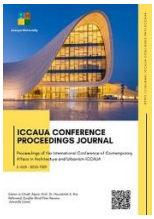

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Innovative Methodology for Implementing Micro-Scale Nature-Based Solutions Using Spatial Technologies and AI

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A b s t r a c t

The implementation of nature-based solutions (NBS) and green-blue infrastructures tends to become a requirement for urban planning, because sprawl and loss of urban green spaces aggravate the potential impact of climate changes and cause negative phenomena, e.g. greenhouse effect, urban heat islands, soil erosion, landslides, or floods. Our study aims to identify, assess and implement micro-scale NBS, continuing previous research on implementing green-blue infrastructures in and around Bucharest. To this end, we identified five abandoned and degraded sites together with the 6 sector city halls of Bucharest and designed NBS-based urban regeneration models using innovative approaches, based on AI solutions combining ecological, social and technological issues with design solutions cantered on local communities. Our results are important for developing standards concerning recommended plant species and changing the local planning framework to increase urban resilience, and may be beneficial for Bucharest and other cities facing similar problems in Romania or elsewhere.

Keywords: Nature-Based Solutions; Blue-Green Infrastructure; Micro-Scale; AI Solutions For NBS; Urban Regeneration.

1. Introduction

Urban areas occupy 2-3% of the Earth's surface and are home to approximately 4.5 billion people, representing 57% of global population. Current global environmental research estimates that urban areas produce 60% of pollutant emissions and 67% of total greenhouse gases, concentrating most risks caused by the potential impact of climate change, e.g., greenhouse effect, urban heat islands, soil erosion, landslides, floods, etc. (Crupi, 2022). Global responses to societal sustainability challenges have resulted into innovative integrated solutions such as 'nature-based solutions' (NBS). NBS have emerged as an umbrella concept for ecosystem-based approaches to mitigating societal challenges of climate change, natural disasters, food and water security, human health and well-being, and economic and social development (Maes *et al.*, 2015; Cohen-Shacham *et al.*, 2019; EC, 2025). While there is no single definition of NBS, those expressed by the International Union for Conservation of Nature (IUCN) and the European Commission (EC) are the most widely accepted (Seddon *et al.*, 2021; O'Sullivan *et al.*, 2020). IUCN defines NBS as “actions to protect, sustainably manage and restore natural ecosystems that address societal challenges effectively and adaptively, for the simultaneous benefit of both people and nature” (IUCN, 2025). Furthermore, IUCN has developed a series of NBS standards, widely accepted globally. Compared to the IUCN definition, the EC places a stronger emphasis on the cost-effectiveness and economic benefits of NBS (de los Casares and Ringel, 2023). The European Union (EU) supported the first expert group on this topic in 2014 to promote research and finance several NBS projects, putting the concept on the agenda of key policy strategies (Faivre *et al.*, 2017). Since then, the science and policy of NBS have developed rapidly and efforts have focused on building a knowledge base to identify successful models in order to replicate them and advance the institutionalization of NBS (Davies *et al.*, 2021; Faivre *et al.*, 2017; de los Casares and Ringel, 2023). With respect to NBS, McPhearson *et al.* (2015) highlighted the need for planners and managers to move beyond a simple understanding of NBS, towards better articulating the multiple values of urban ecosystem services for cities. Therefore, to integrate NBS for urban resilience, new relationships and partnerships of planners (Coaffee, 2013) need to expand to include multiple disciplines, in particular, urban ecologists, water and environmental engineers, horticulturists, IT specialists and landscape planners (Parris *et al.*, 2018; Scott *et al.*, 2016, Bush and Doyon, 2019).

NBS involve a wide variety of actors, from public to private sectors, and require particularly strong participation from local communities, which are directly affected by their impacts and, for the most part, responsible for their maintenance (Randrup *et al.*, 2020).
In implementing city-level NBS, identifying available and suitable land is a first step. Implementing NBS requires different types of approvals and must meet varied planning requirements. Since NBS projects integrate multiple types of land use, NBS may not fit properly within existing types and urban design regulations. Another impediment is that urban planning tools that analyze the territory within the administrative boundaries usually lead to inconsistency between planning scales and urban challenges (Halbert, 2006; Williams *et al.*, 2016). A major challenge for urban planners is ensuring sustainability, by integrating economic growth, social well-being and environmental conservation – especially at the urban/rural border – through coherent development policies (Gopinath and Jackson, 2010).
The neighborhood scale is defined as a section of a city defined by the distinctive character of the urban fabric or by a particular administrative division (Szkordilisz *et al.*, 2018; Amen et al., 2023).Neighborhood seems to have the greatest potential for implementing NBS, but many issues need to be investigated and complex expertise is needed for decision-making. Integrated efforts and strategies require firm and explicit support from interested local authorities, especially the mayor, and legislative support at the central level. Involving the population can provide a solid basis for such actions, although the practice of public participation can seem laborious, lengthy, dangerous and allegedly unprofessional. The object scale refers to the scale of a construction site, i.e. a building or an open space with dimensions of several hundred meters with local characteristics (Barbano and Egusquiza, 2015). The best examples are rooftop gardens, vertical walls, rain gardens, or community pocket parks. Therefore, in the strategies for developing green infrastructure in cities, an important role is assigned to the use of modern technologies and design trends. It is necessary to identify additional data on the trade-offs associated with the implementation of NBS. For example, poorly planned urban regeneration efforts can lead to social inequalities (Anguelovski *et al.*, 2019; de Souza and Torres, 2021; Shokry *et al.*, 2020; Aziz & Ali, 2025) or benefits may only emerge after a considerable time (e.g. ecosystem restoration can take decades to deliver the desired benefits).
For effectively conserving biodiversity, territorial planning is an essential tool at any spatial scale, especially for a country like Romania, where economic development prevails almost always over nature conservation (Popescu *et al.*, 2022), and in general for developing countries, where environmental issues are neglected for immediate economic profit (Ianoş *et al*., 2009, 2012). For this reason, connectivity analyses require geospatial information tools and a good knowledge of the landscape characteristics of the study area in terms of biodiversity value, socio-economic value, connectivity aspects and the type of ecosystem services offered. The implementation of modern technologies based on Artificial Intelligence (AI) and the widespread use of GIS have created new opportunities for planning and managing green spaces, and for specific concepts and approaches.
Although there are many fundamental studies that analyze the dynamics of urban areas using geospatial technologies, including comparative studies on the implementation of NBS, there is very little applied research worldwide that shows the effective use of these technologies in NBS planning at the object level.
To fill in these gaps and highlight the added value of using geospatial technology and AI, our study aims to identify, together with local authorities, vacant lands where the landscape ensures ecological resilience and habitat quality and helps people and species adapt to climate change and improve people's physical and mental health. We design innovative approaches to NBS elements combining ecological, social and technological aspects after consulting the population of the studied area through surveys including all age groups and as many professions as possible. The results may be beneficial not only for Bucharest, but also for other cities in Romanian or other countries facing similar problems.

2. Materials and methods

2.1. Study Area

Bucharest, the capital of Romania, is located in the south-east of the country (Figure 1). Administratively, Bucharest is divided in six sectors, from its center to the fringes, in a radial way (Figure 1). While there is an administration of the entire city (City Hall), there are separate local administrations for each of the 6 sectors. Also, the development of the city is governed by a Master Plan, but also by Zonal Plans for each sector.

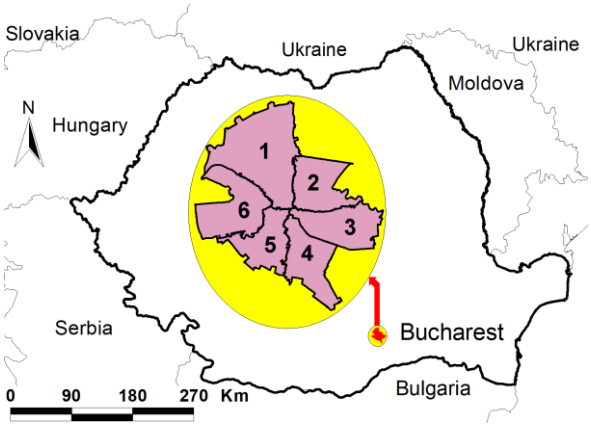

Figure 1. Location of the case study and delineation of its sectors (Developed by the Authors).

2.2. Methodological Steps

The methodology is based on the results of research grant PCE1/2022 'Bucharest Green Belt – Smart integrated models for sustainable management of urban green spaces (GreenSmartB)', more precisely the identification of two possible green belts of Bucharest and a connectivity study of its green-blue infrastructure (Figure 2). Starting from the connectivity study, with the support of sector mayors and according to the Cadastre, several abandoned and contaminated lands belonging to the administration of Bucharest were identified. These lands were selected as the closest possible to the green connectivity corridors identified in the aforementioned project. Finally, several relevant pilot landscaping projects were developed on the abandoned lands, demonstrating how available resources can be used efficiently to promote biodiversity and social cohesion in practice.

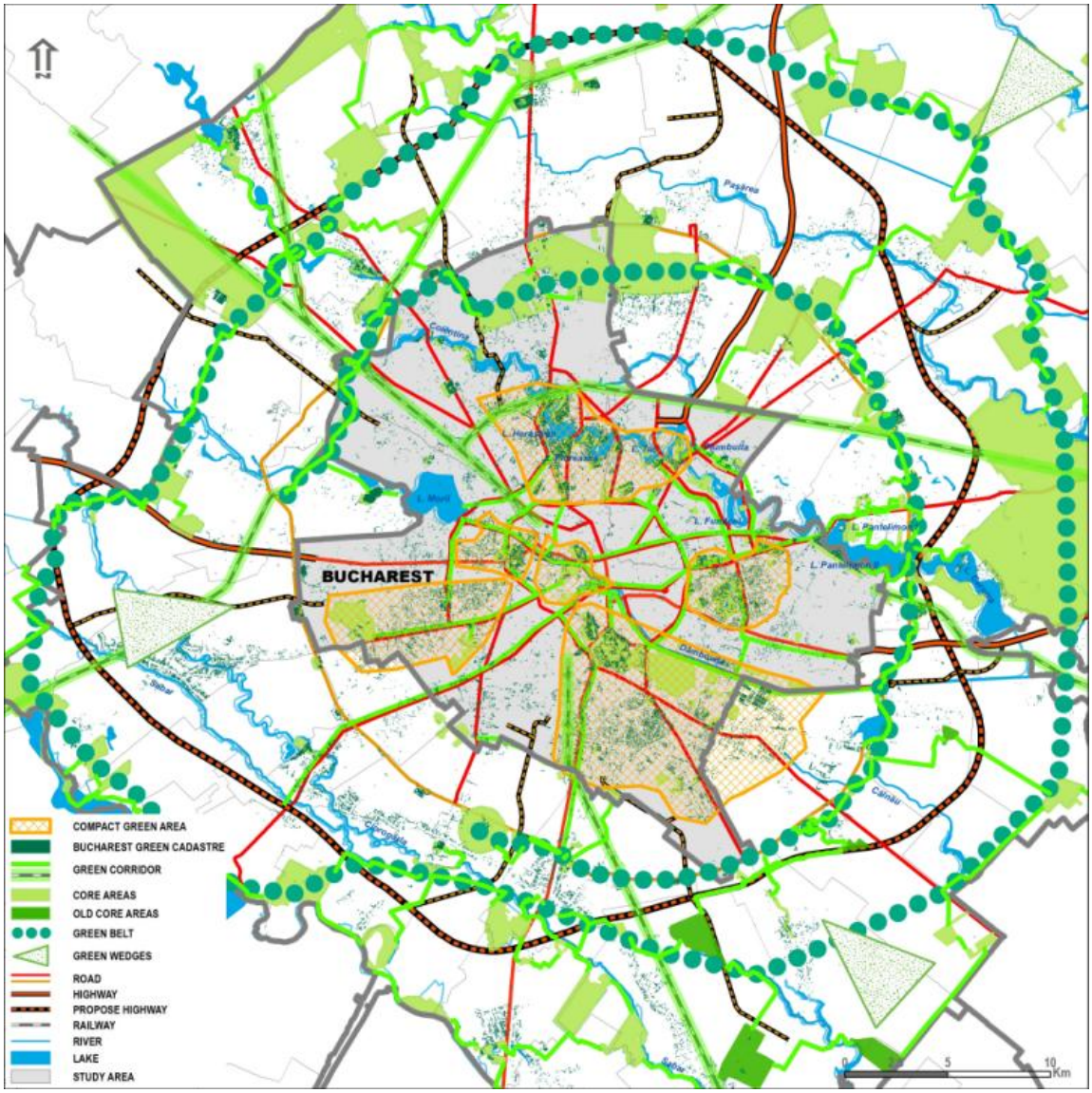

Figure 2. Local connectivity analysis using GIS Linkage Mapper for the metropolitan area of Bucharest (Developed by the Authors).

The study methodology, presented in Figure 3, consisted of: (1) assessing the development vision for Bucharest, using the historical and geographical context, and social and economic elements as a lens; (2) evaluating the national legislation for implementing NBS and blue-green infrastructure; (3) identifying abandoned lands using data from the Heritage Department of Bucharest City Hall and Cadastre and analyzing good practice examples of the implementation of NBS in Bucharest; and (4) selecting, together with the district mayors, abandoned lands for implementing pilot landscaping projects using innovative approaches that merge ecological, social and technological criteria.

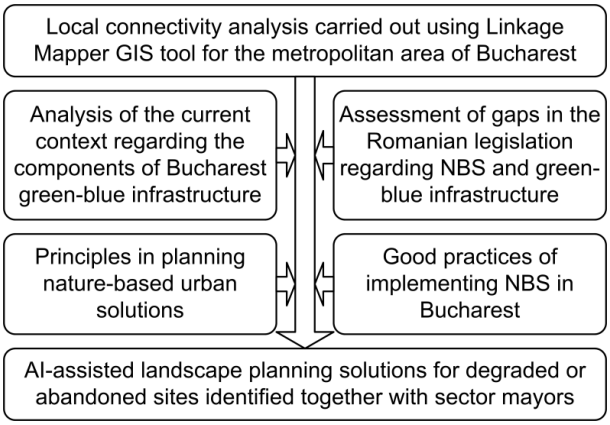

Figure 3. Schematics of the study methodology (Developed by the Authors).

2.3. Sources of Data

The Green Space Register (GSR) of Bucharest is a tool for identifying and inventorying dendrological material in Bucharest, with an informative, technical role, but without producing administrative and legal effects. The green cadastre assumed the inventory of trees and green spaces on the public domain. Green spaces were considered to be parks, gardens, squares, alignment plantations, cemeteries, etc., according to Law no. 24/2007 on regulating and administering green spaces within built-up areas of settlements. According to the 2011 Green Space Register, Bucharest has 4512.2 hectares of green spaces, including Băneasa Forest, Văcărești Natural Park and the Zoo. Bucharest, according to the Green Cadastre, has numerous green spaces, some of which are of great landscape value, but quite isolated. In this regard, according to the EU recommendations, Romanian cities, especially Bucharest, must connect these green areas through green corridors, making the green-blue infrastructure functional. The Green Cadastre, a tool for managing and maintaining green spaces in Bucharest, is also useful as long as it is permanently updated, so that any interventions on green spaces are recorded. The lack of management plans for natural and cultural landscapes of national and local importance has led to the degradation of many landscapes in Bucharest and its metropolitan area. Without a solid legal basis, including national guidelines, the implementation of NBS and green-blue infrastructure remains confined to individual initiatives of cities that understand their advantages for spatial development, sustainability and resilience. While the new environmental policies contain concrete actions aimed at implementing NBS and green-blue infrastructure (e.g., National Strategy and Action Plan for Biodiversity Conservation 2014-2020, Local Environmental Action Plan of Bucharest (2022), National Strategy for Adaptation to Climate Change for 2022-2030 with a 2050 perspective and National Action Plan for the implementation of the National Strategy for Adaptation to Climate Change), territorial planning policies and strategies still do not prioritize the integration of ecological principles in urban and territorial planning regulations. This implies revising existing policies or creating new ones that require the inclusion of green space, multifunctionality and connectivity in urban and territorial development plans. Unfortunately, the Code of Spatial Planning, Urbanism and Constructions that is pending approval by the Senate (after being tacitly approved by the Chamber of Deputies) has only one reference to lands where green spaces are located, in which local public administration authorities delimit and highlight these lands in urban plans, ensuring citizens' access to public green spaces at no more than 15 minutes' walk from residential areas. There is no reference to highlighting ecological corridors in spatial plans, or NBS and green-blue infrastructure in urban or metropolitan plans. There is also no reference to the delimitation of urban natural areas, even though the parliament analyzes a law on defining urban natural areas. In these conditions, there are still initiatives of implementing NBS from sector mayors, NGOs, and the private sector.

3. Results

3.1. Examples of Good Practices of NBS in Bucharest

In order to integrate individual NBS in degraded or abandoned lands, we collaborated with the sector mayors to identify abandoned lands owned by the Bucharest City Hall and develop pilot projects that demonstrate how the available resources can be used efficiently to promote biodiversity and social cohesion in practice.

The National Territorial Development Strategy and the Local Environmental Action Plan of Bucharest, documents that underline concrete actions for the urban renewal and regeneration of neglected and degraded areas aimed at improving the living conditions, served as a starting point. We also accounted for the five principles proposed for the planning and governing urban NBS (Kabisch *et al.*, 2022), i.e.: (1) urban NBS represent integrated solutions and should imply a systemic approach, due to the need for cross-sectoral collaboration achieved by involving different urban planning departments, e.g. social policy, transport and mobility, green space planning, water infrastructure and health, when planning for the inclusive and multifunctional integration of NBS into the urban tissue; (2) urban NBS should secure a balanced provision of multiple services for people and biodiversity; (3) urban NBS should be designed, planned, implemented and managed in an inclusive manner in order to ensure long-term benefits; (4) urban NBS should be implemented accounting for the local context in a respectful way; (5) urban NBS ensure an increased awareness of the public on urban sustainability issues.

Urban and landscape architects must take into account the capacity of NBS components to regulate temperature, air quality, water storage and drainage, and noise reduction. In order to do this, it is necessary to translate scientific

knowledge regarding the functionality of ecological infrastructure into practical design principles. Experience demonstrates the need to develop standards for green spaces (plant species recommended for different types of uses – alignments, green terraces, squares, and the like). For this reason, the multidisciplinary team must integrate a horticultural specialist who selects tree and shrub species taking into account the following aspects: pedo-climatic conditions of the area and degree of adaptation of proposed species to these conditions, specific CO_2 retention capacity of proposed species, measures necessary to ensure the quality of urban landscape. These activities are supported by specific studies targeting plant species, trees, shrubs and pedoclimatic/geomorphological conditions, or other appropriate issues.

We analyzed good practice examples in implementing NBS in Bucharest. We found many examples in sectors 3 and 6, and also in new residential assemblies or around large supermarkets. The list includes a residential complex on Zagazului Street (sector 1), which integrates green roofs and green walls, urban gardens, pocket parks and ponds with exotic fish; also, a land parcel intended for urban agriculture on the rooftop of a supermarket (Kaufland, Bucureştii Noi area) and an urban forests created by Kaufland Popa Nan supermarket (sector 3); pocket parks, water retention planters, community gardens, and corridors protecting technical infrastructure or green streets with rainwater collection created by sector 6 City Hall; Teilor Park in sector 3, which is an example of reconstructing contaminated areas based on the principles of imitating the original ecosystem conditions; and the modernized Alexandru Ioan Cuza lake and park, construction of many sport fields and new green spaces, or creation of urban forest alignments along Unirii Boulevard.

3.2. Selection of Pilot Areas

Five pilot areas were selected together with the district mayors from among degraded or abandoned lands, and we used them to create urban regeneration models that can be applied to other abandoned areas of Bucharest. Three of them belonged to former textile factories, a fourth abandoned plot contained several houses demolished 40 years ago, and the fifth one is larger and has a disputed legal status, but the sector mayor wants to take its ownership and develop it as a multifunctional green area. The first step in developing design solutions was evaluating, knowing and photographing the plots with cameras and UAVs. In the case of plots belonging to former communist factories, soil assessments are necessary and foundation remains still exist. In the case of the other two plots, there are no problems related to soil quality or concrete remains identified. Along with the local authorities, we recommended hybrid landscape design solutions for all five pilot areas, also integrating sustainable elements.

We present here only two case studies, corresponding to the first and fifth pilot areas. The first pilot area analyzed is the land of a former textile factory where a supermarket was built (Figure 4). Next to the supermarket, an area of almost 1500 m^2 remained, where the implementation of NBS would be very useful. This pilot study was named the 1 Mai Boulevard – Auchan Site, based on its location. In this regard, the project envisions the transformation of this space into a functional and aesthetic area, characterized by the arrangement of three fountains of various sizes, around which places for relaxation will be created, promoting social interaction. Spacious pedestrian routes will be developed and appropriate urban furniture placed, in order to improve accessibility and user comfort. These interventions contribute to the creation of an oasis of relaxation and optimal use of available space. In addition, the integration of an efficient public lighting system was proposed, which would ensure visibility and safety at night, while also contributing to the aesthetic appearance of the area. The irrigation system is designed to maintain vegetation in an optimal condition, and the materials used are chosen to support long-term sustainability and aesthetics. In addition, ecological solutions will be introduced, such as recycling rainwater and using native plants, which would minimize the ecological impact and promote local biodiversity. These measures facilitate not only the functionality and attractiveness of the space, but also its harmonious integration into the existing urban context.

Figure 4. Pilot area 1 Mai Boulevard – Kaufland (ARCGIS PRO view and 3D landscaping) (Developed by the Authors).

The fifth pilot study is a land plot located on Vasile Lascăr Street (sector 2) between Monterra and Nico Design kindergarten and school (Figure 5), with a considerable potential for urban transformation. We propose developing it by creating a children playground and a socializing space, encouraging community interaction. In addition, we propose the construction of a gazebo harmoniously integrated into the landscape, contributing to the optimal use of available green space. The valorization of land also includes implementing appropriate urban furniture, supporting the functionality and aesthetics of the area. These interventions aim not only to improve the life quality of nearby residents, but also to create a safe, attractive and accessible environment for all age groups, integrating them into existing educational and commercial context. Our intervention aims to strengthen community ties and improve the urban experience of all users, regardless of age. The materials used for landscaping are sustainable, contributing to increasing the quality of urban environment. The playground has modern, safe equipment adapted to the needs of children, while the socializing area includes elements that facilitate interaction and comfort, such as benches, tables

and shaded areas. The gazebo, strategically located, provides a quiet refuge and serves as a meeting point for various community activities.

Figure 5. Lascăr Boulevard pilot area (Photography and 3D landscaping) (Developed by the Authors).

4. Discussion

4.1. Scientific Significance and Importance of the Results

The present study expands the results of PCE1/2022 project entitled "Bucharest Green Belt – Smart integrated models for sustainable management of urban green spaces (GreenSmartB)" which aimed to design the green-blue infrastructure and identify the ecological connectivity between Bucharest and its peri-urban areas. Modern technologies, in particular the use of GIS, showed their usefulness for planning and managing green spaces, and for specific concepts and approaches. The experience of studies carried out has demonstrated the need for a good knowledge of the landscape characteristics of the study area in terms of biodiversity and socio-economic value, connectivity aspects and type of ecosystem services provided. From a technical point of view, it is important to identify the abandoned and degraded lands belonging to Bucharest City Hall and contributing to the connectivity of the green-blue infrastructure of the city. The key element is to preserve the multi-functionality of open space, more precisely the green-blue areas and habitat corridors that need to be secured in order to support ecological functions and benefits for people in terms of social well-being and recreation. Therefore, an essential role in designating degraded or abandoned lands belongs to local authorities, especially sector mayors of Bucharest. Local authorities are the main factor ensuring a balance between the interests in developing residential areas and using open space.

The novelty of our approach consists of implementing NBS planning at the micro-scale, while maximizing the use of space, integrating green solutions and water management systems by the means of modern technologies and design trends based on LUMINOR artificial intelligence. Our results are important for setting standards for

developing blue-green areas, including appropriate plant species for different kinds of uses, hybrid blue-green approaches and creation of community-centered solutions. We also proved the need for creating a local planning framework able to minimize vulnerability and increase resilience. More exactly, we proposed that projects of new residential areas should be approved only if they include at least 20% blue-green areas, contributing to mitigating of climate change effects.

4.2. Internal Validation of Results, Related to Research Objectives

Currently, climate change is at the top of urban planning agenda in many cities and regions. The implementation of NBS and green-blue infrastructure becomes absolutely necessary in territorial planning because habitat fragmentation can aggravate the potential impact of climate change and cause negative phenomena, i.e., greenhouse effect, urban heat islands, soil erosion, or landslides.

4.3. External Validation of Results, Related to Other Studies

In the EU, there is limited information on the integration of NBS at local scales, in particular a lack of studies that access such integration in urban policy and planning. A positive example is France, which by approving the Grenelle laws (I-II) (Palazzo, 2000; Ruffolo, 2009), is carrying out a thorough process of reforming environmental policies closely linked to the instruments of inter-institutional governance. Thus, the planning system has developed through numerous urban projects a new model of city, ecologically oriented, and based on sustainable and resilient strategies. Unlike the French model, in major Romanian cities, an innovative green-blue infrastructure methodology was designed by the study team based on a very large volume of data from related fields, e.g., hydrology, land cover, agriculture, horticulture, urban planning, and environmental sciences, and on two ARCGIS 10.8 tools used in particular to identify ecological corridors for large mammals. The green connectivity study of Bucharest allowed for identifying available and suitable lands for implementing NBS. NBS involve a wide variety of actors to validate landscape modeling at the micro-scale level, from the public to the private sector, and require particularly strong participation from the local community. A holistic, multidimensional approach is a necessity in creating and implementing effective strategies and plans for long-term success.

4.4. Methodological Limitations and Future Research Directions

A first problem related to methodological limitations is the lack of involvement in urban and landscape design of actors from the academic environment, private sector, most importantly, local citizens. This study highlighted the need for close collaboration of local authorities and designers, both in identifying abandoned and degraded lands and the actual design part. Also, the implementation of micro-scale NBS involves the support of citizens and interested private individuals. For this reason, it is necessary to carry out sociological surveys with all interested factors, which would validate the landscape design intended for abandoned or degraded land. It is essential to define not only the multitude of benefits offered by NBS, but also the entire range of potential trade-offs in order to develop effective strategies and reduce or eliminate potential negative consequences. Future research will focus on implementing NBS and blue-green infrastructure in urban and territorial plans.

5. Conclusions

The present study aimed to continue previous research on implementing NBS in the green-blue infrastructure of Bucharest. While the first study concerned the metropolitan area and urban area where constructions activities are permitted (aedificandi area) of Bucharest, the current one aimed to carry out five pilot studies on implementing micro-scale NBS on degraded or abandoned lands, using innovative approaches combining ecological, social and technological aspects with community-centered design by using AI solutions. For this reason, the study required the participation of numerous specialists from different fields, i.e. urban and landscape architects, horticulturists, engineers specialized in hydrotechnical and public works, ecologists, sociologists, IT engineers, etc. The first step in implementing NBS in Bucharest is to identify available and suitable lands for green areas. An important source for identifying degraded or abandoned lands is the database of the Heritage Directorate of the Bucharest City Hall. For the pilot areas we chose degraded lands using data obtained from the sector authorities and verified as public lands, according to the Land Book excerpt. Their choice was also based on the connectivity analysis carried out in Bucharest, so that these lands connect other elements of the green-blue infrastructure of the city. Landscape and urban planning design requires a consistent analysis of landscape in the pilot areas, both in terms of biodiversity and socio-economic aspects. An important role in the incipient landscape design is played by horticultural specialists who identify the species of plants, trees, shrubs depending on the pedo-climatic conditions. The methodological limitation of our study concerns the lack of involvement of stakeholders and local actors in developing pilot studies for implementing NBS locally. Sociological surveys should be conducted with all stakeholders and local actors, to collect their opinion regarding the choice of NBS for various degraded or abandoned lands, or even at the neighborhood level. Studies for the implementation of green-blue infrastructure and NBS at different scales can boost the inclusion of green-blue infrastructure and NBS in urban and territorial development plans at the national, regional and local levels.

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Conflict of Interests

The Author(s) declare(s) that there is no conflict of interest.

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