FRAMEWORK FOR PLANNING BLUE GREEN INFRASTRUCTURE SYSTEM WITH THE USE OF LANDSCAPE-FUNCTIONAL UNITS (LAFU) FOR THE CITY OF PRAGUE

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Abstract

Blue Green Infrastructure (BGI) plays a key role in maintaining microclimate and stormwater management. BGI is therefore, a tool to increase the resilience of cities in terms of impacts of urbanisation and climate change. This research combines two approaches for identification and planning of BGI systems – Land Use Functional Units (LaFU) and Morphological Spatial Pattern Analysis (MSPA) for the city of Prague, Czech Republic. The first stage was carried out with the identification and classification of various natural and semi-natural land uses areas to LaFU and evaluating these units to identify the strengths, potentials, and threats in the functioning of the BGI system. LaFU assessment was followed by Morphological Spatial Pattern Analysis (MSPA) to identify the spatial connections and fragmentation between BGIs in the form of cores and connections. The total of 29,600 Ha of area was identified as BGI in Prague under LaFU analysis. Of this area, 28.6% was identified as cores and 15 % was constituted by connections in the form of loops connecting the same cores and bridges connecting the different cores. The results from the LaFU-MSPA intersection analysis were used to design a transformation vision and strategies defined by the distribution and functionality of the BGI of the city. The study could help augment the research in the field of BGI and provide further guidance in decision making for Prague Climate Plan 2030.

Keywords: LAFU, Infrastructure, Land Use Functional Units, City Planning, Resilence cities.

1. INTRODUCTION AND LITERATURE REVIEW

The world is witnessing a rapid growth in urbanisation because of increased demand of jobs and aspiration for better living standards. The United Nations projects that about 60% of the world population is expected to be living in cities by 2030 while for European nations, this percentage is even higher. Due to these projections, the city-regions are therefore witnessing unprecedented growth in terms of expansion in area. The urban expansion is usually carried out at the expense of surrounding natural areas. Land conversions and/or habitat fragmentation leads to disturbance of ecological processes, water cycle imbalance and biodiversity loss. The expansion of impervious layer also known as grey cover which forms the major part of urban elements, comprises of the built-up areas like buildings, mobility networks and the drainage systems, contributes to the process.

Grey cover is often associated with Urban Heat Island (UHI) effect which causes the ambient temperatures of built-up areas to rise than its outlying areas. UHI effect also exerts an increased consumption of energy. Additionally, the frequency of extreme weather conditions like heat waves, and excessive rainfall, linked with climate change has also increased. The persistent occurring of these events affect human health and there have been cases of increased mortality associated with them. Several European cities are likely to record rise in daily temperatures as an impact of climate change (Guerreiro et al., 2018). Besides, there are incidents of increased run off (due to impervious surfaces) and higher energy consumption in urbanized areas. This calls for nature-based solutions to reduce the environmental and health impacts of climate change. The World Bank defines nature-based solutions as measures "to protect, sustainably manage, or restore natural ecosystems, that address societal challenges such as climate change, human health, food and water security, and disaster risk reduction effectively and adaptively, simultaneously providing human well-being and biodiversity benefits". Therefore, to deaccelerate the impacts of urbanisation, demands for sustainable cities have been generated. One of the nature-based solutions to tackle this problem is the planning and incorporation of green and blue infrastructure (BGI) within cities which provide various ecosystem services and act as an efficient tool for sustainable management.

BGI could be defined as a strategically planned network of vegetation (green) and water (blue) elements of natural and semi-natural areas. The green components comprise of living land cover such as parks, green roofs, trees along the street whereas the blue infrastructure consists of ponds, wetlands, and water streams. There has been an increased dependence upon the human-engineered grey infrastructure such as roads, dams, pipes and water treatment plants to tackle water related issues such as shortage and storage, and to mitigate disasters. However, this approach is more damaging to environment, expensive to build, and requires high maintenance (Commission, 2021). On the other hand, the combination of blue and green components together in urbanised areas provides multiple services like regulation of temperature, climate change mitigation, food production, water purification, better air quality, biological connectivity recreation and adaptation within urban space (Langemeyer & Baró, 2021; Niedźwiecka-Filipiak et al., 2019). In recent years, with the emergence of the concept of BGI, efforts are being made to reduce the dependence on grey infrastructure and adopt strategies using BGI to ensure a more sustainable approach to territorial development and resilience to climate change impacts (Corwin, 2019).

However, the building up of BGI within urban spaces is met with certain challenges like space constraints, initial infrastructure cost, and water demand by vegetation. Therefore,

planning of BGI requires a proper methodological approach. Recently, BGI has been implemented for flood reduction in urbanized areas such as in Dutch Island (Alves et al. 2020), sponge city construction in China (Leng et al., 2020), improving biodiversity of the Swiss lowlands region (Donati et al. 2022), and for mitigating the impacts of climate change (Macháč et al., 2022). Kaur and Gupta (2022) applied a set of accessible geospatial tools to identify the BGI network in Ahmedabad (India) for sustainable stormwater management. An algorithm based hydrodynamic model was assessed to analyse the BGI as a measure to reduce flood risk, minimise cost and obtain maximum co-benefits from the system (Alves et al. 2020). The study suggested that the incorporation of BGI within an urban build-up is more beneficial with the aim at obtaining multiple benefits rather than focussing on just one component. Niedźwiecka-Filipiak et al. (2019) introduced green infrastructure planning by Land use Fuctional Units (LaFU) method, where an LaFU was described as a functional area with a particular land cover type. The researchers implemented LaFU to plan a system of green infrastructure in the Wroclaw region which is undergoing rapid development in terms of grey infrastructure causing habitat fragmentation and reduction in green cover. The results of LaFU based analysis was found to be effective in designing a multifunctional green infrastructure in the region (Niedźwiecka-Filipiak et al., 2019).
In the context of Czech Republic, there have been studies suggesting the possibilities of incorporating surface ponds for stormwater retention (Kopp and Preis.2019), or tree cover (Lehnert et al. ,2021) as a part of BGI implementation. Lehnert et al. (2021) compared the thermal variability of some selected sites of four Czech cities namely, Brno, Olomouc, Ostrava and Plzeň based on universal thermal climate index. The green cover associated with tress in particular was found to have significant impact on cooling of the areas compared to lawns or blue cover. These results form the basis of incorporating particular elements of BGI while urban planning under the pretext of climate change (Macháč et al., 2022).
This study focuses on the quality of BGI by reviewing the environmental and development policies and their connectivity since the physical continuity of landscapes plays a crucial role in their management. The research is limited to streets and mobility networks for grey infrastructure as studies have found wide co-benefits of retrofitting mobility infrastructure to introduce BGI along its network and encourage modal shift from motorised to soft mobility (Jia et al., 2021; Pauleit et al., 2017).
By employing a novel method of using the tool of LaFU and intersecting them with morphological spatial patterns, this study is aimed at developing a framework for categorizing and evaluating the quality and continuity of blue green infrastructure and to recommend a vision and strategies for the improvement of their preservation and connection. The objectives of the study are to:

1. Develop a system of categorization from diverse land use of the green and blue environmental features into land use functional units (LaFU) based on their functions, quality, and scale.
2. Factor in the environmental regulations and speculated urbanisation as degree of protection and risk to degradation respectively, and generate levels of obligatory actions required for BGI protection.
3. Assess the continuity of BGIs with the help of Morphological Spatial Pattern Analysis (MSPA) and overlay them with LaFU categories.

4. Compare existing strategies for green and blue infrastructure through the lens of LaFU categories, and propose strategies for their conservation and improvement of their continuity.

2. METHODOLOGY

The general methodology of this research is conducted in three stages (Fig 1). The first stage is the prelimanry process of spatial and policy data investigation and their paraparation to be used in the following stage two. It consists of two parts – 1) extraction and reorganisation of data of existing natural and semi-natural areas from the current land use followed by their reclassification into LaFU, and 2) exploration and spatialisation of the existing regulatory framework at local, regional and supra-regional scale that aim at protecting, conserving and connecting the existing BGI. This also involves assessment of planning documents and future plans that might threaten the BGI or degrade their quality through construction and urbanisation.

The second stage is also subdivided into two parts, 1) the LaFU analysis for evaluation and conservation of BGI, and 2) the MSPA for assessing and improving connections of BGI. The first step of LaFU analysis in this study deviates from (Niedźwiecka-Filipiak et al., 2019) approach on Warsaw, Poland due to differences and limitations in the datasets and the urban context. Instead it focuses only on the categorization of LaFU. It uses the synthesis from the previous stage and applies it to map the study area into three parameters: importance (or categorization), degree of protection (or hierarchization) and risk of degradation associated with the identified LaFU. Lastly, with the consideration of the above parameters, a map of obligatory action is produced to identify the level of prioritisation (obligatory actions) needed for the conservation of the BGI in the region.

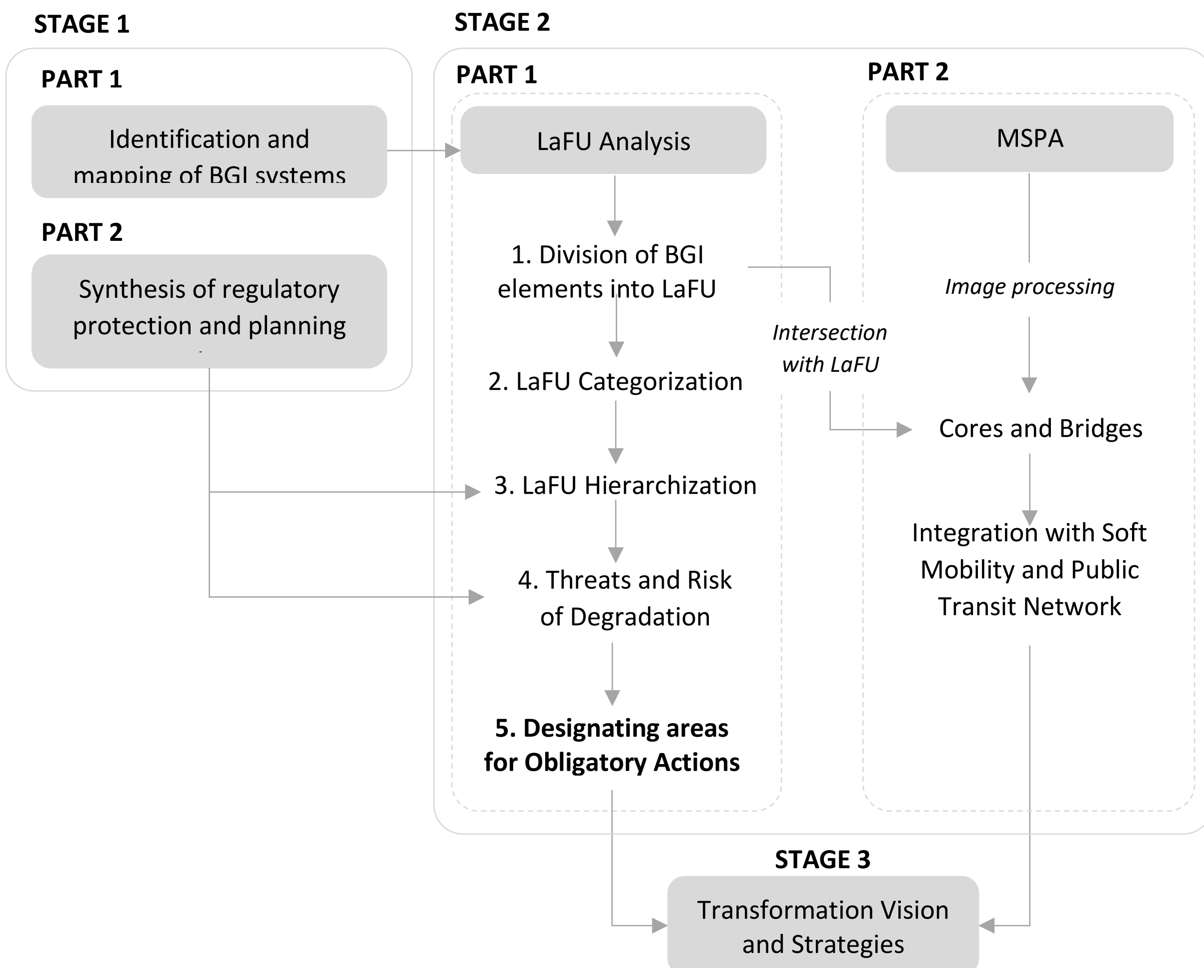


Figure 1. General methodology

The second part of MSPA uses the raster from existing land use data and transforms it into morphological classifications of cores and connections (Soille & Vogt, 2022). The MSPA is one of the tools used to analyse the landscape patterns and fragmentation of forests and other natural land covers.

The analysis was conducted in an image processing software called GuidosToolbox (GTB) (Soille & Vogt, 2009) where a binary image consisting of the identified LaFU as the foreground and everything else in the study area as the background is processed to generate seven classes of the foreground representing the BGI with the pixel size of 33 m x 24 m. Studies often select the cores and connections (bridge and loop) from MSPA to understand the existing BGI network or changes in it over time to highlight possible deteriorations and opportunities in reducing further fragmentation of cores (Kang & Kim, 2015) (Wei et al., 2018). Our study, however, extends this method and classifies the cores and connections along with their LaFU characteristics. Of these classes, the cores, bridges and loops obtained from MSPA are intersected with the broad LaFU of forests, farmlands and open areas, and water bodies (Saura & Rubio, 2010). The results produce deeper

insights on the characteristics of the MSPA elements, guiding decision makers to propose specific strategies for different kinds of cores and connections, and also prioritise them according to their importance.
The third and final stage of the study consists of development of a vision from the outputs of the overlay analysis of LaFU and MSPA. The visionary diagram would play as a guide for prioritisation and execution of contextual strategies for the improvement of the BGIs and strengthening their connections. These strategies use the tools of ecosystem services and nature-based solutions by including social, economic and cultural activities and integration of sustainable modes of transportation to transform the BGI into multi-functional spaces as well as protected natural elements.

3. CASE STUDY AND SPATIAL DATA

3.1. About Prague

Prague is the largest and capital city of Czech Republic and in European Union it is the 13th largest city. Besides, it is the most populous city in the country with 1.3 million residents. Prague is a city with a rich cultural heritage, an economic and commercial hub, and a major tourist destination across the globe. The temperature variability is showing an increasing trend in Prague and future projections show high incidents of heat waves and warmer days than usual (Badura et al., 2021). But on a positive side, the city recognises the anticipated impacts brought by climate change phenomenon and has adopted several sets of nature-based measures as a part of Prague Climate Plan 2030 with the aim of improving environment and liveability of the city. Extending BGI network by the conversion of impervious layer to BGI has been one of the objectives of the plan. Around 7 sq.m of the urban area has been changed to BGI in terms of 1000 population/year. The population of the city is growing and therefore, more BGI networks are required to be incorporated to further enhance the liveability and counteract the impacts of climate change.

3.2. Data for green bule Infrastructure (BGI) of Prague

The blue and green elements in the study area of Prague were derived from the city's existing land use data. The classifications and scale of different land use and land cover sources such as Open Street Map (OSM) (2017), Copernicus Urban Altas Programme (2018) and official open data geoportal (2022) were compared and the current land use data from the Geoportal Praha (2014) was chosen since it presented 26 detailed classifications of green and blue elements. Other than blue and green elements, 11 brownfield sites from OpenStreetMap (2011) are also included in the categories of LaFU as they hold potential for future sustainable development and greening strategies. Additionally, for grey infrastructure that consists of mobility and public transport, data from official geoportal was used. These databases established the foundational layers of both LaFU analysis and MSPA.

3.3. Data for environmental and development policies in Prague

The environmental and development policies influencing the degree of protection of the BGI or threatening them by promoting urbanisation were extracted from several local and regional sources. The regional protected sites such as Přírodní parky or Natural parks and elements identified under Plán ÚSES (Plan for Territorial system of ecological stability) for Prague such as the biocentre and bio-corridors were also taken into consideration (Praha, 2022a). Moreover, INSPIRE or Infrastructure for Spatial Information in Europe, an initiative of the European Commission from where protected sites such as Natura 2000, IUCN's (International Union for Conservation of Nature) designated sites - Habitat species management area, Natural monument, protected landscape and natural buffer zones were also extracted (Praha, 2022b).

The floodplains of the Vltava and Berounka rivers with 100-year recurrence interval (Opendata Praha, 2022a) that indicate need for enhanced mitigation efforts to the escalated flood risk were adopted in the analysis. Similarly, the heritage city centre defined by UNESCO is factored in because it emphasises inclusion of placemaking and sustainable mobility strategies using nature-based solutions for this part of Prague (UNESCO World Heritage Centre, 2008). These policies and plans are spatialized and mapped in Section 4.2.

To understand the impact of developmental and urbanisation policies, two layers were used in the analysis of "risk of degradation to LaFU". The first is a planning regulation derived from the territorial plan, Územní Plán of Prague that has demarcated the future developable areas in the city (Institut plánování a rozvoje hl. m. Prahy, n.d.-b). The second layer is the proposal of large development areas, Velká Rozvojová Území (VRÚ) defined by the territorial plan (Institut plánování a rozvoje hl. m. Prahy, n.d.-a). Such developments have the capacity to transform the sites into a built area. If such proposals overlap on existing LaFU, they could threaten the existence of the natural elements that need to be protected.

4. DATA PREPARATION AND POLICY SPATIALIZATION (STAGE 1)

Inspired by the methodology proposed by Niedźwiecka-Filipiak et al. (2019) for the city of Wroclaw, Poland, we have used the Landscape-Functional Units (LaFU) method for planning of the green infrastructure system in the city. The method has two primary stages, first is identification and analysis of existing natural and semi-natural areas.. The second is the evaluation of the BGI system by dividing them into LaFU and evaluating these units to identify the strengths, potentials, and threats in the functioning of the BGI system.

4.1. Identification of and mapping BGI systems (Stage 1 – part 1)

All the natural and semi-natural elements are extracted from the current land use map from Prague's open data portal (Praha, 2014). These elements as mentioned in Table 1. were sub divided to (26) detailed categories.

Table 1: Coding according to land use type for the city of Prague. (Source.Authors.2024).

	Code	Land use type
1	RPU	park-landscaped areas
2	HY	water courses and areas
3	LRO	Forests
4	LRR	forest parks
5	ND	accompanying vegetation
6	NNK	non-forest stands of trees not associated with shrub
7	NM	wetlands without woody plants
8	NNO	non-forest stands of woody plants not associated with trees and shrubs
9	NZO	non-forest stands of woody plants connected with trees and shrubs
10	NZK	non-forest stands of trees mixed with shrubs
11	NNS	non-forest stands of woody plants not associated with trees
12	NZS	non-forest stands of woody plants connected with trees
13	PLP	production field
14	PRZ	agricultural production
15	PLU	field – fallow
16	RAP	natural recreation areas
17	RAZ	recreational and garden settlements
18	RPP	garden park areas
19	RPH	Cemeteries
20	RV	educational recreational areas - ZOO, botanical gard
21	VPN	pedestrian area
22	ZL	meadows, pastures, grass fields

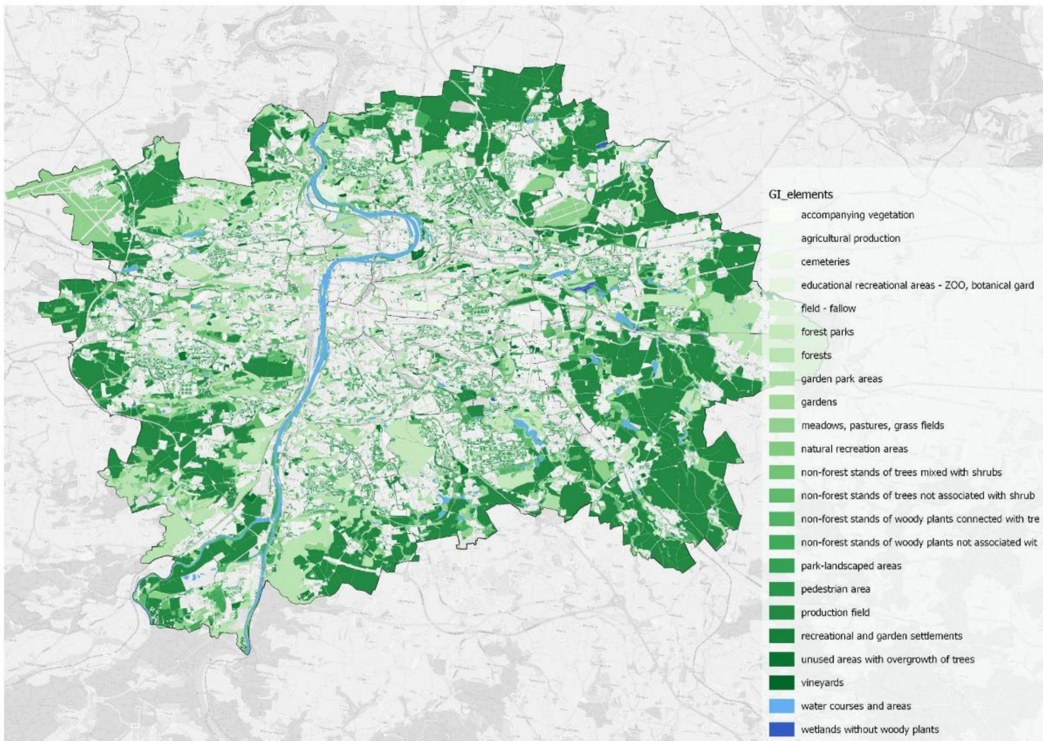
	Code	Land use type
23	ZSZ	Gardens
24	XZ	unused areas with overgrowth of trees
25	ZSV	Vineyards
26	BR	Brownfields

The green and blue areas are to be mapped in such a way that they could be eventually categorised as per the description of LaFU (detailed in Section 5.1). In the case of Prague, we re-categorized the 26 BGI elements identified earlier into the following LaFU types as suggested by Niedźwiecka-Filipiak et al (2019):

Table 2: LaFU types. (Source.Authors.2024).

Symbol	Type of Unit—Description
A	forests and groups of greenery with a compact area over 25 ha
B	forests and groups of greenery with a compact area over 25 ha with surface waters
C	forests and groups of greenery with a compact area over 25 ha with internal open spaces
D	forests and groups of greenery with an area of about 5–25 ha
E	greenery complexes—with an area of about 0.5–5 ha
F	watercourses in open areas (farmlands)
G	watercourses with greenery
H	surface standing waters with treeless surroundings (in open areas)
I	surface standing waters together with groups of greenery
J	orchard complexes
K	domination of open areas (farmlands)
L	urbanized areas—cities
Z	various types of LaFU with housing complexes and/or economic activity zones

Map 1. Green and blue infrastructure from current land use(Source.Authors.2024).



One of the challenges to recategorize the existing blue green infrastructure as per the city's dataset into LaFU, the compact or continuous elements has to be determined (as LaFU types in table 2 require compact areas). If a forest or any other BGI element is traversed by a road or street, the dissected parts can be seen as two separate elements. However, if the element has a circulation system of "footpaths" (shown in red in map.2), they cannot be considered as fragmenting elements and need to be dissolved with the adjacent green elements.

To achieve these compact green elements without footpaths fragmenting the polygons, the footpath network was spatially joined with the adjacent green element layer in BGIS (spatial join with elements sharing the longest border) and then dissolved likewise (map.3).

Map 2. BGI fragmented by footpaths.(Source.Authors.2024).

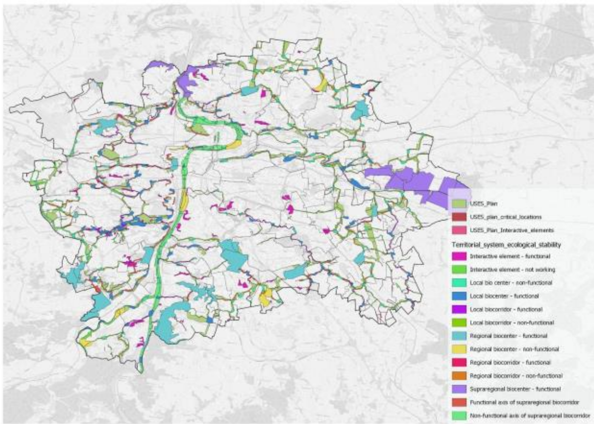
Map 3. BGI after dissolving footpaths.(Source.Authors.2024).

4.2. Spatialization of environmental and regulatory policies (Stage 1– part 2)

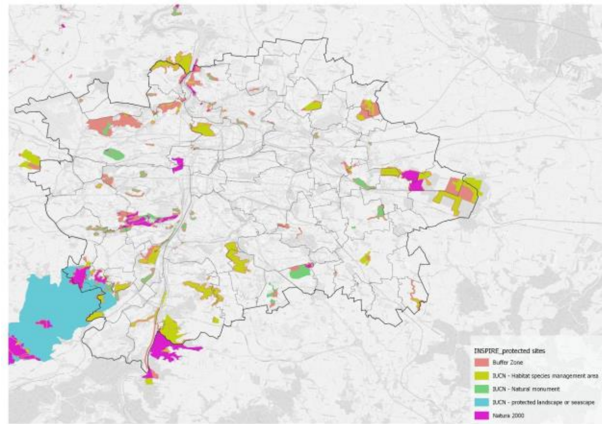
The second part of the first stage of LaFU analysis includes understanding the protection and regulatory status of the green and blue infrastructure in Prague and spatializing them so as to include them for eventual GIS analysis. For this, following layers were taken into consideration:

- Plán ÚSES - Plan for Territorial system of ecological stability, that drafted the local and regional biocentre, bio-corridors and axes along with interactive and critical landscape elements as defined by the plan (map 4).
- European Commission's INSPIRE or Infrastructure for Spatial Information in (Commission, 2015; Republiky, 2022), that defined the protected sites such as Natura 2000, IUCN's (International Union for Conservation of Nature) designated sites - Habitat species management area, Natural monument, protected landscape and natural buffer zones (map 5).
- Natural parks Praha (2014) defined by the regional authority, a protected area with a lower level of protection (according to Act No. 114/1992 Coll. on the Protection of Nature and Landscape) (map 6).
- The historic centre of Prague as defined by UNESCO Centre (2012) (map 7). It identifies this area as of architectural and cultural significance and promotes improvement in the quality of public spaces and streets. The UNESCO report also suggests landscaping and nature-based strategy to improve ecosystem services and climate resilience in the core city (UNESCO World Heritage Centre, 2008).
- Floodplain - Areas threatened by flood risks under Q100 category which is a flood event with a 100-year average return interval of the Vltava and Berounka rivers (Praha.2022a) (map 7).

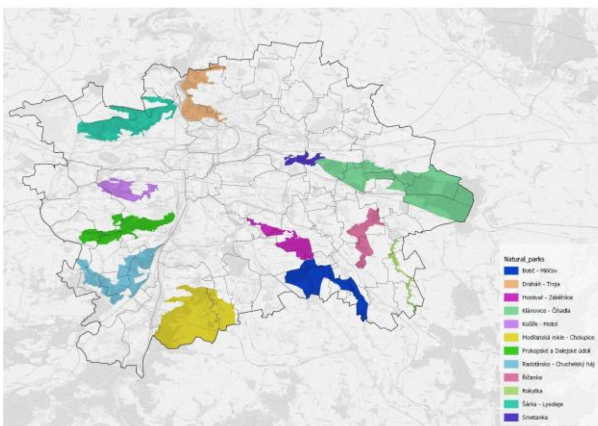
This ends the first stage of compiling and mapping the data of blue and green infrastructure that will be evaluated and analysed in the second stage.



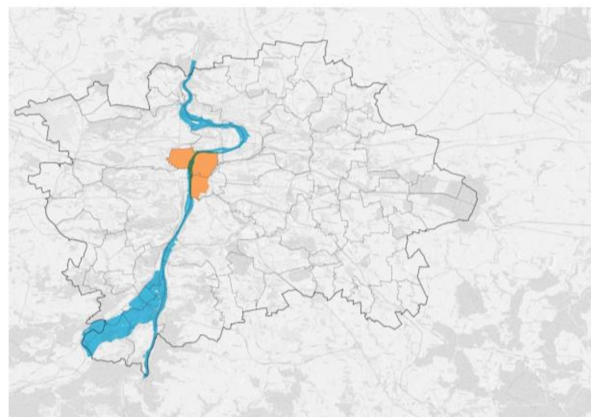
Map 4. Plán ÚSES. (Source.Authors.2024).



Map 5. Natural elements under INSPIRE. (Source.Authors.2024).



Map 6. Natural parks. (Source.Authors.2024).



Map 7. UNESCO city centre and floodplain 100Y. (Source.Authors.2024).

5. LAFU ANALYSIS ON PRAGUE (STAGE 2 – PART 1)

To identify the level of prioritisation for conservation actions for BGI network, the LaFU analysis is conducted in five sub-parts wherein the first one is applying the LaFU types identified in Section 4.1 and transforming the BGI network into LaFU (section 5.1). The second sub-part is to plot them into four categories based on their importance denoted by their ecological value and size (section 5.2). Next, the LaFU types are mapped into four hierarchies based on their degree of protection (section 5.3) and risk of degradation (section 5.4). Lastly, in section 5.5, the final output of obligatory action for LaFU conservation in Prague is generated with the function of previously developed maps of categories, hierarchy, and degradation.

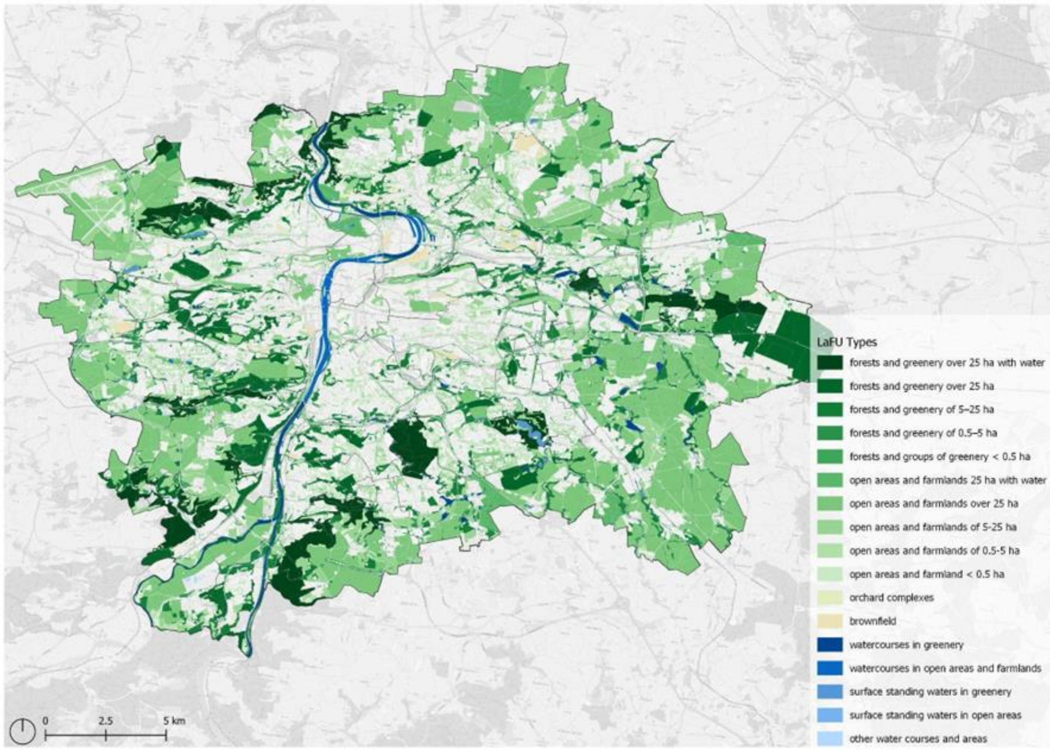
5.1. Division of elements into LaFU types (Stage 2 – part 1.1)

As the green and blue elements in Prague's datasets are more fragmented and detailed, the recommended classification by (Niedźwiecka-Filipiak et al., 2019) was improvised with some addition and removal of some LaFU types based on the regional context. For example, the original category "forests and groups of greenery with a compact area over 25 ha with internal open spaces" is eliminated since the city is a complex mix of forests and open areas or farmlands. Instead, two major categories - "forests and group of greenery" and "open areas and farmlands" are used and subdivided based on their areas and presence of water bodies in or around them. Moreover, a new LaFU type consisting of forests or open spaces with an area less than 0.5 ha is also mapped. These smaller units of BGI are taken into consideration because many of them are crucial points of nature in highly urbanised districts of Prague that might need unique actions for conservation and potential connections. The LaFU types for Prague developed from its "current land use types'' are as listed below and mapped (map 8):

Table 3: Division of land use types into LaFU types. (Source.Authors.2024).

LU codes	Current land use description	General LaFU type	LaFU type
LRO	Forests	forests and group of greenery	forests and greenery over 25 ha with water forests and greenery over 25 ha forests and greenery of 5-25 ha forests and greenery of 0.5-5 ha forests and greenery < 0.5 ha
LRR	forest parks		
ND	accompanying vegetation		
NNK	non-forest stands of trees not associated with shrub		
NM	wetlands without woody plants		
NNO	non-forest stands of woody plants not associated with trees and shrubs		
NZO	non-forest stands of woody plants connected with trees and shrubs		
NZK	non-forest stands of trees mixed with shrubs		
NNS	non-forest stands of woody plants not associated with trees		

LU codes	Current land use description	General LaFU type	LaFU type
NZS	non-forest stands of woody plants connected with trees		
PLP	production field	open areas and farmlands	open areas and farmlands 25 ha with water open areas and farmlands over 25 ha open areas and farmlands of 5-25 ha open areas and farmlands of 0.5-5 ha open areas and farmland < 0.5 ha
PRZ	agricultural production		
PLU	field – fallow		
RAP	natural recreation areas		
RAZ	recreational and garden settlements		
RPP	garden park areas		
RPH	Cemeteries		
RV	educational recreational areas - ZOO, botanical gardens		
ZL	meadows, pastures, grass fields		
XZ	unused areas with overgrowth of trees		
RPU	park-landscaped areas		
ZSV	Vineyards	orchard complexes	orchard complexes
ZSZ	Gardens		
BR	Brownfields	Brownfields	Brownfields
HY	Water courses and areas	surface and water courses	watercourses in greenery watercourses in open areas and farmlands surface standing waters in greenery surface standing waters in open areas other water courses and areas



Map 8. Division of elements into LaFU types. (Source.Authors.2024).

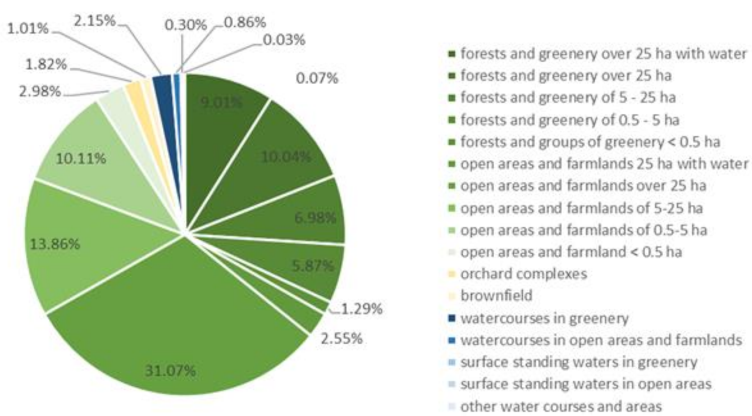


Figure 2. LaFU Area (in Ha). (Source.Authors.2024).

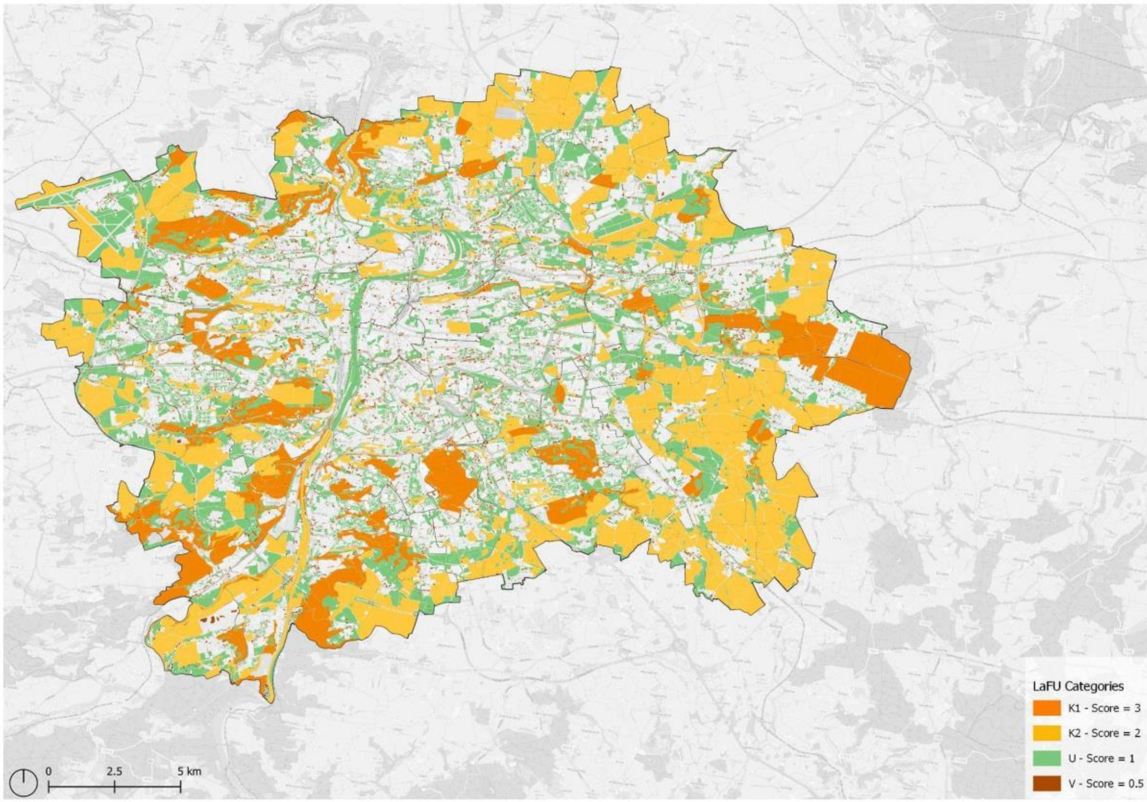
5.2. LaFU categorisation (Stage 2 – part 1.2)

This sub-part consists of determining the significance of the landscape units for maintaining the continuity of the designed BGI system and connection between important areas with ecological reasons in mind. For this, the LaFU are categorised in codes and scores (map 9) based on their ecological significance and need for protection as followed:

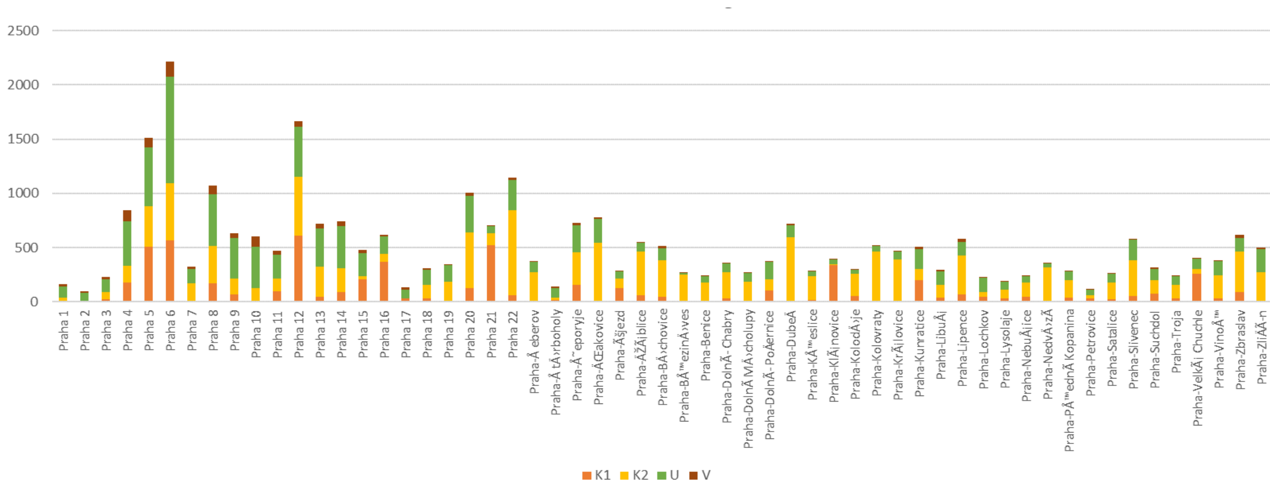
- K1 - BGI units with large areas and high greenery and/or large surface water areas - 3 points.
- K2 - complementary BGI units of the core K1 category that do not share a large quantity of greenery and/or surface water but are important in connecting the K1 unit. They might accompany some economic activity such as farming or horticulture - 2 points.
- U - BGI units supporting K1 and K2 units and are not on the high priority for conservation. They may be intermixed with urban elements - 1 point.
- V - Scattered and smaller BGI units such as neighbourhood parks with low vegetation quality but of local urban importance - 0.5 point.

Table 4: Categorisation of LaFU

	LaFU type	Code	Score
1	forests and greenery over 25 ha	K1	3
2	forests and greenery over 25 ha with water	K1	3
3	forests and greenery of 5 - 25 ha	K2	2
4	forests and greenery of 0.5 - 5 ha	U	1
5	forests and groups of greenery < 0.5 ha	V	0.5
6	open areas and farmlands 25 ha with water	K2	2
7	open areas and farmlands over 25 ha	K2	2
8	open areas and farmlands of 5-25 ha	U	1
9	open areas and farmlands of 0.5-5 ha	U	1
10	open areas and farmland < 0.5 ha	V	0.5
11	orchard complexes	U	1
12	Brownfield	U	1
13	watercourses in greenery	K2	2
14	watercourses in open areas and farmlands	U	1
15	surface standing waters in greenery >= 3 Ha	K1	3
16	surface standing waters in open areas	U	1
17	other water bodies	V	0.5



Map 9. LaFU categorization into weighted classes. (Source.Authors.2024).
Figure 3. District Wise LaFU Categories (in Ha). (Source.Authors.2024).



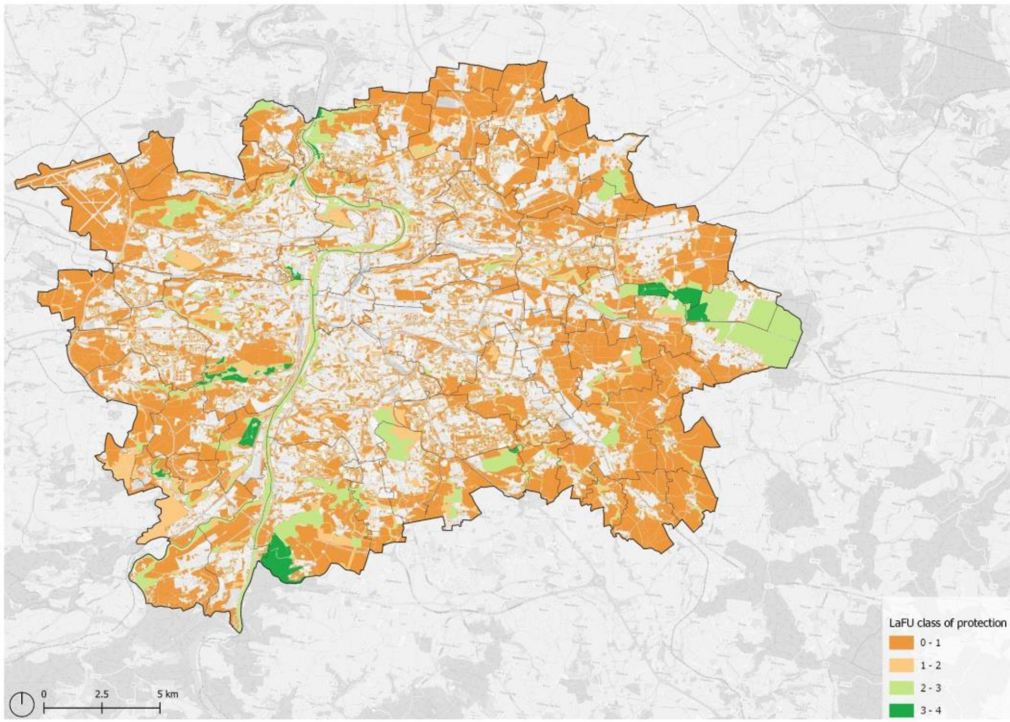
5.3. LaFU hierarchization (Stage 2 – part 1.3)

This sub-part defines the classes of the LaFU system based on their level of protection under the legal and regulatory framework. As compiled in part 2 of stage 1, 'Determining the leading functions of BGI units'**,** a hierarchical classification of LaFU is constructed by factoring in the layers of regulations for protection and conservation. For this, the following spatial measures by European, state, and local authorities with scores based on the level of protection were compounded, indicating higher score for BGI elements under higher layers of protection:

Table 5: Hierarchization of LaFU types

	Environmental protection regulation / programme	**Score**
1	USES (planning, critical and interactive elements) Praha (2022c)	1
2	USES ecological stability elements (local and regional biocentre, bio-corridors and axes) Praha (2022a)	1
3	Natura 2000 under Infrastructure for Spatial Information in Europe (INSPIRE) Republiky (2022)	1
4	Sites under The International Union for Conservation of Nature (IUCN) and INSPIRE Republiky (2022)	0.5
5	Buffer zones defined by INSPIRE Republiky (2022)	0.5
6	National parks Praha (2014)	0.5
7	Q100 flood risk zone Praha (2022a)	0.5
8	UNESCO historic centre of Prague Centre (2012)	0.5

These layers altogether can allocate a minimum 0 to a maximum of 5 score to BGI elements (map 10).



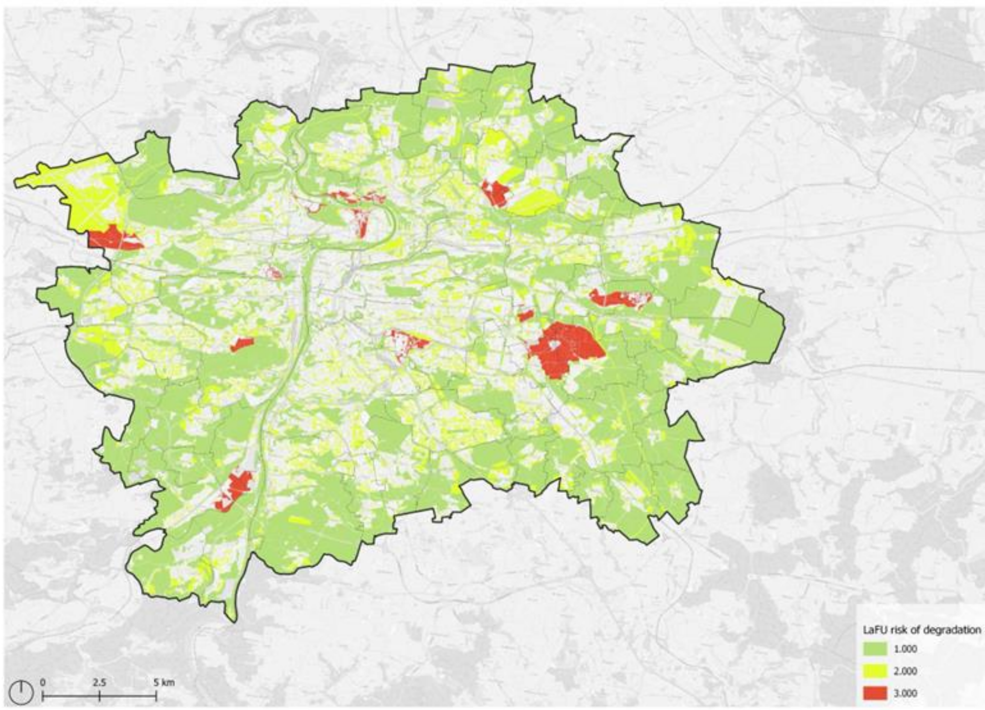
Map 10. LaFU hierarchization based on protection measures and priority. (Source.Authors.2024).

5.4. Dysfunction and threats (Stage 2 - part 1.4)

After demarcating the level of protection, the fourth sub-part aims to gauge the risk of threat and degradation the identified BGI elements might face due to current or future development plans. Previous studies have indicated that Prague has witnessed loss of agricultural land use with higher quality soil to suburbanization (Spilková & Šefrna, 2010; Veith & Jebavý, 2017). Moreover, in recent years, some natural areas that are significant in providing ecological services and climate resilience were permitted to urbanise by the authorities and witnessed criticism and citizen backlash (Holubcová, 2017; Péče, 2022). Therefore, if the planning authorities redefine the land use of the GI elements as 'buildable' or suitable for urbanisation instead of enforcing conservation efforts on them, the BGI elements would face the possible risk of urbanisation. Similarly, if a development project is already proposed on an existing BGI element and is of predominantly urban character with a high proportion of built up, the BGI element shall be considered as at certain risk of degradation. With these presumptions, three degradation risk classes were defined with the help of future land use and planning proposals by the local and regional authorities of Prague.

Level 1 - not at risk of degradation - 1 point, large units of green areas and forests with no development proposal or those areas with layers of environmental protection as listed in the section 5.3.

Level 2 - at low risk of degradation - 2 point, units with a potential threat from possible future development because they are demarcated as buildable areas as per the planning document (Prahy.2019) implying that the authorities have given a green flag to future urban development on the land parcels. Another category at risk are the former rail yards or barren areas marked as 'brownfield' and proposed for redevelopment. These are not at very high risk of degradation as the proposal indicates recreational use and greenification of the sites (Development, 2022).
Level 3 - at high risk of degradation - 3 point, BGI units with threat from upcoming large scale developments proposed under the territorial plan. These development projects are predominantly urban and have been marked for residential land use, indicating that the GI will certainly be lost on the said land parcels (Prahy.2019) (map 11).



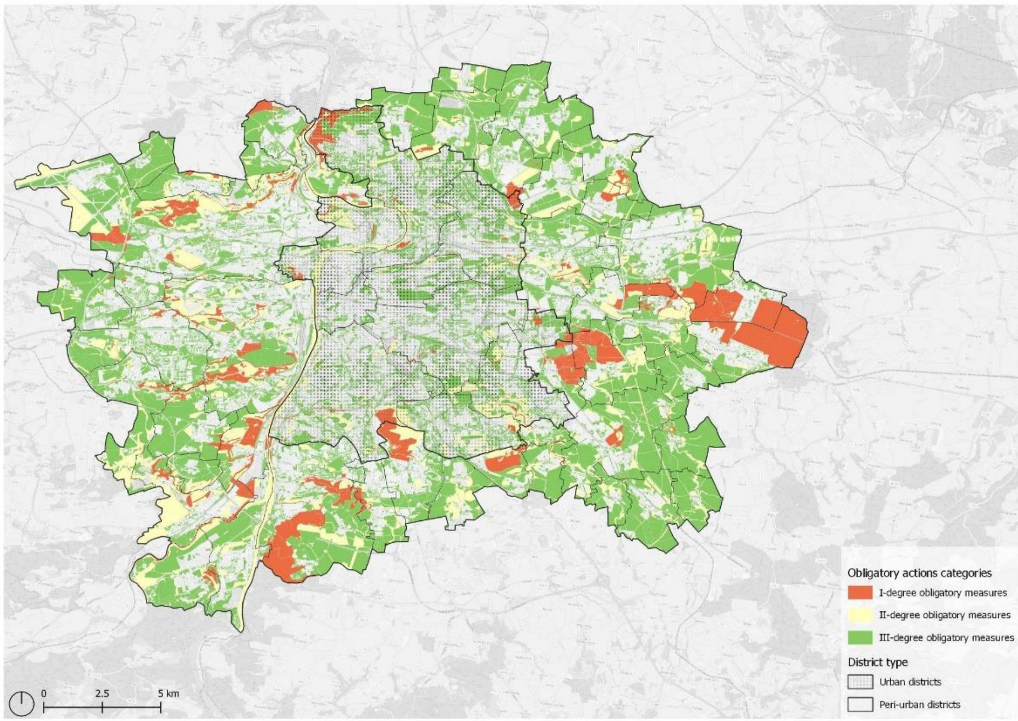
Map 11. LaFU dysfunction and threats. (Source.Authors.2024).

5.5. Designating areas for obligatory actions (Stage 2 - part 1.5)

The final sub-part of the LaFU analysis is estimating the level of obligatory actions by summarising the LaFU category, hierarchy and threat mapped in the earlier sections.
It allows for localization of protective or corrective actions necessary for the proper functioning of the designed BGI system. These could be used as the basis for changes in the records of planning documents at both local and regional levels. The LaFU are assigned an obligatory action score according to the following formula adopted from the study (Niedźwiecka-Filipiak et al. 2019) for the case of Wrocław, Poland:

$$O_i = (K + C) * T$$

where, K is the category of the LaFU, C is the class of the LaFU, T is the type of threat, O is the action obligatory, and $_i$ is the unit number assigned in the BGI system. On execution of the formula, the O ranged between 0.5 to 16.5. The higher the score, the higher the urgency and magnitude of measures needed and vice versa. As map 12 indicates, a very small proportion of BGI elements are under high need of obligatory options (score 5 to 16.5). Furthermore, they all fall in the peripheral districts that are identified as peri-urban in characteristics because more than half of their area consist of BGI, generating an intermixed landscape of urban, rural, and natural elements.



Map 12. LaFU obligatory actions categories. (Source.Authors.2024).

Of the total 29600 Ha of BGI in the Prague region, 12% falls under first degree obligatory action, suggesting that they are at the highest priority for protection. As demonstrated in fig.4, three types of LaFU viz, forest and greenery over 25 Ha with and without water and open areas and farmlands over 25 Ha are in the need of 1st degree obligatory action. The 2nd and 3rd degree action areas are 21% and 66% respectively.

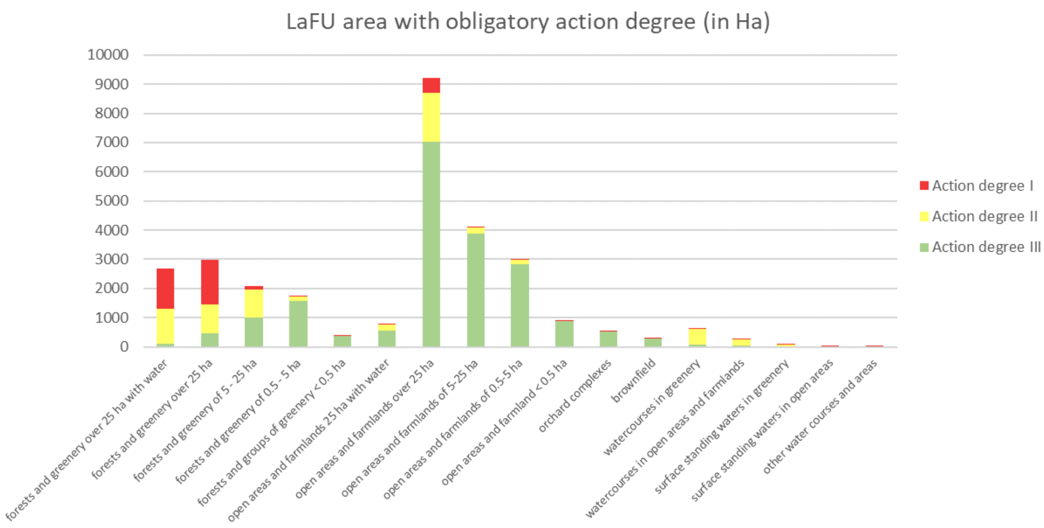


Figure 4. Area of LaFU types with obligatory actions (in Ha). (Source.Authors.2024).

Likewise, fig 5 visualises the action priority on district level. Districts named Praha 5 and Praha 6 located on the west side of the Vltava River have natural parks or large agricultural fields with no strong regulatory protection and are under the risk of potential or proposed urbanisation. There is Praha 12 on the west of the river in the south, that is a well protected forest land but marked as buildable by the territorial plan. Praha 21, Praha-Dubeč and Praha-Klánovice located on the east end of the city also have a high proportion of BGI with the need of 1st degree obligatory action. The outputs from map 12 indicate the need of urgency in taking actions and applying strategies for protection and improvement of the LaFU.

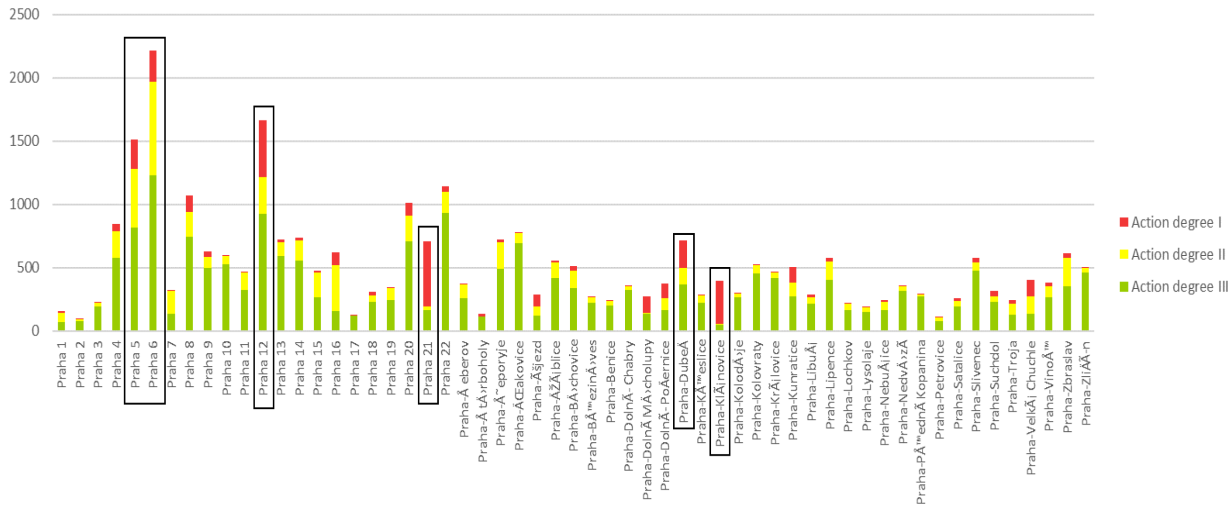


Figure 5. District wise degrees of obligatory actions (in Ha). (Source.Authors.2024).

6. MSPA ON PRAGUE (STAGE 2 – PART 2)

Following the LaFU analysis for the evaluation of the quality and characteristics of BGI in Prague, MSPA is adopted to identify the spatial connections and fragmentation between them. The MSPA of Prague generated an output of the 7 elements of BGI network as followed:

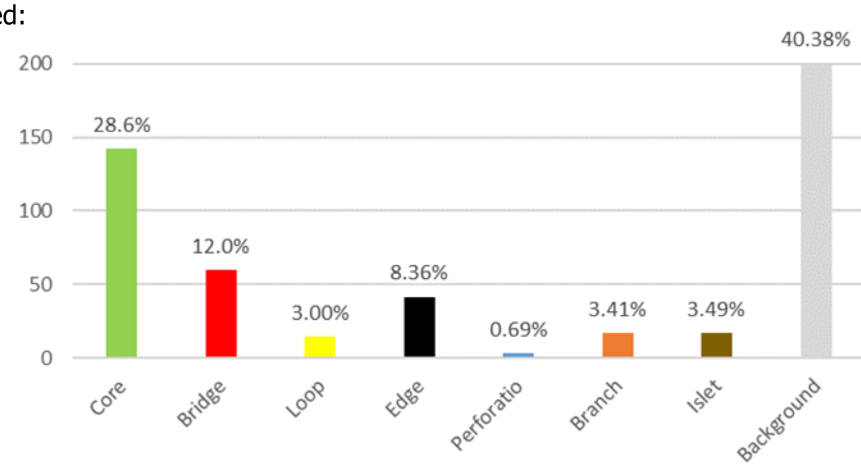
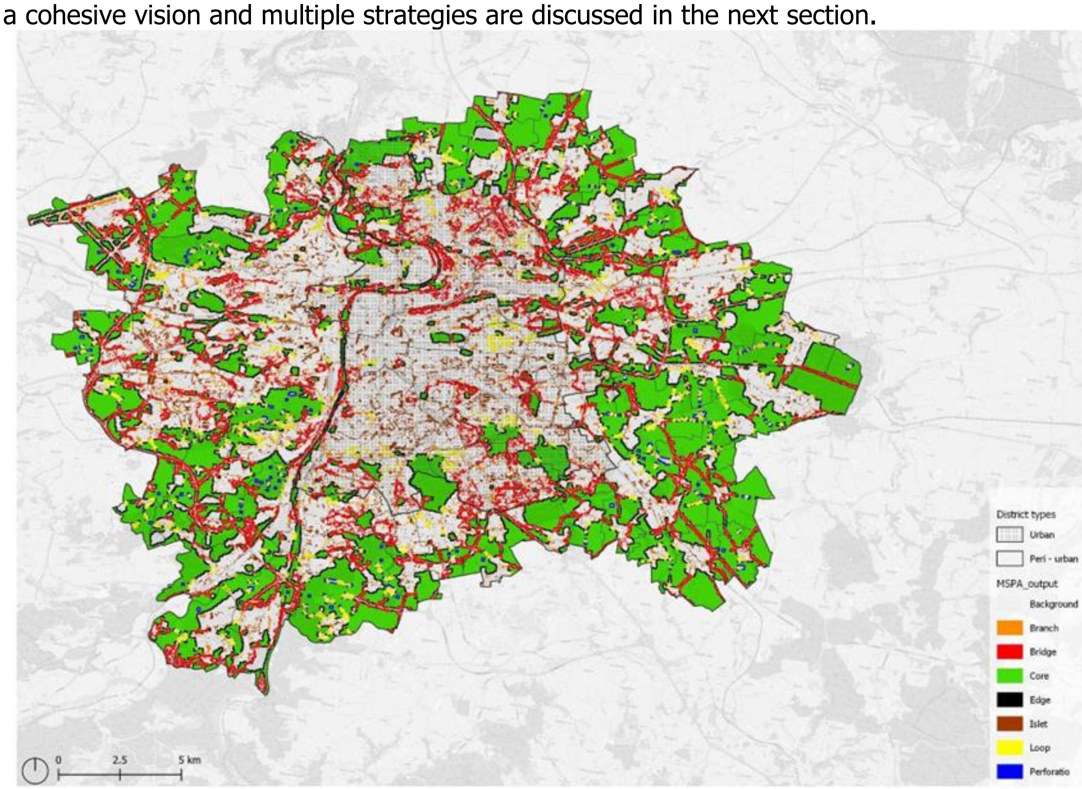


Figure 6. Outcome of MSPA on the study area (in km.sq).(Source.Authors.2024).

Of the total 296 km.sq BGI in the city, 28.6% are core areas whereas 15% constitute connecting elements of *bridges* and *loops*. As visible in map.13, urban districts predominantly contain *islets* that are freestanding LaFU with no core area and come in the categories of smaller open areas such as parks and gardens. While *loops* connect to the same core, *bridges* connect different cores and are hence, selected as connections linking

cores. The large areas of cores in the city periphery are divided by roads or railway lines and are commonly identified as bridges as per MSPA output (map. 13). These linear dividers can be used as important focus points in reducing the fragmentation of their adjacent cores by enriching their quality and also supporting species movements.
On overlapping and intersecting the MSPA's cores and connections on board LaFU types, a further detailed picture emerges. Map. 14 demonstrates the cores and connections sub-divided into forests, open lands / farmlands, brownfields, and waterbodies. The connections of forest cores followed by that of water bodies possess the highest value and need for protection since these BGIs are the richest hotspot of ecosystem and biodiversity. The farmlands, open areas and brownfields, while in need of value augmentation through sustainable strategies, links connecting them can be improved after those of forests and water bodies. With the help of LaFU assessments and their intersection with MSPA's results, a cohesive vision and multiple strategies are discussed in the next section.



Map 13. MSPA results with seven morphological pattern elements. (Source.Authors.2024).

Referring to map 14 and fig 7 to understand the distribution of the types of cores and connections between Prague's districts, it can be noticed that in several districts, the cores and connection areas are 30% to 40 % smaller than their total LaFU blue green infrastructure. This is because of the removal of MSPA elements such as islets and branches. This deduction in area is seen predominantly in urban districts with major proportions of fragmented green infrastructure in the form of urban open spaces such as parks or gardens.

To understand the presence and distribution of connections, especially those of forest cores is crucial to design strategies and set priorities to protect and enhance their quality and discourage ecosystem fragmentation. Fig 7 indicates non-urban districts such as Praha 5, 6, 12, 13, 14, 20 and 21 and peripheral urban districts such Praha 8,9 and 10 consisting of a higher proportion of forest connections. Some of these districts such as Praha 12 and 21 have BGI under the need of first-degree obligatory action. This marks the need of strategies to prioritise the protection of connections and cores in the given districts.

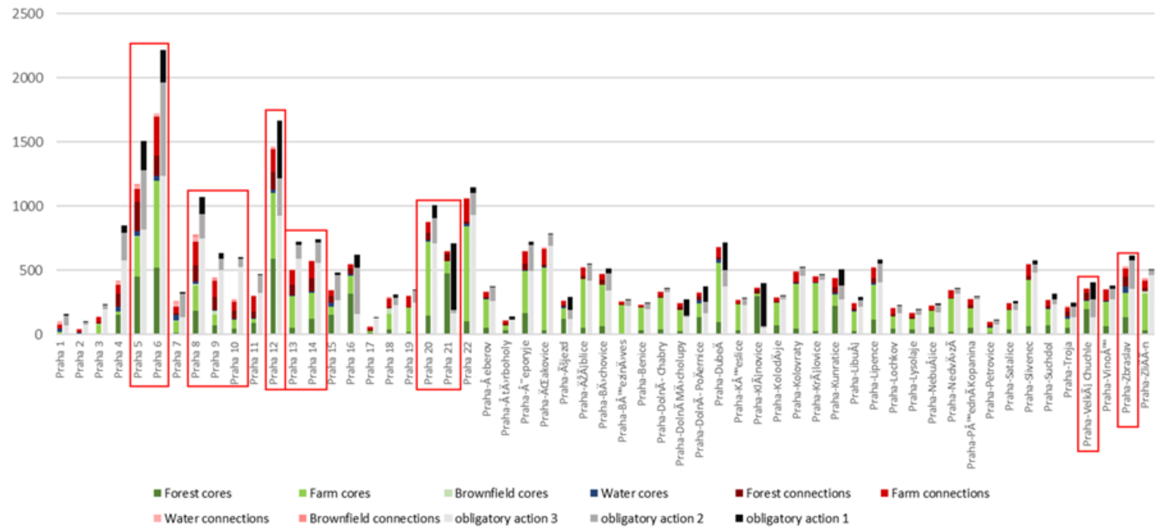
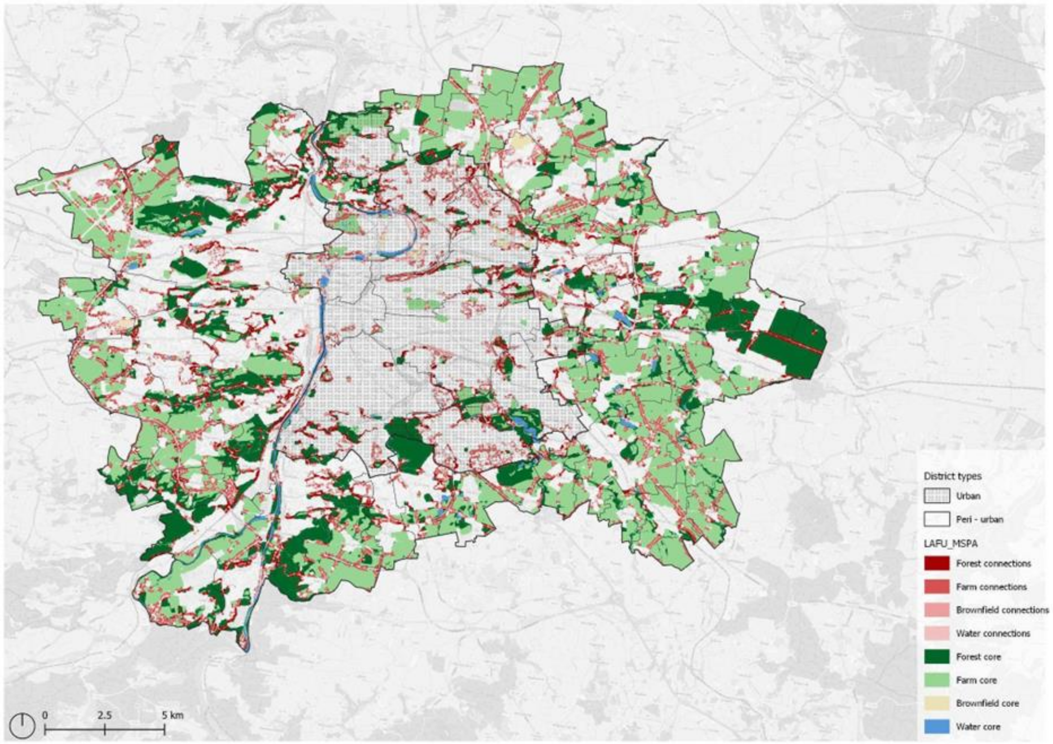


Figure 7. MSPA cores and connections compared to LaFU obligatory actions (in Ha). (Source.Authors.2024).



Map 14. Cores and connections from MSPA overlaid over broad LAFU types. (Source.Authors.2024).

7. VISION AND STRATEGIES (STAGE 3)

The integration of LaFU analysis and MSPA in this study has presented interesting insights to guide the BGI vision of Prague. We used the results from the LaFU-MSPA intersection analysis and designed a strategic map defined by the distribution of BGI functional typologies in the city.

A prominent natural element visible in Prague are the rivers Vltava and Berounka traversing it north to south (fig 8). The diagram also highlights the forest and farm cores on the periphery of Prague. While the central districts are largely urbanised with smaller green areas scattered across them, the forest cores exist adjacent to the urban districts. Although the forest cores and connections are not continuous, they approximately form alternate wedges of forest cores and connections around the urban districts, with some forest wedges radially converging into the river zone. Beyond the forest ring, there is a dominant presence of farmlands that are fragmented by streets and roads. The final vision, as presented in fig 8, aims to guide for more cohesive strategies for defragmentation and improvement of the quality of Prague's BGI.

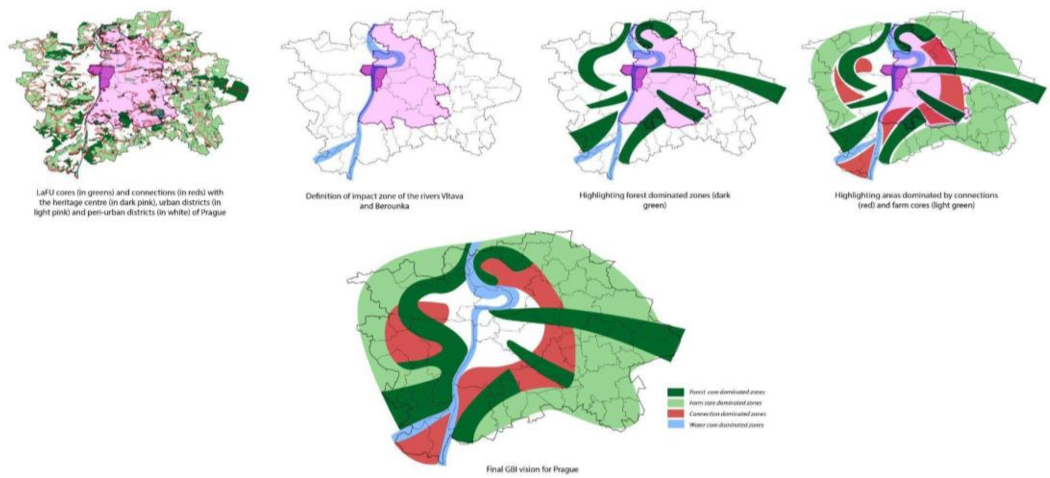
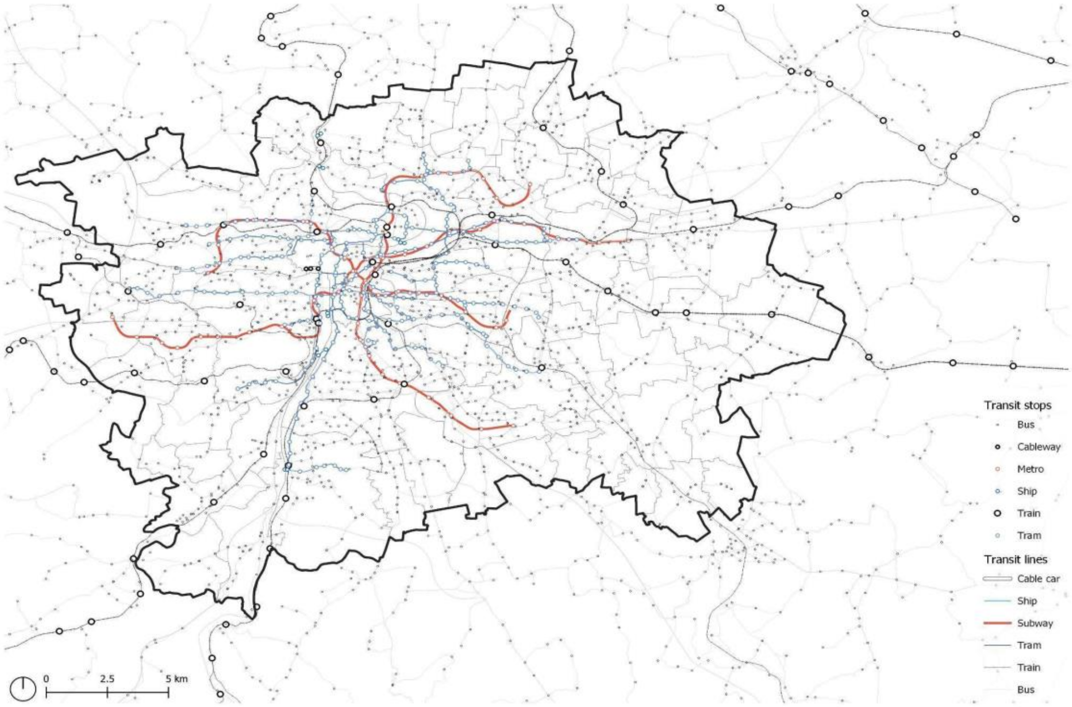
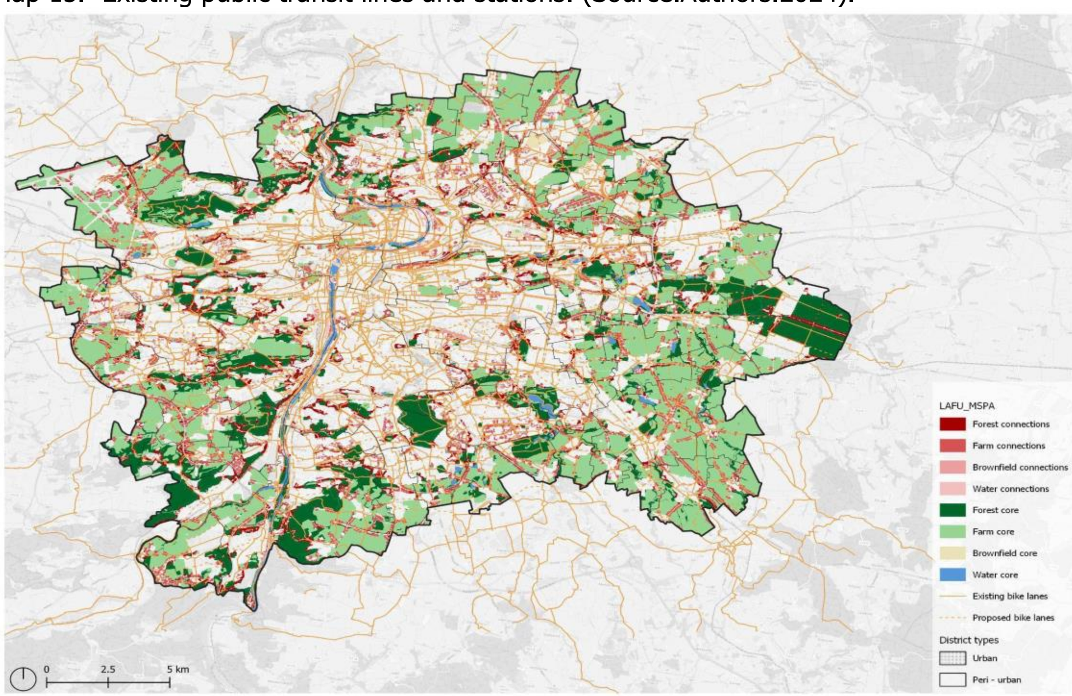


Figure 8. BGI transformation vision formulated from LaFU MSPA insights. (Source.Authors.2024).

The components specified in the vision are functional and spatial units of blue green infrastructure. The following and final stage of this research formulates strategies with the guidance of local development and landscape protection plans, to protect and enhance the quality of BGI cores, connections, and other morphological elements. The strategies are sub-divided into urban and peri-urban districts as this context would crucially define the extent and type of naturalisation efforts. The table 6 lists down strategies for each LaFU types for urban and peri-urban context and concludes with additional strategies for farm and forest connection elements (generated from MSPA) to ensure the continuity of the BGI network. Lastly, the networks of public transport are laid over and, existing and proposed bike infrastructure are superimposed over the LaFU-MSPA results to indicate the need for integration of sustainable mobility with the green and blue infrastructure. As clear from map 15 and map 16, Prague holds a wide network of bike lanes and plans to densify it further, percolating in the green cores. The city also shows a satisfactory presence of the public transit network, especially bus lines that connect central urban districts to the surrounding larger green areas as well as interconnect peripheral districts with one another. This compilation of strategies, that are synergized with the help of literature and existing policies, is drafted opposite to the LaFU. They can, therefore, add value to existing plans and guide decision makers with more insights and evidence-based recommendations on the functionality and continuity of the BGI network of the city.



Map 15. Existing public transit lines and stations. (Source.Authors.2024).



Map 16. Existing and proposed bike lanes with LaFU - MSPA elements (Source.Authors.2024).

Table 6: strategies for each LaFU type. (Source.Authors.2024).

Regional	Strategies	LaFU Type																
		forests and greenery over 25 ha with water	forests and greenery over 25 ha	forests and greenery of 5 - 25 ha	forests and greenery of 0.5 - 5 ha	forests and groups of greenery < 0.5ha	open areas and farmlands over 25 ha with water	open areas and farmlands over 25ha	open areas and farmlands of 5-25 ha	open areas and farmlands of 0.5-5 ha	open areas and farmland < 0.5 ha	orchard complexes	brownfield	watercourses in greenery	watercourses in open areas and farmlands	surface standing waters in greenery	surface standing waters in open areas	other water courses and areas
Non-urban	Introduction of green buffer strip between fields						X	X	X									
	Vegetation accompanying water reservoirs	X					X							X	X			
	Forestation of areas of low valuation class soils									X	X		X					
	Restoration of proper natural habitat conditions	X	X	X	X	X	X							X	X	X		
	Introduction of native species	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Protection of wetlands	X												X	X	X		
	Fruits and flowering trees plantation along trails and routes	X	X	X	X		X	X				X						
	Biking and trekking tours	X	X	X	X													
	Ecotourism	X	X	X	X													
	Water sports and tourism													X		X		
	Bike lanes	X	X	X			X	X										
	Weekend tourism	X	X	X														
	Removing developable zones of natural and semi-natural areas in land use plan	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Areas with settlement	River and riverfront recreation	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Eco-education	X	X	X	X	X	X	X	X	X		X				X	X	
	Organic food production	X	X	X	X	X	X	X	X	X	X	X	X					
	Heritage and cultural activities	X	X	X	X	X	X	X	X	X	X	X	X			X	X	
	Flooding and water retention	X					X							X	X	X	X	X
	Nature based solution for rain and waste water management	X					X							X	X	X	X	X
	Reusing treated waste and rain water	X	X	X	X	X	X	X	X	X	X	X	X					
	Preventive measure for soil erosion				X	X	X	X	X	X	X	X	X					
	Green roofs and facades	X	X	X	X	X	X	X	X	X	X	X	X					
	Bike lanes	X	X	X	X	X	X	X	X	X	X	X	X					
	Bike sharing stations	X	X	X	X	X	X	X	X	X	X	X	X					
	E-bike charging stations	X	X	X	X	X	X	X	X	X	X	X	X					
	Community gardening	X	X	X	X	X	X	X	X	X	X	X	X					
	NBS living labs	X	X	X	X	X	X	X	X	X	X	X	X					
	Place making projects	X	X	X	X	X	X	X	X	X	X	X	X					
	Tactical urbanism	X	X	X	X	X	X	X	X	X	X	X	X					
	Water fountains		X	X	X	X		X	X	X	X	X	X					
	Outdoor sports	X	X	X	X	X								X	X	X	X	
	Vineyards - wine production						X	X	X	X	X	X	X					
	Orchards and fruit production						X	X	X	X	X	X	X					
	Daily tourism			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Single-day tourism			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Thematic villages	X	X	X	X	X	X	X	X	X	X	X	X					
	Agro-tourism						X	X	X	X	X	X						
	Recreating historic alleys and rows, tree plantings along roads	X	X	X	X	X	X	X	X	X	X	X	X					
	Planting trees in private property areas	X	X	X	X	X	X	X	X	X	X	X	X					
	Creation of new parks	X	X	X	X	X	X	X	X	X	X	X	X					
	Creation of green squares	X	X	X	X	X	X	X	X	X	X	X	X					
	Isolating vegetation near industrial and service facilities	X	X	X	X	X	X	X	X	X	X	X	X					
	Non-dispersion of buildings and location of new buildings within designated built-up areas	X	X	X	X	X	X	X	X	X	X	X	X					
Connections	Introduction of native plant species	X					X						X					
	Nature based solution for rain and waste water management	X					X						X	X				
	Planting trees along roads and railway lines	X					X						X					
	Construction of eco-bridges at critical species migration crossings	X												X				
	Bike lanes and trails	X					X						X					
	Increase of permeable surfaces	X					X						X					
	Removing developable zones of natural and semi-natural connections in land use plan	X					X						X					

8. CONCLUSION AND DISCUSSION

The research presents a unique and advanced approach to analyse BGI by intersecting two methods - LaFU and MSPA. The LaFU evaluated them on the basis of their importance, scale, degree of protection and threat, whereas MSPA generated the spatial pattern of the BGI network in the form of cores and connections. The final result provides insights that are advanced to the individual outcomes of both the methods and evidently indicate the functionalities of cores and connections of the BGI.

With the LaFU analysis in the first half of the study, very limited districts in the periphery of the city were found to be in need of first-degree action implying that those BGIs parcels were environmentally valuable and yet not sufficiently protected by legislation and under the threat of urbanisation. This analysis provided us with a strong foundation to draft distinct strategies for the protection and conservation of every LaFU type. Similarly, our study also provides a comprehensive framework and new classification of BGI to build upon new decisions and define new studies for the city of Prague.

This study aims to contribute to the domain of climate change and resilience by focusing on the potential values of urban and regional BGI and present a mechanism to be used to address local climate challenges. We argue that the recommendations from this study can guide the efforts of the quality improvement of natural, semi-natural and water infrastructure in Prague and strengthen their connections, which in turn can immensely help in environmental and socio-economic issues. The ecosystem services offered by BGI and nature-based solutions are known to tackle air pollution by providing carbon-sink, reducing water pollution by enhancing water ecosystems that naturally oxygenate and purify water sources, mitigating urban heat island effect by providing shade and through evapotranspiration, provide comfortable public spaces for recreation and movements, and so on. The benefits of connection and protecting BGIs are multi-dimensional and the results from this study should be used in localising the strategies to address context-based issues.

9. SCOPE AND LIMITATIONS

The research process faced multiple challenges in terms of defining the theoretical framework as well as technicalities. Firstly, the datasets were in Czech language. Therefore, integrating them and transforming them into English resources was a cumbersome task. Secondly, we also faced the conventional challenges such as in data wrangling and processing with several attempts to make it suitable for the analyses. Therefore, several trials were conducted in formulating an appropriate methodology.

This study also paves ways for future research in the field of BGI and for the case of Prague. As the case study of Wrocław (Niedźwiecka-Filipiak et al. 2019) highlights that such a method is appropriate for city-regions with the goal of sustainably develop and coherently manage their BGIs in a trans-scaler way, our study reinforces this method by confirming its replicability in Prague. We used pre-defined BGI polygons from Prague's official geoportal, but we now recommend the use of other data sources such as NDVI and satellite imagery for delineation of BGI and identification of LaFU to compare with our results. The study also limited its scope on the evaluation of BGI through LaFU and their connections but did not establish relationships with other elements such as built environment, mobility and traffic movements, air pollution or urban heat effect. However,

we encourage future research to question and investigate the relation of the LaFU, cores and connections with aforementioned factors.
Although this study has taken the research in BGI a step forward, it holds immense potential for further extension of its scope and objectives. Adoption of this methodology to design and define regional BGI strategies of another case study could also be an important use of this research. Moreover, the study advises engagement of stakeholders and concerned authorities to verify its vision, while encouraging more studies to support and challenge the approach.

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