CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

FACULTY OF ENVIRONMENTAL SCIENCES

ANALYSIS AND EVALUATION OF GREEN INFRASTRUCTURE OF PRAGUE CITY

BACHELOR THESIS

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FacultyofEnvironmentalSciences

BACHELORTHESISASSIGNMENT

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EnvironmentalSciences
AppliedEcology

Thesis tle

Analysisandevaluaonofgreeninfrastructureofpraguecity

Objecvesofthesis

Greenareasinthecityprovideecologicalservicesandmakethelivingareamoresustainable.Green infrastructuresuppliesbasicneedsforhealthfulandrestliving.Thesepartsoftheenvironmentare constantlychangingwithmeintheirsizeanddiversity.Bytrackingthedynamicsoftheirdevelopment, wecoulddeterminetrendsandusereceiveddatatoimprovethelivinglevel.Collecteddatacouldalsobe usedtoavoidmistakesinlandscapeplanning.
Thisthesisaimstodealwiththemaintypesofgreenandblueinfrastructureandhowtheyinfluenceeach other.Thisthesiswillshowfundamentalmethodsandanalysisoftheurbangreeninfrastructuremodel.

Methodology

For the analysis, I will be comparing how biodiversity has changed over the past few years. For evaluation, I will be comparing how the sizes of green and blue infrastructure changed and what impact those changes brought to the sustainability of the environment. For example, restoring wetlands (blue infrastructure) entails changes for ecotypes around or some mes restoring in green infrastructure. That means that the total area of green and blue infrastructure will be changing. We can ask ourselves if there is a specific ratio of blue and green infrastructure in Prague that can’t go below the minimum number of the green and blue areas, which provide ecological survives. This thesis will discuss fundamental types of ecological services, how they change over the years, and what impact they have on each other.

The proposed extent of the thesis

50

Keywords

Green infrastructure, Prague, Biodiversity

Recommended informa on sources

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Prohlašuji, že jsem bakalářskou práci vypracovala samostatně pod vedením Ing. Lucie Zemanové, a že jsem uvedl všechny literární prameny, ze kterých jsem čerpal. Souhlasím se zveřejněním bakalářské práce.

V Praze, dne 15. 4. 2014 Podpis: ……………………...

Abstract

Analysis and evaluation of green infrastructure of Prague city

The formation of green infrastructure is a constant process that requires a complex approach, which contains its element with their own functions. The Analysis is focused on the fundamental structure of green infrastructure, its functions, and difficulties. This paper discusses the biggest challenges for modern green infrastructure and urban environments, such as the urban heat island effect and flooding. Urban dynamic depends on climate change, the level of urbanization, and the city's basic structure created by historical events. It is building a sustainable city based on interactions with blue and grey infrastructure to benefit all.

This paper questions if there is a hierarchy between different types of green infrastructure. If yes, what is it based on? The evaluation considers economic, environmental, cultural, and social factors, and discovers essential needs based on the literature review.

Keywords: green infrastructure, urban biodiversity, Prague

Abstrakt

Analýza a vyhodnocení zelené infrastruktury hlavního města Prahy

Vznik zelené infrastruktury je neustálý proces, který vyžaduje komplexní přístup, který obsahuje vlastní prvky a jejich funkce. Analýza je zaměřena na základní strukturu zelené infrastruktury, její funkce a komplikace. Tento dokument pojednává o největších výzvách moderní zelené infrastruktury a městského prostředí, jako je efekt městského tepelného ostrova a záplavy. Dynamika města závisí na změně klimatu, úrovni urbanizace a základní struktuře města vytvořené na základě historických událostí. Budování udržitelného města založeného na interakcích s modrou a šedou infrastrukturou ve prospěch všech.

Tato práce se ptá, zda existuje hierarchie mezi různými typy zelené infrastruktury. Pokud ano, na čem záleží? Hodnocení bere v úvahu ekonomické, environmentální, kulturní a sociální faktory a objevuje základní potřeby na základě přehledu literatury.

Klíčová slova: zelená infrastruktura, Praha, urbanická biodiverzita

Contents

Chapter 1

Introduction

Cities are developing quickly and require more attention and care for their environment; at the same time, the modern life of people is changing too through their needs. Together with the economic changes and new modern illnesses such as depression and anxiety, people are seeking for new solutions to make their life more sustainable and their cities healthier. What are the crucial points for healthy and motivated life, and how can the existing condition, which the landscape provides, help?

The answer to a healthy and sustainable environment is knowing valid characteristics and skills to combine them.

Aims

The aim of this work is to focus on all the types and their functions of green infrastructure and highlight its benefits, describe its connectivity with blue and grey infrastructures, and work out analyses and evaluations based on social, economic, cultural, and aesthetic aspects.

Chapter 2

Literature Review

2.1 Urbanization concept and its content from an ecological view

Urbanization is a complex process that transforms the rural or natural environment into an urban and industrial landscape by creating diverse mosaic patterns of natural or anthropogenic origin, mainly controlled by local conditions and social and economic factors. Any landscape is formed as a functionally interconnected system that has to be balanced, in other words, sustainable. A definition of economic, environmental, and social sustainability must characterize the urban landscape and its current development.

From the point of view of ecology, we understand the landscape as heterogeneous parts of the earth's surface, composed of a set of interacting ecosystems that repeat in a given part of the surface in similar forms (Forman a Gordon, 1993). In the modern urban landscape, there are three main types of cover with similar properties that can be distinguished: grey infrastructure (GrI), blue infrastructure (BI), and green infrastructure (GI). The city's urban forms, such as living areas, institutions, and other public spaces, must be connected and regulated to form a united system.

Grey infrastructure can be viewed as the vehicle for delivering socio-economic benefits. Examples include buildings and plants for manufacturing processes, providing infrastructure to move goods and people, and energy distribution. (Natural Economy Northwest, 2009). Blue infrastructure refers to natural and artificial water in the urban area; this infrastructure can provide economic and environmental benefits and a range of ecosystem services. Blue infrastructure includes rivers, canals, ponds, wetlands, floodplains, and water treatment facilities (Potchter et al.,2019). We can relate the term BI to GI in a concept of a multifunctional system that can provide ecological services in close connection with each other's areas and their systems. Green infrastructure is the network of designed and natural vegetation found in our cities and towns; this network includes public parks, recreation areas, remnant vegetation, residential gardens, street trees, community gardens, and innovative and emerging new urban greening technologies (such as rain gardens, green roofs, and green walls) (Norton. B et al., 2013).

2.2 Ecological services

Blue-green infrastructure has gained much attention in urban planning and development because of its properties as a provider of ecological services. Eco-services make together a complex of natural-based benefits that have huge potential to support sustainability in urban developing areas The main flow for fundamental ecosystem services contains so-called “natural capital,” which presents a stock of natural features such as freshwater, habitats, lands, soil, air, biodiversity, and biological processes. Natural capital together with other forms of capital (manufactured, human, social, and financial) are needed to produce flows of ecosystem services (Ncube and Arthur, 2021). An excellent example of these flows is how trees, wetlands, and natural soil formations soak up and restore water, regulate floods, and support the water regime. Likewise, the cooling effect of trees and their ability to absorb and store carbon facilitates the regulation of gases in the atmosphere (Jarrin et al., 2019, Liekens et al., 2013).

2.3 Co-benefiting infrastructures

Co – benefiting of blue, green, and grey infrastructures bring a multifunctional approach to urban areas with their constantly changing natural hydrological and climate processes.

Grey infrastructure provides an excellent drainage system, protecting urban areas against storms. However, rapid urbanization and more frequent extreme storm events instigated by climate change make traditional grey infrastructure become less effective and efficient. So-called ecosystem-based adaptation measures make use of blue and green infrastructure (e.g., green facades, greenery in public spaces, permeable areas or reservoirs for intercepting rainwater, etc.), as opposed to so-called "grey infrastructure", focused only narrowly on construction or technical solutions (Macháč et al., 2016). At the same time, water scarcity has become increasingly severe in many cities worldwide. Urban rainwater, as a useful water resource, has not been properly collected and utilized in many cities. (Xu et al., 2019). Blue-green and grey infrastructure can't replace each other benefits completely. That is why urban city planning aims to create new strategies or symbiosis out of concrete and natural forms of city mechanisms. These new strategies emphasize the use of green infrastructure to protect, restore, or mimic the natural water cycle to effectively and efficiently improve community resilience and quality of life (Allen, 2013).

Blue-green infrastructure (BGI) can be an ecosystem-based measure for smart cities and is an excellent alternative to grey infrastructure. BGI provides multicore natural or semi-natural ecosystem services to cities, such as water and air quality regulation, flood risk reduction, water retention of an urban landscape, soil erosion reduction, aesthetic values, recreation areas, harvest production, support to biological biodiversity, local and global climate regulation. As for climate change adaptation measures, green and blue infrastructure refers, e.g., to the greenery in public spaces, green roofs, and facades, measures for rainwater absorption, retention reservoirs, measures to slow down water runoff, etc. These measures positively affect people's lives in cities and their health due to ecosystem services, which may assume various forms (Macháč et al., 2016).

2.4 Urban climate change: Heat Island Effect

Anthropogenic factor has the most significant impact on climate change; with the largest urban growth in history, the temperature could expose to extreme heat. Climate change is already affecting Europe's ecosystems and is expected to pose further threats to biodiversity and ecosystem functioning in the future (Environment Policy 2015). Next to a changing climate both in Europe and globally, there is an ongoing urbanization process. In 2007, half of the world's population lived in urban areas, and it is predicted that by 2050, 66% of the world's population will live in urban areas (UN 2014). The growing density of the urban regions brings new requirements to city planning in order to prevent the potential occurrence of natural or human-induced physical events or trends or their physical impacts on the natural environment that influence surroundings locally and globally. Extreme heat, drought, and flooding together bring one of the most common threats to human health, well-being, and environmental sustainability to many communities. The urban climate often differs from the surrounding rural countryside as it is generally more polluted, warmer, rainier, and less windy (Givoni, 1991). Especially in summer, cities with impervious land cover suffer from more extreme climate damage and pay a higher price to recover than ever before (Hsiang et al., 2017; Koop and van Leeuwen, 2017). The phenomenon of urban air temperature being higher than the neighboring rural environment has been defined as the urban heat island effect (UHI effect). The extent of the temperature differences varies in time and place as a result of meteorological, locational, and urban characteristics (Oke, 1987). The city influences its climate on a large scale as a one-piece unit modifies the regional climate conditions, which can be seen in climate conditions' differences (precipitation, air temperature, wind speed) between the city and its surroundings. On a smaller scale, the location and orientation of buildings and outdoor spaces powerfully influence the microclimate in the city, which can vary remarkably in a distance of even a few meters. The UHI effect has the following causes:

1. Higher prevalence of dark surfaces with low reflection as the result of vegetation reduction, which increases heat storage by building materials and decreases evaporation because of 'waterproof surfaces'; See Fig.1 for illustrations.

2. The formation of large amounts of smog and air pollutants and a resulting degradation in the quality of air;
3. Increasing anthropogenic heat from combustion processes, such as traffic, space heating, and industries;
4. A reduction of wind speed decreases the turbulent heat transport from within streets;
5. Powerful impact on urban ecosystems and residents' well-being (Kleerekoper et al., 2012., Mohajerani, 2016).

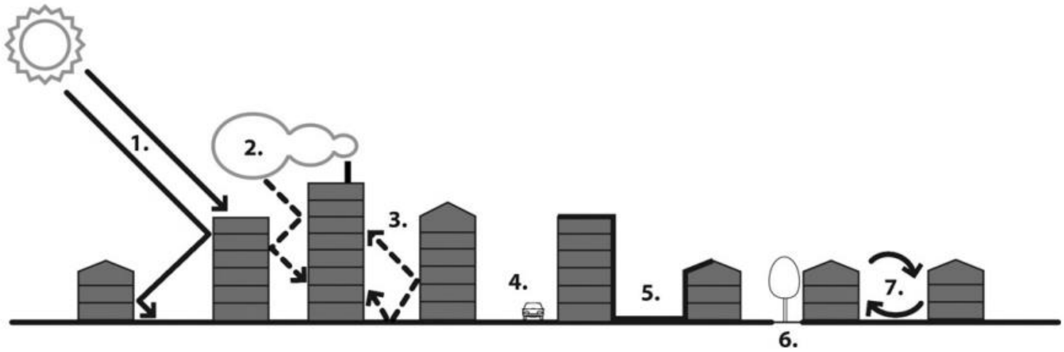


Figure 1. Causes UHI. (Kleerekoper et al., 2012)

European cities seem to develop weaker UHIs (based on the surface temperatures) than northern cities (Ward et al., 2016). This is because the soil in southern Europe tends to dry out strongly during these types of events, making the countryside warmer; hence, the surface UHI effect is less pronounced or even negative. An extreme heatwave can be defined by the Heat Wave Magnitude Index of Russo et al. (2014), where a heatwave is a period of ≥ 3 consecutive days with maximum temperature above the daily threshold for the reference period 1981-2010. The threshold is defined as the 90th percentile of local daily maxima, centered on a 31-day window (Urban adaptation in Europe, EEA Report, 2020).

According to the simulation of the urban climate model UrbClim (De Ridder et al., 2015), Prague is predicted to middle extreme heatwaves and a very intense UHI effect in shortly(2020-2052).

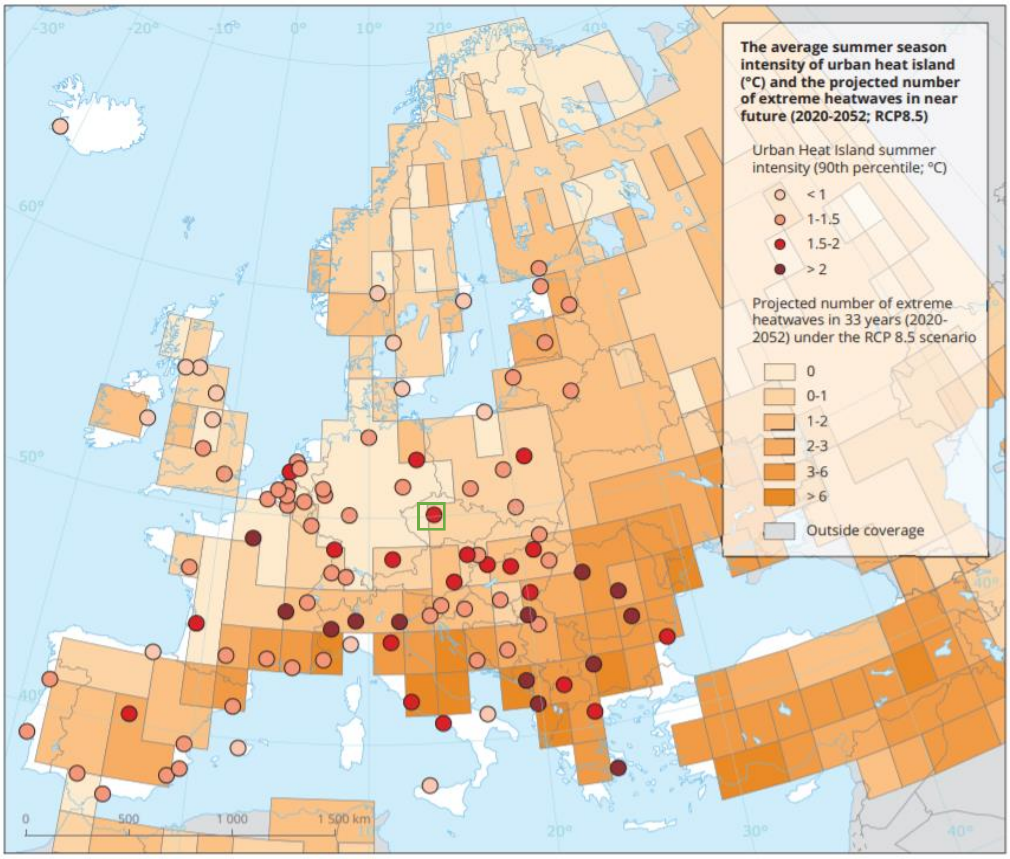


Figure 2. the summer season intensity of urban heat islands (UHIs) (°C) and the projected number of extreme heatwaves shortly (2020-2052; RCP 8.5). Source: Urban adaptation in Europe: how cities and towns respond to climate change, EEA Report 2020.

2.5 Air pollution: in the UHI effect context

Urbanization expansion brings out changes to the hydrological cycle, defining new steps for landscape shaping and land cover; these actions are bringing consequences in the form of energy consumption, heat release, and air pollution. The main issue for city planners in the past decade has been built around the UHI effect; in order to create a sustainable living area, the parameters that have a direct impact on the UHI effect have to be analyzed: size, shape, density, and scale cost significant actions of urban objects. Macro-scale studying of spatial configuration has a more complex effect on UHI than micro-scale studying (such as thermodynamics or fluid mechanics) (Liang, 2019).

City structure defines energy consumption, which greatly impacts thermal comfort and air quality (Martilli, 2014). UHI effect and air pollution constantly influence each other: air pollution contributes to climate change, and climate change creates higher temperatures, in turn, higher temperatures intensify some types of air pollution (Ding, 2022).

Air pollutants:

- Ozone (O_3)

Ozone comes from a photochemical reaction with volatile organic matter, which composes a high part of urban smog with particulate matter (volatile organic matter, nitrogen oxides, sulfur dioxide) and ammonia gas, which affects the respiratory system, and causes chronic illnesses. Rich higher concentration in the atmosphere during summer time due to its formation on sunlight.

- Particulate Matter

PM10 (large particle) and PM2.5 (fine particle). PM is too small to be seen by the naked eye. Their aerodynamic diameter starts at ten micro centimeters and is smaller or less than 2.5 micro centimeters. Particulate matter is a mixture of pollutants that attract to each other and come from industrial and domestic sources (cigarette smoke), such as dust, trace elements, sulfates, heavy metals (lead, arsenic, mercury, cadmium, chrome, nickel, vanadium) nitrates, fragments of bacteria and even water. PM2.5 is more significant in putting health (mainly the respiratory system) in danger because of its fine size.

- Nitrogen dioxide (NO_2)

Nitrogen dioxide is a strong, toxic gas with significant yellow color, and the main source is vehicular traffic. Due to its acidic properties, it contributes to acid rain, which leads to nitrate concentration in the ground.

- Carbon monoxide (CO)

CO is represented in the cities by vehicular traffic, and the higher concentration appears to be at the slowest traffic. CO limits oxygen transportation through the bloodstream.

- Sulfur dioxide (SO_2)

The main source is the usage of fossil fuels, released as tintless gas. Has a dramatic influence on respiratory health (Brunelli, 2007; Suh, 2000).

Despite the very tracible correlation between the concentration of pollutants and heat accumulation, their relationship depends on the thermodynamic process and temporal and spatial variation (Wang, 2021). Due to urban thermodynamics, the UHI effect and air pollution (AP) mutually influence others. Liang and colleagues (2021) show in their research that the UHI effect mainly influences the concentration of air pollutants, unlike any other factors, for example, the density of the city or spatial location. With the help of simulation, they have shown that rising temperature by 1.23 ◦C will bring degradation of air quality by 23% in a non-urban environment.

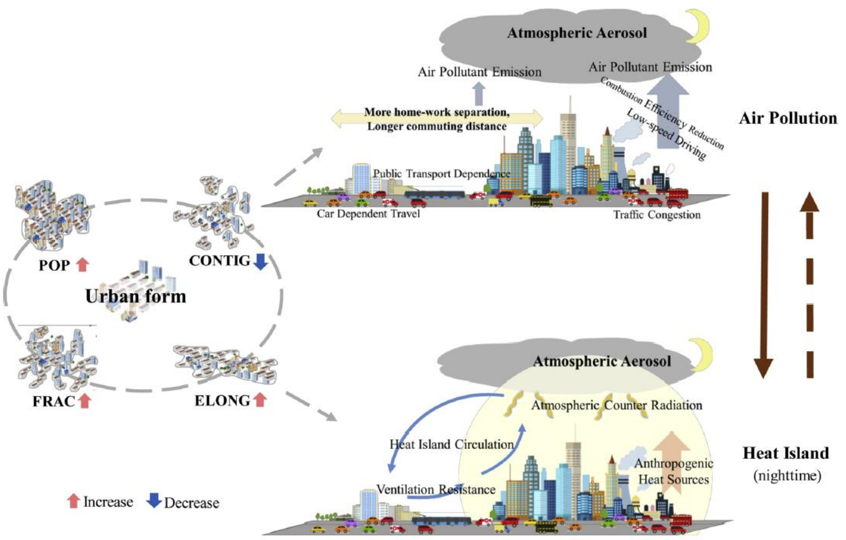


Figure 3. diagram describes the conceptual relationship between urban air pollution and the urban heat island effect: brown arrows on the right demonstrate the relation between AP and UHI, and the fat arrow shows that there is enough scientific evidence in the literature that air pollution has an effect on UHI, while the dotted one shows the lack of scientific evidence (there are modeling studies but no real prooves yet) (Liang, 2021).

2.6 Green infrastructure as a tool for urban design:

2.6.1 Strategies and principles.

Population growth and limited resources challenge and put pressure on urban planning developments to find restoration solutions and prepare mitigation strategies; consequently, the ecological planning of cities has become a crucial field of study. GI is the main sustainable city planning concept, which has ecological value and functions within a spatial network (Weber et al., 2006). The urban scale of GI has to bring multifunctionality in response to adaptation needs and improve system resistance against climate hazards. Urban designers and planners are now asking how urban forms and designs can harbor ecological systems while still focusing on the connections between social and economic systems (Marcus & Colding, 2011). To provide a greater diversity of social and ecological functions, there are principles developed by Ramyar et al. (2021) that can be expressed in three tiers:

- Spatial integration:

Connectivity improves functional connections between ecological spaces and creates a networking system of independent fragments.

The multi-scale approach considers land sizes from small to large because planning requires covering various needs and planning for resources at different scales, from local projects to city regions. Urban GI planning aims at linking different spatial scales within and above city regions.

- Resources integration

The multi-object approach considers urban green infrastructure as a kind that seeks to integrate and coordinate urban green with other urban infrastructures in terms of physical and functional relations (e.g., built-up structure, transport infrastructure, and the water management system).

The multifunctionality of UGI planning presents the ability to provide ecological, sociocultural, and economic surveys, such as urban parks and landscapes do, that can be designed to support specific ecosystem services that benefit the local community, fully integrating social sciences and ecology. The ecosystem services concept is suggested for operationalizing multifunctionality. GI provides economic, social, and ecological functions of green spaces considering the owners‘ and users‘ needs and preferences.

- Social-economical integration perspectives

Social inclusion in urban green planning means that GI provides social benefits that improve the sense of community and environmental justice, health benefits, and better air quality (ecosystem services).

- Social-economical integration perspectives

Social inclusion in urban green planning means that GI provides social benefits that improve the sense of community and environmental justice, health benefits, and better air quality (ecosystem services).

Economic inclusion in terms of GI is ecosystem surveys that provide direct ecological benefits, such as food and fiber production, and indirect economic benefits, such as heat reduction and air pollution removal.

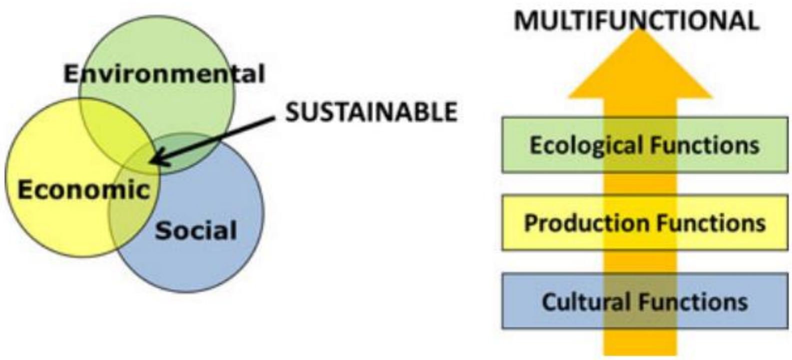


Figure 4. The overlapping of environmental, economic, and social scopes presents sustainability. Multifunctionality can be present as the staking of ecological, production, and cultural functions (Lovell and Taylor, 2013).

A great example is community gardens, which create the complexity of power in cultural, social, and economic fields. Gardeners create urban planning and design ideas by cultivating their small plots of land. Work on community development projects and social movements creates alternative food systems.

(Braden & Johnston, 2004; Ramyar et al., 2021; Paulet et al., 2017; Baker, 2004; Lovell and Taylor, 2013).

Sustainable urban planning requires tools and pieces of knowledge on the path to the most efficient and multifunctional GI. The use and benefits of green surfaces can be maximized through spatial arrangement and the provision of plant properties. By spatial correlations between priority areas with their own benefits, either by the spatial overlap in different factors that contribute to different benefits or if the same underlying factors influence multiple benefits, multifunctionality can be achieved in a purely spatial context (Tran et al., 2020).

2.6.2 Elements, functions, and practices of GI.

Green infrastructure provides the ability to control stormwater volume and brings water quality benefits as one of its primary functions (Water Environment Federation, 2014). This concept is very common because of the very close relations between blue and green infrastructures that benefit and helps to develop each other. However, GI is often criticized for a narrow focus on stormwater management, ignoring opportunities for multifunctionality (Newell et al., 2013).

In this abstract, the concept of GI is rewired by basing on the economic, sociocultural, and environmental benefits of eco-services. Analyzing and noticing the heterogeneity of key elements and their functions helps benefit from ecosystem services and see their performance of multifunctionality more clearly. It is important to note that GI types are often combined into "treatment trains" to function more effectively and fit more efficiently into sites.

2.6.2.1 Green roofs (GR) (based on Koc et al. 2016)

Green roofs are important elements of GI that existed throughout history. They represent a veneer of vegetation that covers grey infrastructure; GR has hydrologic characteristics, such as infiltration and evapotranspiration of stored water, they can be optimized to achieve water quantity and quality benefits, and characteristics closely match surface vegetation than the roofs. (Water Environment Federation, 2014).

Based on the plant material and the usage of the roof area, modern vegetated roofs can be categorized as green rooftops, rooftop gardens, eco-roofs, and living roofs. All of these types of green roofs have some differences in technology performance, structure, and forms, which are based on the roof cover and supported by the building‘s structural frame and roof deck. Green roofs can be retrofitted to dissimilar roof shapes and designs and have different lifecycles and vegetation features (Wilkinson et al., 2016). This type of GI shows perfectly how multifunctionality works; based on the heterogeneity of green roof types, there is a comprehensive list of ecosystem surveys they can provide:

- Reducing UHI effect.

During hot temperatures, green roofs provide a cooling effect by reducing heat flux with their ability to evapotranspiration, physically shading the building, and increasing insulation and thermal mass. UHI effect can be reduced by increasing vegetation cover with sufficient soil moisture for evapotranspiration (Oberndorfer et. al., 2007).

- Stormwater management

Vegetated roof covers, natural roofs, or eco-roofs, or green roofs, remarkably expand water retention and help prevent urban flooding. The green roof mechanism is another form of bio-retention cell, which has a soil layer at the top with a drainage system for draining away the excess water (Paithankar, 2020). Many types of research have proved that green roofs are a very effective solution for reducing runoff volume and reading and delaying the peak flow. A green roof covers impact the water quality of the green urban environment, and they help neutralize the acidic nature of stormwater and reduce the number of different metals like Ca, Al, Zn, Pb, Cd, Fe, Cu, etc. (Moller, 2017). Eco-roofs can be used as storage because of their ability to absorb a large percentage of stormwater in a similar method to that which is found in the natural world (Köhler, 2013).

- Reduction of urban air pollution

Green roofs are able to reduce air pollution with the annual removal of PM10, SO2, NO2, and O3 compared to conventional roofs (Speak, 2012).

- Biodiversity (plant health, species richness, pollination, soil organic matter, weed suppression)

Most of the natural green roofs are defined as self-sustaining ecosystems, with a plant cover of about 60-75% showing a high quality of vegetation has been achieved, but very often, only a few types of plant species are chosen as a focus group. The complex overview should come from focus on regional native plants, which can be included in the design to benefit biodiversity at the highest level (Köhler, 2013). Green roofs might not be able to support the needs of animals with a larger range of requirements (like mammals), because of their limited size (green roofs are generally small). Green roofs are isolated fragments of GI with a noticeably higher temperature than ground-level habitats, making them unsuitable for biodiversity conservation. However, green roofs are accessible to the most mobile animals, such as birds, insects, and other arthropods (Wilkinson, 2016).

- P, N, S retention

Biomass production and carbon balance

- Socio-cultural benefits

Migration of the UHI effect, improvement of air quality, and stormwater management are examples that benefit society. In addition, green roofs, such as green roof gardens, are the aesthetic part of the socio-cultural benefits. They might not be providing the same level of benefits as local parks, although rooftop gardens supply an open space for collaboration between artists and the community in the growing of food (Bianchini, 2012. Franklin, 2011). It is a perfect modern space for social networking.

- Primary production: economic benefits

With the integration of rooftop gardens in urban developments, their socio-economical value has increased for users and urban residents. Rooftop vegetable gardens minimize food miles by shortening chains and reducing the carbon footprint of growing and transporting food (Wilkinson, 2016). Rooftop agriculture provides fresh and healthy local food, contributing to nature and socio-cultural life.

- Reduction of building energy consumption: Economic and social benefits

Due to evapotranspiration, one of the most important phenomena, green roofs' vegetation is able to dissipate part of surface heat into the external environment. With these properties of the green roof, the thermal performance increases the building's energy efficiency and is a more cost-effective cooling strategy than operating air conditioners. In addition, a green roof layer provides thermal isolation for buildings, preventing heat flux from being transferred to the indoor environment in summer (Bevilacqua, 2021).

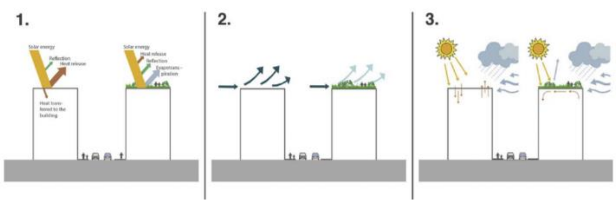


Figure 4. reviewing 3 types of ES (1. UHI effect reduction – cooling, 2. reduction of urban air pollution, 3. reduction of building energy consumption)(Moller Francis, 2017)

2.6.2.2 Tree canopy as a part of urban woodlands, forests, public squares, parks, and green open spaces (GOS)

2.6.2.2.1. special conditions of urban trees:

Urban trees’ stress level directly depends on their placement. City trees are more often forced to exist in extreme conditions due to air pollution, soil quality, and city dynamics than forests (Roloff, 2016).

Tight surface cover around plants creates challenging conditions caused by rising temperatures and limits root growth. Due to those limited sources for urban plants, their planting is controlled by state law, providing safety for the plant’s growth. Public greenery has to be developed to maintain GI health according to modern biological, urban planning, technical and aesthetic principles. Each urban tree is an individual element of Green Infrastructure, and it requires specific treatments and safety measurements for its trunk, crown, and root systems to keep it healthy. In the Czech Republic, those methods and rules are fixed by the state Law on Nature and Landscape Protection114/1992 Coll.

Protection of the root space in city areas is defined by how much space it should take to keep safe from mechanical influence and deformation due to space limits according to the activities of the environment in tree perimeter. Three main zones are taken in accounting to define the safe zone of each element during spatial planning:

- Statistically significant root plate (SSRP. cz: SVKT- staticky významný kořenový talíř)
- Critical Root Zone (CRZ. cz.: CZZ - kritická kořenová zóna)
- Root zone (RZ. cz.: KZ - kořenová zóna) *(viz. figure 4.)*

Statistically significant root plate is the critical zone for spatial planning because mechanical damage in this area can bring to imminent failure of the tree. Another crucial zone in urban planning is a secondary thickening of the trunk’s base, which will push the soil around while thickening. Because of developing potential, there is a minimum size of SSRTf or young trees (r=0.5 m). technical equipment must not be spaced in the area of increased risk of deformation.

The critical Root zone is the area of the large statistically significant roots; when it is located in a limited space which can shape root deformation, the safe root area should be increased.

The root zone, also known as the root system, is individual to each specie and forms differently based on limited factors. Space for both root and crown systems in an urban environment is limited by space, which is taken by transport and infrastructure needs. Areas for root and crown systems should be researched and calculated individually depending on specie (Institut plánování a rozvoje hlavního města Prahy, 2021., Zákon č. 114/1992 Sb., o ochraně přírody a krajiny, v platném znění.).

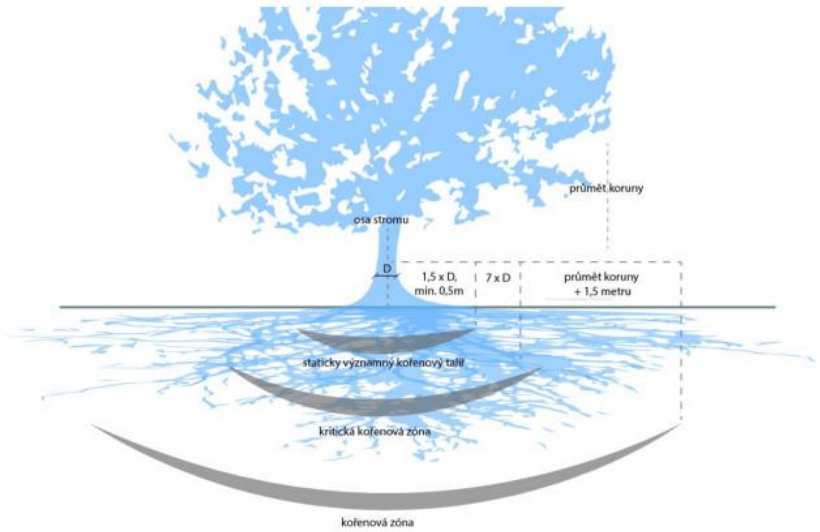


Figure 5. Zones of protection of the root spase of trees in the natural enviroment. From up to down: SVKT, KKZ,KZ. (Institut plánování a rozvoje hlavního města Prahy, 2021).

Unpenetrable surfaces such as concrete, asphalt, solid decks, and stones that shape some Grey Infrastructure (streets, parking loads, driveways, playground surfaces) block water flow into the soil; moreover, they absorb sunlight that is released as heat, which causes Urban Heat Island effect (Oke, 1973). Tree canopy is a very powerful tool to reduce the UHI effect and make microclimate more sustainable, but by providing those services trees get negatively affected (Berrang et al., 1985). Because of the functions provided by urban trees (via 2.5.2.2.3. functions), their health status has to be monitored occasionally to create and support the urban microclimate. Unhealthy trees with dry crowns can cause risks to people and infrastructure. Moreover, they start losing their aesthetic purposes. Unhealthy elements have to be detected as quickly as possible to use irrigation treatment, but using visual condition assessment is nearly impossible in large cities, which brings this issue to the next level methods (Roman, 2013). Remote sensing from planes and helicopters allows using of Airborne laser scanning data fusion, which detects unhealthy trees' spectrum by chlorophyll content in leaves. Another method is Aerial Vehicles, which help indicate individual tree crowns by using automatic segmentation. Bot of hose methods helps identify unhealthy, damaged, and dead trees effectively and quickly (Roman, 2013; Zakrzewska, 2023; Nasi, 2018).

Damage to tree species can be caused by pests, parasites, or insects, which expose disturbed elements to high temperatures, faster evaporation, and heat explosion. In those cases, the most effective method to use is the analysis of thermal infrared data, which is a more accurate souse of data during the daytime (radiation can be detected by its reflection during the daytime). The origin of intervention can be used to decide if the satellite or airborne method is more effective in collecting data. The thermal property of trees is often used in agriculture (Hais and Kučera, 2008; Leuzinger and Korner, 2007).

Poor soil quality is one of the most influential conditions on urban canopy health, which stops trees from optimal development. Low soil quality is often influenced by gray infrastructure development, which causes soil compaction and lack of irrigation. As the natural environment changes to urban soil structure and growing potential dramatically degrades. Gardening, general soil disruption, topsoil removal, and vegetation suspension change soil physical characteristics (Randrup and Dralle, 1997). Interactions between living organisms, climate, topography, organic and non-organic matter, and the time that it takes for minerals to add to soil are key components that take part in soil formation; in addition to that, there is an anthropic factor. Anthropogenic disturbance defines urban soil as a distinct taxonomic class with its morphological structure functions that are different from rural, native, or agricultural types of environment (Pavao-Zuckerman, 2008).

Mechanical interactions are causing the low quality of urban soil, the UIE, changes in local climate and cloud cover, modification of hydrologic regime that is influenced by urban infrastructure, affection on soil microclimate, heavy metal concentration, high levels of nitrogen and circulation of PM matters in urban ecosystems. All of those factors are responsible for the quality of soil's fundamental physical and biochemical properties and subsequently define properties of ecosystem services (Oke, 1995., Pouyat eet al.1994). Urban soils work as an ecological indicator, on behave of a key component. Their biological, chemical, and physical factors tell all the needed information about the health of the supporting ecosystem (Pavao-Zuckerman, 2008).

With changes in meteorology conditions, there is a risk of a massive drive of elemental carbon (EC) and black carbon (BC), dramatically influencing climate change and air heat. Both EC and BC are particularly dangerous matters (PM) that contain organic carbon mixed with refractory fraction. They have different molecular structures, which define their light-absorbing properties. Elementary carbon is a thermally stable fraction of PM that is determined by thermal-optical methods. Black carbon is light-absorbing PM that also uses optical methods. In an urban environment, those particular molecules, in combination with by-products of fossil fuel, decrease heat outcome air quality and visibility (Petzold et al., 2013; Ponette-Gonzalez et al.,2022). Latest researches show that urban tree canopy does the job of reducing EC and BC particles by up to 30 % by using their leaves, but with the streamflow from the canopy, carbon elements come into the ground and accumulate there (Hara et al., 2014) Ponette-Gonzalez et al.,2022 have shown in their studies on the drive on elemental carbon and its deposition to canopies and soils that EC and BC are especially high variable due very complex-temporal and spatial streams of an urban environment. The highest percentage of PM was detected in trees next to the road so called “edge effects”; 60% of the carbon is retained in tree canopies. These results show that it is urgent to put a lot of attention into air quality improvement, consider meteorology driving facts, and prioritize locations for tree planting.

Dust damages plants by blocking sunlight and decreasing photosynthesis, respiration (gas exchange), and transportation. PM influences light absorption and a decreasing light reflection, which hinders its ecological services' performance and increases the UHI effect's intensity (Roloff,2016. p.276).

City provides a high-stress level for trees by using materials: brick, concrete, asphalt, and buildings absorb sunlight and release it as heat, causing the urban heat island effect and increased temperature (Oke, 1973). While people benefit from ecological serveries provided by greenery, many other organisms benefit from trees while they do their job absorbing heat. Herbivorous arthropod pests are often attracted not by the actual surface of the leaves but by the temperature. The factor of high temperatures increases the growth and reproduction of sap-feeding parasites particularly (Zvereva et al. 2010). Monitoring plants' health is key to benefiting the most from green infrastructure and ecosystem services it provides.

2.6.2.2.2. functions

- aesthetic, culture, psychology, well-being, and health

The first thing about urban greening that pops into the minds of citizens is forced by sensors and the human brain's abilities to analyze the environment. There are visual impressions that recognize blooming, fruit presence, coloring, and structure of leaves which bring to evaluating an urban environment's aesthetic part. Additional information about living forms around us gives the senses of smell and those complete the ability to appreciate changes in seasons and even changes in daily weather. Taste and touch also provide important information and make the experience more complex (Roloff, 2016).

More green spaces provide support for mental health and well-being, reduce stress and anxiety, and help with depression. Green infrastructure has a positive social and economic impact on the neighborhood and gives room for more social activities like exercises, yoga and dance classes, lections, and many others. Ecological studies found that by supplying those opportunities to society, GI reduces mental illnesses and prevents suicide attempts. In sum, studies proved that local green canopy is one of the most important health-related factors (Lee, 2023). Green city planning has to be done considering basic human needs in order to keep their lives comfortable in action and movement. Active live helps to improve concentration, working memory, spatial cognition, and navigation skill. Active cities also reduce the risk and symptoms of dementia (Roe and McCay, 2021).

Parks are public green areas that can sometimes be called: woods, gardens, playgrounds, picnic areas, greenways, parkways, squares, courtyards, and others. In sum, all public green arias can be divided by the type of usage, called "active" and "passive" types. There is infrastructure in active parks that supports team games, skateboarding, running, hiking, exercising, and playground equipment. In the less active zones, people can enjoy music, relax on the grass, paint, read, watch wildlife or peacefully walk (Harnik, 2010.).

- Dust and noise reduction

Dust is presented by particular matters; they start with fine size (less than 0.1 micro millimeters) and continue to coarse (bigger than ten micro millimeters). Dust gets into sediment quickly, then heavier particles, then faster they will sediment. PM gets transferred by wind, which urban trees can control. Tree canopies build residential “walls,” making park zones dust-free and noise-free, similar part play herbs and grass on a lower scale. Another tool used by trees to control dust levels is their natural ability to catch dust particles. That function is given to trees by their anatomical and morphological characteristics (leaf relief, hair, leaf venation, glands, wettability, and others). Some tree crowns accumulate dust, which can be only partly rinsed or blown, and other trees temporarily detain dust and easily go away by a touch of wind or water. Noise reduction can be performed even by single plants to reduce sound vibration between houses (Roloff, 2016. p. 273-274, 277.).

- Reducing heat (cooling effect)

Using trees as a tool for cooling cities is much more expensive and more time-consuming than using light-colored surfaces, but it is the most effective tool. Tree canopy reduces the UHI effect by evapotranspiration properties, shadows created by trees hide direct sunlight and provide a cooling effect closer to the surface, building so-called cooling shelters for people (Shi, 2023).

- Water management

Transferring moisture and humidity back to the atmosphere is a crucial part of the urban water dynamic, which controls and regulates the urban hydrological cycle. Natural solutions help to manage stormwater in urban areas by evapotranspiration, providing water sources for rain, which restores city water capacity and the water cycle. Of course, the ability to restore water in the city is determined by urban vegetation health and heterogeneity, which is different from the non-city environment (Shao, 2023).

Dense planting creates the so-called “tree trench,” one of the city's most common stormwater management solutions and probably the most naturally built. Regulation of city hydrology is provided by interception and percolation of rainwater into the soil; green ground cover and its root system help to protect soil from erosion. The main requirement is good quality soil for healthy growth, which helps to provide the most effective ecological services (Water Environment Federation, 2014).

- Urban microclimate control

Microclimate control is a combination of ecosystem services functions provided for human health and comfort: air quality regulation through dry deposition of carbon, regulation of stormwater volume and humidity through evapotranspiration, creation of shadow and wind protection, noise control, heat reduction (Wang, 2016. p. 12-13).

- Producing litter (leaves, fallen branches, etc.) that maintains soil fertility and soil carbon banks.
- Plant biodiversity

2.6.2.3 Vertical greenery systems (VGS)

VGS is presented by vegetation that grows vertically indoors or outdoors. There are several types of vertical vegetation systems that are based on the type of construction (Safikhari et al. 2014).

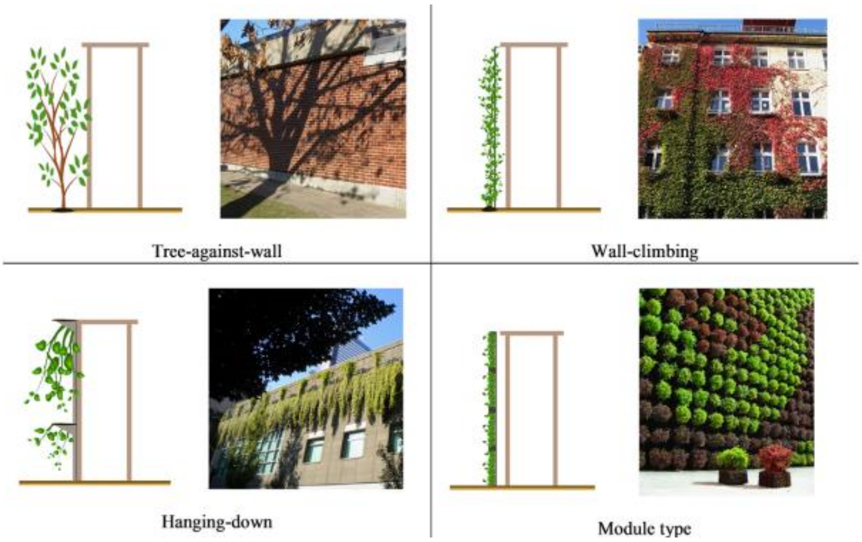


Figure 6 presents four types of vertical greenery systems (Safikhari et al. 2014): tree-against-wall, wall-climbing, and hanging-down, and module type, also known as a living wall.

The first group of vertical systems is defined by vegetation being planted in the soil next to the wall:

- Tree-against-wall is not exactly a type of vertical system, but it provides the same functions as VGS.
- Wall-climbing constructions are typical for traditional architecture; they cover the entire façade of the building by being attached directly to the wall or the second skin of the façade. Most common species: *Hedera helix,*

Aristolochia durior, Parthenocissus quinquefolia, Vitis Coignetiae, and many others.

The second group is wall-based vegetation that is hanging down, typically planted on balconies or the tops of buildings, this type of vegetation is often used on green roofs. Green constructions of hanging-down vegetation are placed on different levels of walls to create a greenish look that covers the concrete completely.

The third type is presented by a modern technique where vegetation is placed against walls, but the growing direction depends on the growing abilities of plants. The benefit of living walls is that they can host wider diversity of plants, but the construction of living walls is pricier than grin facades, where roots are placed vertically into the soil. In literature, living walls have many different names: vertical gardens, bio-walls, or carrier systems (Safikhari et al. 2014).

Vertical greenery systems are not only a modern trend that brings joy to the eye and a safe space, but it is a smart green, and complex solution with a list of benefits.

- Social-economic benefits:

VGS provides a saving of building energy, and they show cooling abilities during summer through their evapotranspiration properties. Living walls isolate building from cold during winter through their layer of soil. In addition, VGS show potential for crop production such as basil, salad mix, cherry tomatoes, strawberries, and other.

- Noise reduction between and inside buildings.
- Increase of urban biodiversity.
- Cultural-aesthetic benefits are increasing due to new open spaces for design.
- Health benefits (Bustami R.A. et al., 2018).

2.6.2.4 community/private/allotment gardens and inner yards

City gardening is a type of urban agriculture that is usually presented in the form of "allotment gardens" the term originally comes from 18th century Germany but has been used lately all around the world during wars or other depressive events (D'Alisa et al., 2015). Urban gardening is focused on food production for self-use only, which makes it non-commercial. People who are in need of financial support have opportunities to use state land, but it gets tricky when the government finds marks of soil pollution or its commercial use. In order to prevent risks of soil pollution, profitable use of land, or any other risks for citizens or for the state, urban gardening should be motivated and focused on its positive outcome (Schram-Bijkerk et al., 2018).

Urban gardening provides a complex of environmental benefits: an increase in biodiversity, an increase in genetic diversity of native species, regulation of water volume and quality, and regulation of outdoor temperature, including the cooling effect of the city. Urban agriculture in the right cultivation can protect, restore, rehabilitate, and re-naturalize habitats or promote new ones. Creating new spaces for urban gardening helps to keep the heterogeneity and connectivity of the city landscape, which brings to the table of benefits more biodiversity, not only in vegetation but attracts animals and insects (Sowinska-Swierkosz et al., 2021). Producing, consuming, and recycling own crops helps to reduce the carbon footprint that is usually spent on the food supply chain (Puigdueta et al., 2021).

On the social-cultural scale, urban gardening shows multiple benefits for individual gardeners as well as for society. Gardens increase the aesthetic value of a city and give space for co-creativity, providing space for activities, which improves physical and mental health. However, all garden owners must follow some policies to bring the most to nature and take back ecosystem serveries highest quality, such as choosing bee-friendly flowers and doing their biodiversity management clearly (Hanson et al., 2021).

On the economic side of the benefits, there is the usage of renewable sources of energy. By increasing health quality, there is a lower cost of medical services. Gardening can inspire many people to choose green jobs in the future(Sowinska-Swierkosz et al., 2021).

2.6.2.7 fruit orchards

Fruit orchards are an example of traditional sustainable management, they support the restoration of the environment, support biodiversity on all living levels (vegetation, insects, pollinators, vertebrates). Fruit orchards provide complex ecosystem services: improving air quality, helping to restore the hydrological cycle, and bringing aesthetic and social-cultural value. By being the most common agroforestry type in central Europe, they take part in landscape conservation and provide benefits for the economy. Fruit orchids are often parts of urban and suburban areas; they represent the rural natural environment in urbanized areas and make the landscape more heterogenic, which benefits the environment (Rada et al. 2022).

2.6.2.7 innovative solution: The first algae air purifier in Serbia

Ecological crises nowadays dramatically influence air quality conditions, and there is a custom solution to that problem. Dr. Ivan Spasojevic, Ph.D. in Biophysical sciences, and his colleagues developed an innovative tool to reduce greenhouse gas emissions: the liquid tree (LIQUID 3). This instrument that looks like a terrarium works on microalgae that produce pure oxygen through photosynthesis. The volume of water with microalgae is six hundred liters, and it can replace a ten-year-old tree or two hundred square meters of green surface (like a lawn). LIQUID 3 can be used in urban environments with limited space or non-survival conditions for trees. It works on solar panels, giving economic benefits through renewable sources. Liquid trees provide some of the ecological services typical green infrastructure can provide, such as reducing carbon dioxide; some people might find it pleasurable to the eye, increasing aesthetic function (Castim, 2022. Online).

Figure 7. liquid tree. Source: (Castim, 2022) https://worldbiomarketinsights.com/a-liquid-tree-scientists-in-serbia-make-incredible-innovation/

2.6.2.7 Green Infrastructure in action: water management

Water management is the critical function of GI; its spatial planning is organized by the ability to control stormwater volume and prevent storm events; the most effective way is when different types of IG that are specialized in stormwater management are combined. Some types of green infrastructure are defined by their components and relevance to environmental conditions:

- bioretention/rain garden

this type is created by the combination of specially selected native vegetation (*Viburnum opulus, Cornus sanguinea, Helleborus foetidus, Ajuga reptans, Eupatorium cannabinum, Campanula glomerata, Iris pseudacorus, Juncus effusus, Osmunda regalis, Dryopteris felix-mas, Dryopteris dilatata*) and solid "bed" made out of sand or gravel to catch and store water. Bioretention systems are controlled by engineered under drained to prevent to help slowly release of filtered water into the soil.

- Vegetation curb extensions

One of the most common types of stormwater management is presented by small green areas between streets, buildings, or sidewalks restricted by carb lines. The design is similar to rain gardens but combined with a tree canopy. Functionality is also presented by evapotranspiration and a solid "bed."

- Vegetated infiltration basin
- Functionality of vegetation basins' is mainly focused on storing and infiltrating stormwater into the surrounding area. The technology also combines solid treatment to prevent the clogging of stormwater.
- Planter box

Material selection is the main difference between the planter box and the previously described systems. Boxes can be made from concrete, wood, or recycled plastic. Containers can be placed above soil or underground, and this method is effective by evapotranspiration.

- Infiltration trench

This type of GI contains a combination of grass or trees to slow down water flow. It mainly plays a role in infiltration and water control next to the roadway and street areas.

- Surface infiltration system

Traditionally used for parking loads, playfields, or loans to store stormwater and provide infiltration. Most commonly used with a solid structure that combines stones and geotextile.

- Stormwater wetlands

This structure is mainly focused on runoff control and in addition, on the biological treatment of water. Typically based next to natural water areas and connected with those by stream corridors. Functions: storm volume management provide an increase in biodiversity through its connectivity.

(Water Environment Federation, 2014.; Bray, 2012.)

2.7 Biodiversity and Urbanization

Urbanization directly impacts biodiversity through changes in land cover forced by population growth. Urban areas take about three percent of the total Earth's land cover. Still, according to studies, Europe has one of the highest density or urbanized areas (more than thirty percent is urbanized) (Olson et al.,2001). Urban expansion threatens most living organisms (vegetation, insects, vertebrate species). With urbanization comes fragmentation, which directly impacts land cover and turns on adaptation mechanisms for survival and competition growth. Urbanization increases the expansion of invasive (non-native) species by creating disturbed areas where new individuals are more likely to succeed, which leads to the loss of sensitive species dependent on natural habitats. Chiante and colleagues (2021) established that biodiversity is poorer on human-modified lands, and one of the crucial points is to support the management of natural species. They also find that common birds are indicators of high biodiversity. When species richness is low the role of indicators play generalists and human-related species (for example, Eurasian Magpie and green whip snake). Although the richness of urbanized areas is not necessarily lower than in rural environments, biodiversity highly depends on the number of natural species more likely to survive the changes (Elmqvist et al., 2013).

Consumption and production are economic development factors that impact biodiversity indirectly. Indirect influence on urban biodiversity comes through human activities such as resource consumption and increased production (even green activities that seem to trade goods require material consumption). People developed environmental policies to support the richness of species in balance and perform nature conservation, such as selecting urban trees that are the best to perform environmental survives (Elmqvist et al., 2013).

Chapter 3
Methodology for Prague's Green Infrastructure evaluation:

For the evaluation of Prague's Green Infrastructure will be used multicomplex approach of different aspects to tell the strongest and the weakest parts of each type of GI. Evaluation methods will be divided into a few steps for the whole picture and perspective:

1. Based on analyzing the Action Planting plans for Prague in the nearest past and future, the best ways to support Prague's green infrastructure will be discovered from an economic and environmental perspective.
2. In the second part of Prague's green structure analysis, optimal tree species for green infrastructure will be reviewed based on the literature review.
3. In the third part of the analysis, map layouts of existing types of Prague's green infrastructure will be reviewed. Also, the main points of urbanization history in the last century will be reviewed.
4. For the complex evaluation of Prague's GI SWOT analysis will be applied for each type of green infrastructure.

Chapter 4:

Analysis and Evaluation:

4.1 Action planting plans as a tool to detect the best methods for supporting the functionality of GI from economic and environmental perspective.

Besides environmental services, urban trees create habitats for other organisms. They provide food and support the biological richness of the city. Trees maintain soil fertility and provide pollen nectar for pollinators; fruit trees provide local fresh food sources.

This paper focuses on the biological richness of urban trees and greenery, which provide ecologically survives for the city of Prague. The main goal for building a healthy green environment is to learn more about tree properties (via 2.8.1 selection of urban trees) and to set goals for future action plans.

According to the tree planting plan in action (2018-2022), there is a long-term aim of planting one million trees over the next eight years. The plan is based on the Prague adaptation strategy to climate change including the preparation of the Green Infrastructure strategy concept. Due to the planting action plan for the years 2018-2022, chosen places for planting did not require changes in the valid spatial plan or the approval of the metropolitan plan.

In the years 2018-2022 was planned to plant four hundred seventy-two thousand and two hundred ten trees (472 210 trees) in the following regions of Prague city: Forest Robotka II. part of planting, Forest Arborka, Forest of Musile, Forest of Panenky IV. part of planting, Park in Čeňek III. part of planting, Forest in Panenky V. part of planting, biocorridor Kbely, Forest park of Lady, Forest park of Letňany III. part of planting, Greening of land in Holyn, Jinonice - greening and shielding of the Rescue Station, planting in Ďáblický háj, Forest Pod Cihelnou, Orchad of Lítožnice republic, planting of riparian vegetation along small watercourses and reservoirs, Plantings in orchards, Královská Stromovka- game reserve area, Petřínské sady, Orchad Dubeč, Orchad Satalice, Plantings as part of the overall restoration of tree rows of Prague-wide significance, Vítkov park, Lipanský stream, sady v Kinských, Letenské sady.

According to the plan, planting takes up space in the different types of green infrastructure, which brings multifunctional benefits to the city:

- Parks, forests, and open spaces
- Gardens and orchards
- Streamflow borders
- Tree rows all over Prague, additional installations, and plot’s greening
- Game reserve area
- Bio corridors

For the next three years, there is also a targeted plan for planting that does not require changes to the already existing urban spatial plan. According to the plan for the years 2023-2026, six hundred forty thousand trees (640 000) will be planted in the following areas of Prague: Suchdol, eastern Běchovice, eastern Satalice, Dubeč north, eastern Jinonice, western Vinoř.

The total cost of the projects for the years 2018-2026 will be one hundred thirty-three million and eight hundred sixty-five thousand Czech crowns (133 865 000 czk), in addition, there are costs for the next five years care plan in the amount of three hundreds seventy-six million nine hundred thirty-seven thousand Czech crowns (376 937 000 czk).

Young tree planting is an investment in the future of green infrastructure. Aesthetically older and bigger trees are way more attractive than younger and smaller ones, and currently bring bigger value in terms of ecological services (they are able to produce more oxygen or hold and restore more stormwater). Older trees collect more historical value and are strongly connected with culture, as they were planted on historical events or in memory of influential people. There is more attention coming to the younger trees because of the growth of population and extreme urbanization. People need bigger performance from ecosystem services which younger trees will provide, and one day they become new historical heritage.

(Odbor ochrany prostředí MHMP ve spolupráci s IPR Praha, 2019; Rudl et al.,2019.)

4.2 selection of urban trees: Prague city case.

Visual impression that trees make on people by its coloring, shape, height, shadows they make is very important to people as for users of GI. In addition to the properties that bring sensor pleasure, the trees should be well suited for that job, meaning their response to the natural conditions. For cities are preferable trees that light - loving (opposite to dark and high-density forests conditions). Prague city center experience high temperatures during summer, and because it is the city next to the river some species should be suitable for water stream sides, supporting stormwater management and preventing from flooding. Based on the properties of trees there is a selection of the most common trees for Europe, which is the perfect fit for Prague city:

*Abies (*genus)*:* prefer moist habitats and rich soils. **Native.**

Acer negundo: native to North America. Planted in Prague city parks.

Acer pseudoplatanus: tolerant to wind and environments next to water stream. **Native.**

Ailanthus altissima: originally from China. Growth in any type of soil (with human settelments, like transport structures). Very often used as an ornamental tree.

Betula pendula: light-loving tree, perfect for green roofs. **Native.**

Carpinus betulus: not demanding on soil type, tolerates lack of light and a lot of light. **Native.**

Castanea sativa: comes from southern Europe and western Asia. Contains allergens, the best for gardens or city forests.

Corylus avellana: often used as an ornamental tree. **Native.**

Fagus sylvatica: often used as an ornamental tree, tolerant to wetness, perfect for cities with rich soil or water stream sides. **Native.**

Fraxinus angustifoli: perfect for rich light space and moist nutrient soil. **Native**.

Fraxinus excelsior: prefers rich soil. ***Native.***

Gingo biloba: often used as an ornamental tree. Comes from China. Have good residential aabilities to air pollution, heat, and light.

*Hippophae rhamnoides:*light-loving plant, prefers rich soils. **Native.**

Chamaecyparis lawsoniana: originally from California. Undemanding for soil type, resistant to drought.

Juniperus communis ssp.: not demanding on soil type, tolerates low temperatures.

Koelreuteria paniculata: great city tree, can grow in dry and wet soil. Originally from China.

Liquidambar styraciflua: originally from North America, nowadays is spreaded all around the world. Perfect city tree.

Liriodendron tulipifera: comes from North America. Requires rich soils, common in city parks and forests.

Magnolia grandiflora: comes from south America, in Czech republic is used as an ornamental tree Perfect for city parks.

Malus sylvestris: climatically undemanding, frost-resistant, adaptable**. Native.**

Nyssa sylvatica: comes from North America. The tree can grow in a wide range of conditions, which makes of it a perfect city tree.

Picea abies: an indicator of air pollution.

Picea omorika: undemanding for soil type.

Picea pungens: native to North America. Planted in Prague city parks.

Pinus (genus): undemanding for siol type. *Pinus leucodermis, Pinus sylvestris and Pinus nigra* often used as an ornamental trees.

Pinus cembra: an indicator of air pollution.

Pinus ponderosa: comes from North America, light-loving plant.

Platanus× *acerifolia:* originated from crossing (platanus occidentalis x platanus orientalis), not demanding on soil type and grows fast which makes it perfect urban tree.

Prunus avium: climatically undemanding, adaptable, tolerates air pollution, but need wet soil. **Native.**

Pseudotsuga glauca: comes from North America. Prefers rich soils tolerant to air pollution and low temperatures.

Pseudotsuga menziesii: native to North America. Planted in Prague city parks.

Pseudotsuga menziesii: native to North America. Planted in Prague city parks, prefers rich soils.

Pyrus calleryana: comes from China. Very popular as an oriental tree, prefers llight and resistent to drought.

Pyrus pyraster: climatically undemanding, frost-resistant, adaptable**. Native.**

Quercus petraea, Quercus robur: are **Native** in Czech republic. Very common in the city.

Rhus typhina: often used as an ornamental tree, comes from North America.

Salix (genus): very suitable city tree, often used as an ornamental tree in urban parks. 22 species are **Native.**

Sorbus torminalis: tolerate a wide range of soil conditions, and has very good adaptation properties. **Native**.

Syringa vulgaris: the most popular ornamental shrub ever, known for its blooming.

Tilia cordata: resistant to very low temperatures, prefer dry soils often used as an ornamental tree. **Native.**

Ulmus hollandica Lobel: resistant to very bright light, grows up to fifteen meters, perfect city tree (ideal for freets in living areas). **Native.**

And many others.

Trees are essential for environmental awareness in cities, it is the responsibility of each human being to learn about sustainability and adaptation principles.

(Rollof, 2016; Dendrologická databaze CZU)

Figure 8. Betula pendula as a house decorative tree (Rollof, 2016. p. 31).

4.3 Green Infrastructure of Prague city based on literature review.

Due to the expansion of urban areas in the nineteenth century, new urban lands started changing their shapes and heterogeneity. With the urbanization process in action was hard to think about making space for relaxation, but as modern urban life was shaping and creating new challenges, such as air and water pollution, floorings, and rising temperatures, people created new definitions for natural solutions. Nowadays, the most important reason to go outside is to improve mental and physical health through the benefits of green infrastructure.

Prague, the Czech Republic’s capital city, as intensively formatted during the years 1901-1974. Two main peaks of formation were: “Great Prague” the year 1921-1923 and the year 1974 when the city area reached its current area.

Valid location of green infrastructure was pregerminated by its specific landscape and historical events such as the creation of medieval fortifications and city shaping during of era of Renaissance and Baroque. Prague was changing until the German occupation during the Second World War, back then almost all the parks were closed to the public. After sorrowful events, parks started opening to the public, and Prague was breathing fresh and getting inspired by Scandinavian and Japanese art. Since then new public areas were built, more parks opened to the public, and gardens were reconstructed. In the seventieth urban landscape took on the familiar forms today.

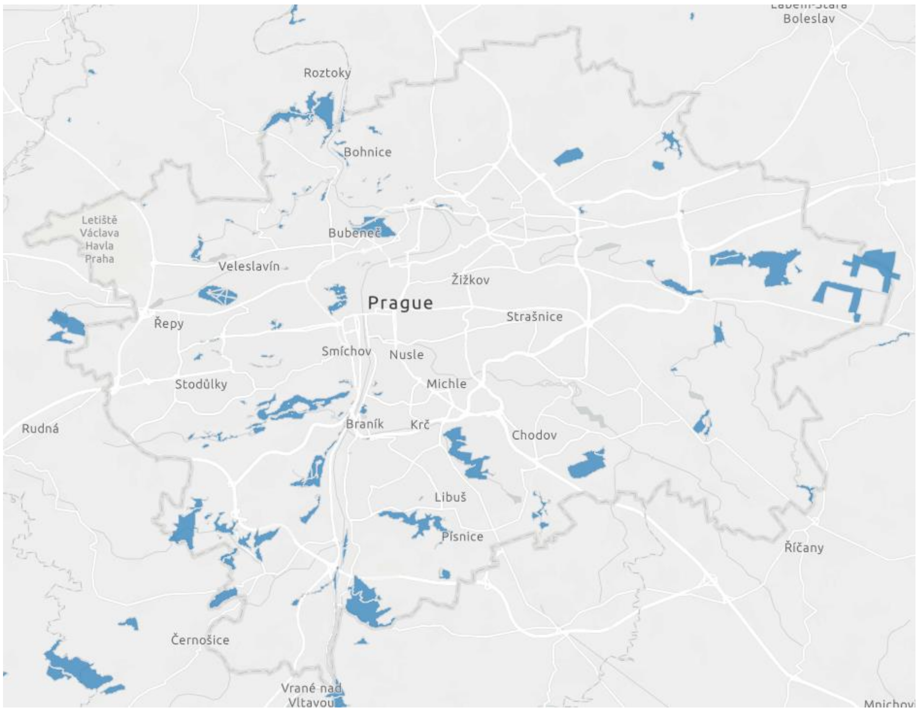
Today public green area make up approximately 19% of the public green area today. Most of the public greenery before the nineteenth century was utside the city (viz. map 2., map 3.).

(Hladíková, 2020)

Specially protected small areas, according to Natura 2000.

Prague collects sixty-three specially protected small areas (list of the areas via. *attachment 1*.), which are intended to protect ecosystems, habitats of species, and phenomena of nature. These valuable areas are important or unique in terms of natural science or aesthetic, which are located in the spaces opened to the public (via. map 1).

(Natura 2000, online)



Map 1. The map represents the amount of specially protected small areas in Prague, areas are highlighted with dark blue color (Natura 2000, online)

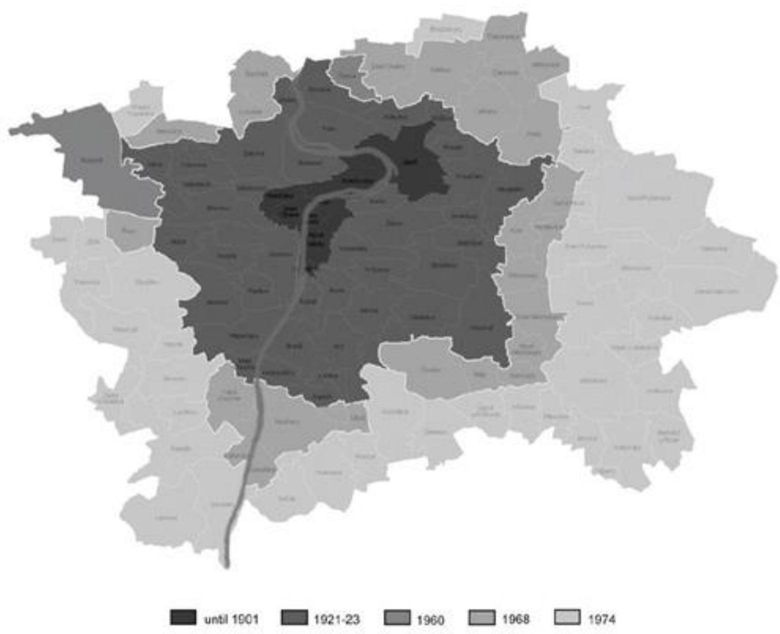
Map 2. Representation of main parts of green infrastructure. (CAMP, 2020. online)

important forest lands

parks in free development

parks

gray infrastructure



Map 3. Formation of Prague the years 1901-1974 (Hladíková, 2000) Green and blue infrastructure:

Currently, in Prague was realized sixteen green roof projects:

1. Green roof on the extension of the Auditorium of the Czech University of Life Sciences in Prague (the realization year 2019-2020)
2. Botanical garden (the realization year 2014)
3. Green roof of the pond from meadow flowers (the realization year 2016)
4. Tokovo building (the realization year 2018)
5. Extensive roof garden at the Office of the Government of the Czech Republic (in the realization)
6. Špork palace (the realization year 2018)
7. "Garden on the fifth floor" - A full-fledged garden of a family house a little higher (the realization year 2014)
8. Inner yard of Andel's Hotel (the realization year 2001)
9. Administration building Vinohradská 230 a. s. (the realization year 2015)
10. Our roof - JAKUB CIGLER ARCHITEKTI, a.s. (the realization year 2019)
11. Main Point Pankrác (the realization year 2018)
12. Zelená Libuš apartment building (the realization year 2019)
13. Residential roof of the apartment (the realization year 2007)
14. Extensive roof on a low-energy house (the realization year 2013)
15. Greening of the building for production and services - extensive green roof (the realization year 2014)
16. Sloped roof on the House (the realization year 2014)

Map 4. Sixteen green roofs which have been realized (Zelené střechy, online).

Brownfields: potential for new Green Infrastructure

Abandoned building and lands with contamination is a massive problem for the Czech Republic that can be defined as brownfields. These areas have huge future potential, as restored areas can attract new neighbors by increasing property value and economic development. In Prague, a lot of brownfields are already located near city infrastructure (public transport, stores, schools et, al.). Brownfields do not require changing valid spatial planning but will need huge financial support for their restoration (Hussein et al., 2020).

4.4 SWOT analysis of each type of green infrastructure based on reviewed literature: Prague city case.

4.5.1 Tree canopy: woodland, forests, public squares, open spaces, parks:

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
1. Improve air quality, 2. Help to restore water (hydrological cycle), 3. Stormwater management, 4. Cooling effect, 5. Reduce dust and noise, 6. Urban microclimate control, 7. Support biodiversity, 8. Have aesthetic value, 9. Increase the economy by attracting people, 10. Improve health, 11. Provide green jobs.	1. Special condition of urban trees (via 2.6.2.2.1).	1. Have potential for planting that does not require changes in valid spatial planning 2. Have potential in the form of brownfields.	1. Could be financially challenging if it is reconstruction of brownfield.

4.5.2 Green roofs:

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
1. Improve air quality, 2. Help to restore water (hydrological cycle), 3. Stormwater management, 4. Excellent Cooling effect, 5. Reduce dust and noise, 6. Urban microclimate control, 7. Support biodiversity, 8. Have aesthetic value, 9. Increase the economy by attracting people, 10. Improve health, 11. Reduction of building energy consumption, 12. Provide green jobs.	1. Require a lot of care	1. A lot of potential space 2. Flexible design	1. Could be very expensive but id depends on the design

4.5.3 Vertical greenery systems:

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
1. Improve air quality, 2. Help to restore water (hydrological cycle), 3. Excellent Cooling effect, 4. Reduce dust and noise, 5. Urban microclimate control, 6. Support biodiversity, 7. Have aesthetic value, 8. Increase the economy by attracting people, 9. Reduction of building energy consumption, 10. Provide green jobs.	-	1. type variability, 2. scan provide stormwater management in combination with water management systems.	1. could be expensive .

4.5.4 community and private gardens, inner yards:

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
1. Improve air quality, 2. Help to restore water (hydrological cycle), 3. Stormwater management, 4. Excellent Cooling effect, 5. Reduce dust and noise, 6. Urban microclimate control, 7. Support biodiversity, 8. Have aesthetic value, 9. Increase the economy by attracting people, 10. Improve health, 11. Reduction of building energy consumption, 12. Inspiration for green jobs, 13. Food production	-	1. Personal touch of creativity 2. Exchange of experience	1. Possible soil contamination by inexperienced gardeners, 2. Planting of invasive species by inexperienced gardeners.

4.5.6 Green Infrastructure for water management:

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
1. Improve air quality, 2. Help to restore water (hydrological cycle), 3. Stormwater management, 4. Cooling effect, 5. Reduce dust 6. Urban microclimate control, 7. Support biodiversity, 8. Have aesthetic value. 9. Green jobs	-	1. Type variability	-

Chapter 5

Discussion

Results from the SWOT analysis showed that all the types of Green Infrastructure have many similarities defined by their functions: air quality improvement, regulation of the hydrological cycle, aesthetic value, heat reduction, support of biodiversity, and dust reduction. In terms of Prague GI must be mostly focused on urban heat reduction and water management.

To reduce the urban heat effect in the city center of Prague, new green roofs should be considered. To analyze the city center areas most vulnerable during high temperatures by spatial thermal analysis. Prague has had a large scale of green open spaces historically but mo. Moreover, it has a lot of potentials presented by spaces for restoration in the likeness of brownfields which do not require changes of valid spatial planning.

Vltava river challenges Prague to provide monitoring for tree rows next to the flow stream. Based on the literature review was established that there is no ratio between blue and green infrastructure; the base of the relationships is a solid structure and understanding of local benefits and natural conditions. Moreover, there is no existing hierarchy between blue and green infrastructure or between different types of GI. The only principle that should be followed is prioritizing based on current requests, which brings us to the next point: noticing what to prioritize.

Green infrastructure creates opportunities for green jobs, in addition to existing principles such as monitoring and providing care of freshly planted trees for the next five years according to the action planting planning. More jobs could be created in more creative areas of green planning, such as green design.

Chapter 6

Conclusion

Summing up, healthy trees provide maximum value for ecosystem services. Green infrastructure brings a lot of opportunities and benefits to everyday life. Prague has collected a lot of aesthetical value and knowledge through history in terms of using and producing green infrastructure. Empty or abandoned places want to be seen as potential. GI management is a constant and complex process which needs to inspire people.

Attachments.

Attachment 1.: list of specially protected small areas of Prague.

1. Roztocký háj - Tiché údolí
2. Údolí Únětického potoka
3. Královská obora
4. Sedlecké skály
5. Bohnické údolí
6. Dolní Šárka
7. Nad mlýnem
8. Divoká Šárka
9. Obora Hvězda
10. Skalka
11. Petřín
12. Hostivické rybníky
13. Čimické údolí
14. Podhoří
15. Opukový lom Přední Kopaniny
16. Kalvarie v Motole
17. U Hájů
18. Prokopské údolí
19. Vidoule
20. Dalejský profil
21. Požáry
22. Radotínské údolí
23. Zmrzlík
24. Lochkovský profil
25. Slavič údolí
26. Klapice
27. Černé rokle
28. Staňkovka
29. Radotínské skály
30. Slavičí údolí
31. Krňák

32. Zvolská homole
33. Šance
34. Komořanské a modřanské tůně
35. Nad závodištěm
36. Chuchelské háje
37. Barrandovské skály
38. Ctirad
39. Cholupická bažantnice
40. Modřanská rokle
41. Chuchelské háje
42. Homolka
43. Nad závodištěm
44. Dvorecké stráně
45. Branické skály
46. Podolský profil
47. Pod Žvahovem
48. Pod školou
49. Údolí Kunratického potoka
50. Hrnčířské louky
51. Milíčovský les a rybníky
52. Obora v Uhříněvsi
53. Mýto
54. Rohožník - lom v Dubči
55. Lítožnice
56. Počernický rybník
57. V pískovně
58. Xaverovský háj
59. Klánovický les
60. Cyrilov
61. Vinořský park
62. Bažantnice v Satalicích
63. Letiště Letňany

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