheme (Figure 3) provides that riverbeds, railway protection zones and green spaces along roadways, including large boulevards in Bucharest, become *ecological corridors*. The numerous abandoned industrial lands can serve as *stepping stones* for the designed ecological corridors. In Bucharest, bicycle paths are designed to connect big neighborhoods and require the development of paths and green corridors.

Digitized data representing core areas helped to define more precisely the existing connections of the green-blue infrastructure network in the Bucharest metropolitan area.

Source of digitized data:

− Data related to Bucharest were obtained by combining the specific layers from the Urban Atlas with data taken from Bucharest Master Plan on road and railway network, watercourses and urban public spaces such as historic squares, promenade areas, etc.
− Data related to the peri-urban area formed by the administrative-territorial units of Ilfov County were obtained by combining the CORINE 2018 database (for land use) with data

from the National Cadaster (use and type of land ownership), data on the network of transport and watercourses, but also with information on projects aimed at the construction of radial roads for the road belt of Bucharest.

The processing and ranking of the data was based on the specificity and history of the studied area, and analyses carried out in the "Manual of Green Infrastructure functionality assessment" within the project "Managing Green Infrastructure in Central European Landscapes" funded by the European Regional Development Fund (ERDF), and the "Guidelines for regional, interregional and cross-border development strategies creating ecological corridors" within the NATREG project financed by the South East Europe Transnational Cooperation Programme.

2.2.2. GIS Tools

In order to quantitatively assess the green-blue infrastructure in the Bucharest metropolitan area, innovative GIS modeling tools were needed, which have been shown to have a high diagnostic and prognostic capacity [44]. The GIS tools used to define the green-blue infrastructure of the Bucharest metropolitan area were *Gnarly_Landscape_Utilities_0_1_9* and *Linkage Mapper*, innovative tools for defining connectivity in the case of green-blue infrastructure.

Gnarly_Landscape_Utilities_0_1_9

According to the requirements of Gnarly_Landscape_Utilities_0_1_9 tool, a table containing data on the resistance of landscape segments that influence movement in the studied area was developed. The higher the resistance value, the lower the connection capacity of green areas. The weights for the ability to move through landscape (resistance) were determined based on evaluations by specialists from our institutions and based on analyses carried out within the framework of several European projects.

As seen in Table 1, we used two rasters (according to the requirements of Gnarly_ Landscape_Utilities_0_1_9 tool):

− A (common) land use raster for Bucharest and its peri-urban area (rrland). For this raster, we used descriptions from the Urban Atlas database and CORINE 2018 database;
− A raster of transport routes within the studied area (rracces). For this raster, we used the names existing in the Urban Atlas, in four categories: (a) streets with medium and low traffic, (b) streets with intense traffic (over 1000 vehicles per hour), (c) railways, (d) highways and designed roads, but not yet built in the field.

These grids were processed according to the ranking of data in relation to the ability to move through the landscape and the requirements of the GIS tool that imposed a reclassification according to Table 1.

Linkage Mapper

The Linkage Mapper tool was used to define the connections of green-blue areas and the design of the green-blue infrastructure of Bucharest metropolitan region. Linkage Mapper uses GIS maps of core habitat areas and their resistances to create a map of the least-cost connections between them.

In order to obtain realistic networks of green-blue infrastructure in different landscapes, the Linkage Mapper tool was used both locally and regionally. Thus:

− At the regional level, we compiled the set of geodata available for the European Union (CORINE CLC, Urban Atlas) with regional and local data sets obtained from the National Cadastre Agency.
− At the local level (built-up area of Bucharest), we compiled the data set of the Urban Atlas with local data sets taken from the Cadastre of green spaces for Bucharest, the Cadastre of Romanian Waters, the Agricultural Cadastre and Bucharest Urban Plan.

All linkages obtained through the implementation of the Linkage Mapper tool were re-evaluated, using high-resolution satellite images obtained through the Copernicus program and correcting the obtained linkages so that deviations from the ground values were

insignificant. Thus, we were able to precisely determine the areas of conflict between projected corridors and transport infrastructure, these areas of conflict being positioned on the digital map.

Table 1. Weighting of the values of the two rasters (land use and road and rail transport paths) used for the analysis of lowest travel costs, according to Gnarly_Landscape_Utilities.

Data Layer	Class ID	Class Description	Extra Info	Resistance
rracces	1	Streets	From Atlas	30
rracces	2	Streets with over 1000 vehicles	From Atlas	50
rracces	3	Railways	From Atlas	60
rracces	4	Highways	From Atlas	90
rracces	5	Future roads (planned)	CNAIR	20
rrland	1	Isolated constructions	From Atlas	40
rrland	2	Constructions with very low density	From Atlas	60
rrland	3	Low density constructions	From Atlas	70
rrland	4	Medium density constructions	From Atlas	80
rrland	5	High density constructions	From Atlas	90
rrland	6	Constructions with very high density	From Atlas	100
rrland	7	Forestry	CORINE 2018	0
rrland	8	Green areas and leisure	CORINE 2018	5
rrland	9	Pasture	CORINE 2018	20
rrland	10	Unirrigated land	CORINE 2018	25
rrland	11	Arable land	CORINE 2018	30
rrland	12	Unused land	CORINE 2018	35
rrland	13	Complex cultivated areas	CORINE 2018	40
rrland	14	Orchards	CORINE 2018	50
rrland	15	Rivers	CORINE 2018	0
rrland	16	Swampy areas	CORINE 2018	20
rrland	17	Small lakes	CORINE 2018	25
rrland	18	Medium lakes	CORINE 2018	50
rrland	19	Lakes with area > 0.7 hectares	CORINE 2018	70

3. Results

According to the conceptual green-blue infrastructure planning scheme, the connectivity analysis was carried out both at local and regional levels.

In order to obtain a more complete picture of the regional green-blue infrastructure, we used green core areas that existed in the past (70–80 years ago) and which are currently arable land in the evaluation.

We also took into account the projected route of A0 highway (the second ring highway of Bucharest) and radial roads connecting to it, even if they are not yet physically implemented on the ground.

In order for the analysis to be complete, we considered existing rivers as ecological corridors, even if there are portions of them that do not fulfill this role.

Finally, by applying the Gnarly_Landscape_Utilities_0_1_9, we obtained the resistance raster of landscape segments in terms of connectivity of the green-blue areas (Figure 5).

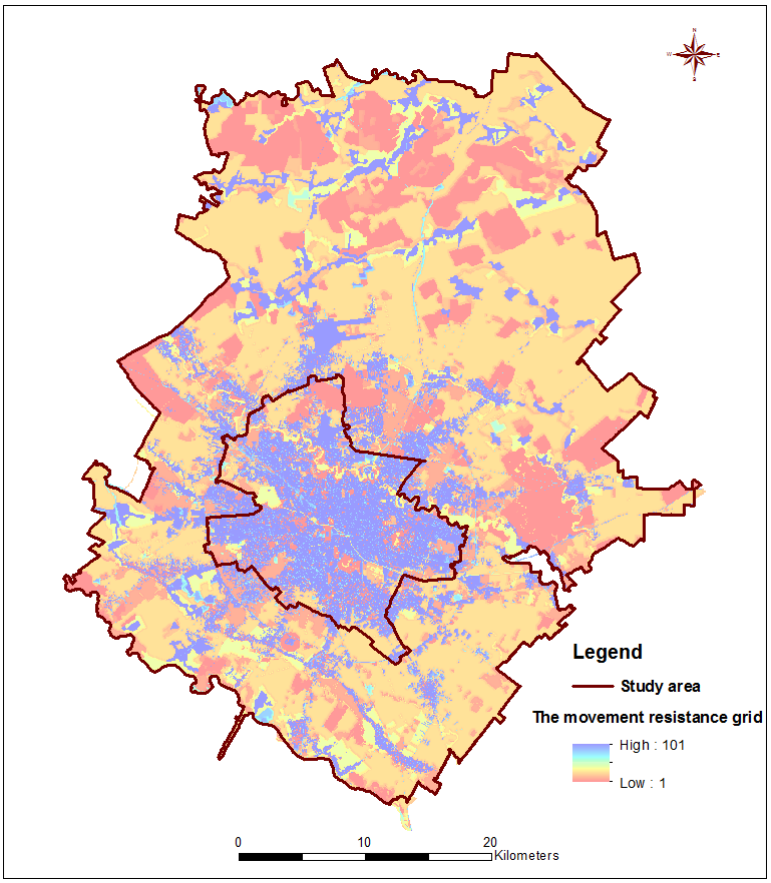


Figure 5. Raster map computed with Gnarly Landscape Utilities representing the movement resistance through the landscape elements of Bucharest metropolitan area.

According to the Legend of Figure 5, we notice that red areas have a very low resistance to movement, which indicates the existence of compact and multifunctional green-blue areas, represented especially by core areas, but also less compact green areas that are part of the matrix or are natural river courses considered ecological corridors. The yellow areas represent agricultural land, unused land, complex cultivated areas, as well as wetlands around lakes and rivers. The blue-colored areas are the areas of high displacement resistance, consisting mainly of constructions or lake surfaces.

3.1. Metropolitan/Regional Level

By using Linkage Mapper, the resistance raster and core areas from the metropolitan area of Bucharest, we obtained the map representing connectivity at the metropolitan level (Figure 6).

It can be seen that, in the south-west part around the belt ring of Bucharest (the first ring), there were no elements of the green-blue infrastructure, so that the green belt could not be closed. Instead, there were sufficient core areas and matrix areas to enclose the green belt around projected A0 freeway second ring). In Figure 6, we also see the links (ecological corridors), in purple, computed with Linkage Mapper, which connect with core areas.

From the maps published 100 years ago, we noticed that many green elements we proposed existed at that time. It is necessary for renatured rivers and streams to be re-arranged by including a wide variety of plant species. They must be used as easily accessible open recreational spaces for people, to bring vitality to the metropolitan area of the city. Also, there is much vacant land that needs to be ecologically restored and returned to nature as they had ecological functions in the past.

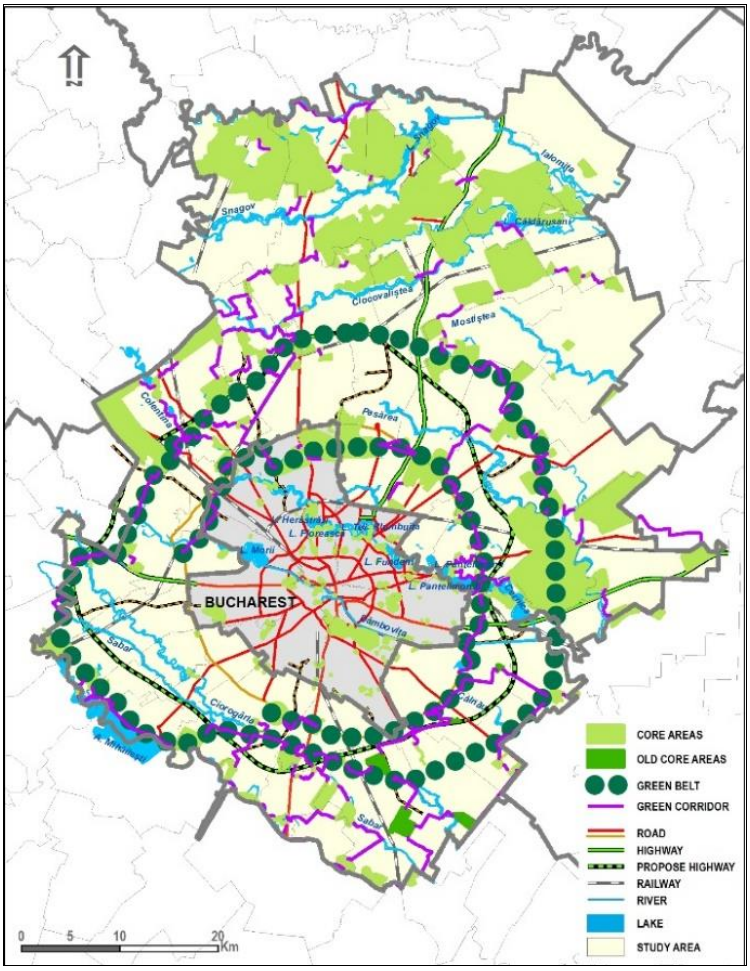


Figure 6. Regional connectivity analysis developed with Linkage Mapper for the metropolitan area of Bucharest.

3.2. Local Level

At the local level, we used the data set from the Bucharest Master Plan, supplemented with geodata on green areas, lakes and rivers in the core of Bucharest, agricultural areas and all existing streets and boulevards in 2022. As core areas, we used green areas from Bucharest with a surface of more than 4000 m^2 and core areas around the central area of Bucharest.

Using Linkage Mapper, the resistance raster and core areas for Bucharest, we obtained a large number of green connections along some important streets and boulevards (Figure 7).

The analysis carried out (Table 1) shows that many of the resulting ecological corridors at local level (green color) develop along major boulevards, which means that there is a need to widen major boulevards and arteries and plant trees. We can see four compact areas (orange color in Figure 7) that contain a lot of fragmented green spaces and some areas—especially in the south and west of Bucharest—that require urgent implementation of green solutions. It results that in the urban area of Bucharest, especially in the city center, but also in certain neighborhoods, there are acute conflicts between high-density development and limited land, with insufficient open spaces for the population.

Taking into account the very high density of housing in Bucharest, innovative green solutions that can contribute to urban regeneration are recommended. Among these we mention green roofs (including solar roofs, for water drainage), green walls and vertical gardens, green street furniture, permeable pavements, and greening linear transport routes.

There is a continuous fragmentation of the areas that contained green spaces 70–80 years ago in Bucharest, caused by the continuous expansion of residential neighborhoods [45]. For this reason, there is also an urgent need for the regeneration of abandoned commercial and industrial areas [46], and, last but not least, the legal designation of some urban protected areas, as an absolutely necessary tool for Bucharest in order to achieve sustainability and resilience targets.



Figure 7. Local connectivity analysis developed with the GIS tool—Linkage Mapper for the metropolitan area of Bucharest.

4. Discussion

4.1. Scientific Significance and Importance of Results

From a scientific point of view, the research carried out represents a viable technical solution for stakeholders, taking into account the quantity and quality of data used, and the innovative IT solutions on green-blue infrastructure. The technical solution is safe and effective under the conditions of good knowledge of the research context and rich experience in using GIS tools. This study presents a way to connect the green-blue areas inside and outside Bucharest, so that road transport rings are surrounded by green belts that can stop uncontrolled urban expansion.

The GIS solutions chosen to define connectivity were designed to support wildlife habitat connectivity analyses. The tools Gnarly_Landscape_Utilities and Linkage Mapper used in this research are usually used in GIS mapping. When defining the models with lowest costs, cumulative cost maps are generated; they highlight areas with lowest costs, respectively, the least expensive ways to travel between core areas. These tools create very

accurate connections if the data are of good quality and well processed. A disadvantage in implementing these tools is the very demanding hardware resources for computing connections. The use of high quality geodata in GIS creates the prerequisites for overlaying with high-resolution satellite or UAV images, which leads to the correction of identified errors and the correct definition of green connections.

At the same time, the research aimed to develop a methodology that would contribute to a better implementation of the green-infrastructure concept in the urban and territorial plans of the metropolitan area of large Romanian cities.

From previous experiences with landscape and connectivity analyses within national ecological networks, we have found that, for a proper assessment, a fundamental step in such studies is the collection of high quality data, as well as the ability to manage the large amounts of data available. Criteria are needed to determine which data to include or exclude from the different sets of information available for connectivity assessment. Assessment processes must be iterative in nature so that the data systems used are able to integrate new and better performing data to improve the quality of assessment tools.

Therefore, the data used in this study, both locally and regionally, required many data sources and additional compatibility analyses with GIS systems. GIS models are widely used tools for designing ecological corridors, and least-cost modeling allows for parameterization and testing through empirical studies. We used two GIS tools, extremely precise in defining the connectivity analysis. Starting from a conceptual model of extended green-blue network connectivity and mapping the components of the green-blue network of the Bucharest metropolitan area (core areas, ecological corridors, buffer zones and ecological reconstruction areas), we were able to obtain a green-blue infrastructure model that introduces mandatory environmental regulations for territorial planning, taking into account ecological resilience, ecosystem vulnerability and ecosystem support capacity.

Overall, our study makes a significant contribution towards the implementation of the concept of green infrastructure in urban and spatial planning, providing tools for planning the green-blue infrastructures of large cities and their metropolitan areas. Implicitly, our methodology helps towards reducing urban sprawl, improving air quality and mitigating environmental threats due to climate change, contributing ultimately to urban sustainability.

4.2. Internal Validation Related to Research Objectives

The lack of management plans for natural and cultural landscapes of national and local importance determined the need to develop an innovative study for designing the green-blue infrastructure of the Bucharest metropolitan area. This study approaches new ways and re-combines natural resources in different and creative ways, so as to control the environmental challenges that Bucharest encounters.

Three main elements contributed to the identification and operationalization of green-blue infrastructure in the Bucharest metropolitan area: Gnarly_Landscape_Utilities and Linkage Mapper GIS tools; data on the property regime in the studied areas; and high-resolution satellite images. With their help, connectivity analyses of green-blue areas were carried out and connections of green areas defined by intersecting as few private surfaces as possible.

The principles of implementing green solutions must be compatible with the general principles of territorial planning and environmental protection. The most difficult problem in the delimitation and management of a green-blue infrastructure of metropolitan areas in large cities is the collection of data and assessment of their quality.

For this reason, various sources of data are aimed at regional- and local-level coverage. It was necessary to join some data sources from the past with current ones and those from future plans and projects, using new technologies, in order to model connectivity needs in the face of imminent climate change. At the same time, we took into account that the spatial and temporal scale of assessing green-blue infrastructure connectivity in a large city (such as Bucharest) is one of the most important aspects of research [47].

Land cover maps available at European Union level, such as CORINE2018 database or the Urban Atlas, can help with a general assessment of green-blue infrastructure connectivity, but cannot provide accurate information on the local network of green-blue infrastructure elements. Therefore, the structure of the database had to be supplemented with the available, detailed regional and local data, such as data acquired from the National Cadaster Agency, Romanian Waters, Cadaster of green spaces in Bucharest, Agricultural Cadaster or data taken from Bucharest Master Plan. The IT solutions used in evaluating the spatial connectivity of green-blue infrastructure components are modern state-of-the-art solutions. The mapping of corridors also highlighted existing points of conflict between the continuity of connecting corridors and transport infrastructure [48]. These conflict points could be precisely identified by using satellite images from the Copernicus program. The use of high-resolution satellite images overlapped on processed geodata also led to accurate results in the assessment of spatial connectivity and green infrastructure components of the Bucharest metropolitan area.

4.3. External Validation Related to Research Objectives

The methodology used in this study presents the advantage of a simple and precise technical solution compared to other international studies [5,17,49]. The chosen technical solution requires very good quality data and good experience in processing and implementation in GIS. The use of land ownership data (either private or state) and the overlap of processed geodata with high-resolution satellite images constitute another advantage of the methodology in identifying the most correct green-blue infrastructure connections.

The study demonstrated the need to integrate the goals and related objectives of green-blue infrastructure planning strategy into as many policy areas as possible [50]. Policy areas particularly highlighted as suitable for this integration are climate, water, nature conservation, especially through the EU Biodiversity Strategy, regional policy, land and soil.

4.4. Methodological Limitations

The limitation of the study is the fact that green-blue infrastructure planning was only carried out at the metropolitan area and city level, as the necessary data on the ecological requirements of the landscape at a neighborhood level were missing. Even though green connectivity has been defined at a very high resolution using Copernicus satellite imagery, a future quantitative and qualitative assessment of green-blue infrastructure elements needs to be carried out at neighborhood level with the involvement of all stakeholders. Data must come from many fields, but green-blue infrastructure implementation projects require the coordination of local-level urban planning departments.

4.5. Future Research Directions

The future research directions will be oriented towards green-blue infrastructure planning within the Zonal Urban Plans of the six sectors of Bucharest. This can be facilitated by digital and GIS-enabled tools, such as mobile phones with GIS and GPS applications and UAV drones. All these activities must be based on a vision for implementing the green-blue infrastructure approved by the urban planning department and the establishment of collaboration and partnerships at a local level [51]. The identification and implementation of local-level projects must take into account the implementation strategy of the green-blue infrastructure of Bucharest.

5. Conclusions

This scientific study represents a model of good practices for the creation of the national institutional framework in order to implement the National action plan for adaptation to climate change. Planning of the green-blue infrastructure of Bucharest metropolitan area required the collection of very high-quality data and geodata compatible with European data on environmental infrastructure—CORINE 2018 database and the Urban Atlas. These

data and geodata must be retrieved from many sources, requiring laborious work to make them compatible with the GIS data format.

An important operation within this methodology was weighting land use values. The weighting of landscape feature values is generally defined according to biodiversity value, economic value, social value, and types of ecosystem services that the landscape provides, and the connectivity aspects of the landscape. In defining the final values, we took into account the specificity and history of the studied area, the experience of specialists in ecology and territorial planning involved in this endeavor and, last but not least, other international experiences, including guidelines for the implementation of green-blue infrastructure at regional and local levels.

There is an urgent need to merge past, current and future data sources with new technologies in order to meet the challenge of modeling connectivity needs in the face of impending climate change. Also, the spatial and temporal scale of assessing green-blue infrastructure connectivity in large cities is probably the most important aspect of any project.

Regardless of size and spatial dynamics, Romanian cities present two spatial challenges: uncontrolled urban sprawl and degradation of urban cores. A shared vision is needed to progress towards spatial sustainability and increase the institutional capacity to promote sustainable urbanization patterns, signaling the shared responsibility of all stakeholders and levels of government to act towards the respective goals and their interdependence with spatial planning. In this regard, the concerns for developing more compact cities and a greater focus on urban regeneration, with an emphasis on achieving sustainability and efficiency through urban planning tools, are valid. Local public administrations should ensure improved integrated planning (territorial planning of metropolitan areas) and access for all residents to green and recreational areas, while focusing on regenerating urban ecosystems through investment in green technologies, urban green infrastructure and nature-based solutions. The main purpose of territorial development must be to recognize that cities are for people and it is crucial for the health and wellbeing of inhabitants to be supported by a good quality of life.

Carrying out the connectivity analysis of green-blue areas creates a premise for planning the green-blue infrastructure in the studied area. The most important objective of future research is the acceptance and integration of this methodology in local, regional and national policies and strategies. The integration of the presented methodology into spatial planning represents a step forward in the protection of the metropolitan territory of large cities from the intensity and dispersion of urban development.

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