Urban Green Network - Synthesis of Environmental, Social and Economic Linkages in Urban Landscape

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Abstract. The city sprawl phenomenon, responsible for incorporating new suburbs into cities, is constantly changing our landscape. The results of this phenomenon are the rapid decrease of forest cover, fragmentation of green areas and loss of biodiversity. The paper examines studies and contemporary Green Infrastructure practices in response to find a solution for an increasing demand for new residential and recreational green areas in urban environment. The subject of the analysis is related to the problems of, both, nature protection and well-balanced development of the built-up areas. This paper was motivated by the three pillars of sustainability – environmental, economic, and social to take an interdisciplinary approach to GI in the context of system of GI linkages. It is focused on the role of green linkages in the integrity of GI network, and their influence on ecological, cultural and landscape functions, in extremely transformed and polluted urban environment. The research makes an attempt to define the role of landscape linkages in the Green Infrastructure.

1. Introduction
Cities create highly modified landscapes with dispersed, continuously shrinking green areas – isolated fragments of nature, valuable for inhabitants and for wildlife [1]. Urban Green Infrastructure (UGI) as a combination of green spaces in cities, interconnected by system of green and blue linkages, is a significant part of urban planning, exceptional for maintaining the sustainability of city environment [2,3]. It delivers multi-purpose advantages: increases economic value of land, adds social and community benefits, enhances environmental quality and biodiversity and contributes to the well-being of cities’ inhabitants [4,5,6,7]. Green Infrastructure (GI) combines nature hubs: reserves, managed native landscapes, working lands, regional parks and preserves, community parks and natural areas which differ in shapes and sizes with the system of linkages e.g.: landscape linkages, conservation of green corridors, greenways (parkways, blueways, paveways, glazeways, skyways, ecoways and cycleways) [8]. The paper focuses on the role of green linkages in the integrity of GI network, and their influence on ecological, cultural and landscape functions, in extremely transformed and polluted urban environment.

2. Methods
The aim of the studies was to determine the scale and extent of the green linkages in urban landscape. The research was based on identifying contemporary practices in Green Infrastructure, focused on
integrity and continuity of green areas on urbanized areas. This paper was motivated by the three pillars of sustainability – environmental, economic, and social to take an interdisciplinary approach to GI in the context of system of GI linkages. It includes the synthesis of ecological, economic, and social SWOT analyses are presented in the table 1, where are also methods, outcomes of urban corridors and recommendations for future projects. The main aim of the paper was to provide significant examples of works, dealing with urban corridors, divided in the paper into: Blue Infrastructure, Grey Infrastructure and Futuristic Infrastructure. The case studies were chosen on a basis of their contribution to restoration of waterways and roadways on urbanised areas through Green Infrastructure. The new term of Futuristic Infrastructure was introduced to highlight possible directions of contemporary cities development, in particular connected with present transformation of suburbs. The analysis include studies of the relevant literature related to the problems of restoration through Green Infrastructure, reports, government and policy documents, conference proceedings and websites of international networks.

Table 1. SWOT analysis of Blue Infrastructure, Grey Infrastructure and Futuristic Infrastructure

|                        | Blue Infrastructure | Grey Infrastructure | Futuristic Infrastructure |
|------------------------|---------------------|---------------------|--------------------------|
| **Ecological**         |                     |                     |                          |
|                        | • Ecological corridor along the rivers | • The corridor of migration of organisms | • Condensation of buildings along the main communication axis provides greater protection for the open landscape against fragmentation and protects agricultural areas |
|                        | • Increasing water retention in urbanized areas and, ultimately, stabilizing water relations | • The roadside green belt forms a sanctuary for the existence of many species of plants and animals |                          |
|                        | • Flood protection using the wetlands and bioswells system | • Absorption of pollutants through roadside greenery (eg heavy metals) |                          |
|                        | • Migrating organisms and increasing biodiversity and gene pool | • The use of green stripes reduces noise |                          |
|                        | • Ventilation of the city and creation of appropriate Eco physiographic conditions | • Posts and power lines form observation points for many species of prey birds |                          |
|                        | • Positive impact on reducing temperature within Urban Heat Island |                          |                          |
| **Strengths**          | • Impact on a sense of security, connection with nature | • Creating neighbourhood spaces within the city | • Due to the density of buildings, easier social contacts |
|                        | • Impact on behavioural and emotional state of people | • Creation of transit areas enabling fast movement of people | • Easy access to services and recreation |
|                        | • Aesthetic and landscape values contribute to the improvement of comfort of life |                          |                          |
| **Social and sociological** |                     |                     |                          |
|                        | • Strengthening the PR’s ability and city's competitiveness | • Communication allows the flow of goods and people | • Multimodal combined transport system organized on few levels |
|                        | • Improvement of the image of the city through the implementation of pro-ecological projects | • The system of grey infrastructure coupled with greenery affects the development of services related to recreation and gastronomy in adjacent areas | • fast movement of people and goods |
|                        | • ProEcological projects influence the increase in the value of real estate |                          |                          |
| **Economic**           | • Riverside areas create sensitive ecosystems | • Large surface runoffs | • Vertical buildings impede access to sunlight |
|                        | • The possibility of faster transport of pollutants over longer distances | • The impermeable road surface reduces the infiltration of water into the soil profile | • Problems with airing and access to fresh air of a residential unit depending on the layout of the mega structure |
|                        |                          | • Increased emission of atmospheric pollution (PM10, PM 2.5, heavy metals, aromatic hydrocarbons, petroleum substances) |                          |
|                        |                          | • Periodic increase of soil and water salinity due to the use of salt on roads |                          |
| **Weaknesses**         | • Creating a physical barrier between districts | • The road is a physical barrier for the residents of the city | • Unification of public spaces |
|                        | • Social conflicts related to degraded riverside areas | • Air pollution affects the health conditions of residents | • The small role of the individual in society |
|                        | • Difficult accessibility of riverside areas located in city centres |                          |                          |
| **Social and sociological** |                     |                     |                          |
|                        | • The need to increase expenditure in the case of implementation of pro-ecological investments related to communication | • Increased outlays for maintaining roadside greenery | • The linear character of the building is connected with the necessity of transporting goods over long distances |
| **Economic**           | • Large investment costs and high costs of use |                          |                          |
Multiscale and multifunctional Green Infrastructure

The Green Infrastructure (GI) is a framework for conservation and development. GI is strategically planned, to connect green areas across urban, suburban, rural and wilderness landscapes and to incorporate environmental services and functions, at the state, regional, community and parcel scales [9,10]. The comprehensive green infrastructure model combines nature-based solutions applied at different scales (regional, local, subarea, district, neighbourhood and site) and in different spatial contexts [11]. At the regional level implementation of green infrastructure, guidelines can help in urban revitalization and landscape preservation e.g. in maintaining and enhancing watersheds, ecological

|                | Blue Infrastructure                                                                 | Grey Infrastructure                                                                 | Futuristic Infrastructure                              |
|----------------|--------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------|
| **Ecological** | • Creation of new seminatural habitats for aquatic vegetation and fauna (especially reptiles and mammals)  
• The possibility of creating a safe migration corridor | • The possibility of creating an Ecological corridor along the road  
• Possibility to include a roadside green belt in the Green infrastructure covering forest areas, pastures, agricultural areas  
• Possibility to create a buffer belt for air, soil and water pollution  
• The possibility of creating parks and other recreational areas over the existing road infrastructure  
• The location of rain gardens along the streets enables bioremediation of pollutants and contributes to the improvement of water relations | • Creating greenery systems combined green corridors with green nodal centres  
• With the adoption of a larger width of linear housing structures, it is possible to create new ecological corridors |
| **Opportunities** |                                                                                      | • The possibility of creating friendly spaces in the city with squares, greens squares  
• The noise has a negative impact on the psychophysical condition of the residents  
• The possibility of integrating green, blue and gray infrastructure | • Thanks to easy access to recreational areas, communication and services, the opportunity to feel a greater bond between the city's residents |
| **Social and sociological** | • Creating people-friendly open public areas (e.g. boulevards, promenades, linear parks) | • The possibility of creating a tourism product based on BI (Blue Infrastructure) projects  
• The possibility of launching riverside transport (eg water trams)  
• Possibility of generating energy by means of water accumulation | • The possibility of creating a multimodal transport system based on the existing road network  
• Possibility of creating efficiently functioning public communication combined with recreational areas  
• Creating greenways increases the attractiveness and economic value of the area |
| **Economic** | • Creating a tourism product based on BI (Blue Infrastructure) projects  
• The possibility of launching riverside transport (eg water trams)  
• Possibility of generating energy by means of water accumulation | • Lowering the groundwater table due to the use of drainage and drainage  
• With poorly functioning dehydration, the possibility of overfilling rain channels  
• Change of use of the roadside green belt for municipal investments  
• The danger of building a roadside green belt | • The functionality of the goods and services distribution system may affect the city's competitiveness in the region and the country |
| **Ecological** | • The threat of interrupting the continuity of the corridor due to expansive urbanization. Excessive overgrowing of river banks may increase the risk of flooding and impede the flow of water in the riverbed | | • Increased risk of ecological disasters in megastructure |
| **Social and sociological** | • Social conflicts related to the change of riverside land functions (e.g. gentrification) | • Roads, constituting a barrier in the movement of people who integrate them, can negatively affect society, favouring the emergence of social exclusion phenomena, in effect contributing to the division of society | • Difficult movement of people as a result of random events |
| **Economic** | • The risk that investment costs will not balance  
• Increased costs related to environmental compensation | • The possibility of occurrence of large environmental contamination in cases of random events | • The possibility of large economic losses for the city as a result of a failure / due to the condensation of buildings immobilization of the smooth flow of goods and services  
• Problems with airing the city increase the environmental and financial costs associated with environmental compensation |

3. Multiscale and multifunctional Green Infrastructure

The Green Infrastructure (GI) is a framework for conservation and development. GI is strategically planned, to connect green areas across urban, suburban, rural and wilderness landscapes and to incorporate environmental services and functions, at the state, regional, community and parcel scales [9,10]. The comprehensive green infrastructure model combines nature-based solutions applied at different scales (regional, local, subarea, district, neighbourhood and site) and in different spatial contexts [11]. At the regional level implementation of green infrastructure, guidelines can help in urban revitalization and landscape preservation e.g. in maintaining and enhancing watersheds, ecological
zones, at local government level in maintaining the continuity of green areas in urban and suburban zones (e.g. through greenways), at the district and neighbourhood level in delivering new amenity space in master planning and urban design. On the larger scale GI is a significant tool in storm water management, which allows to direct runoff to areas that retain and infiltrate water through: bioswales (natural drainage ways implemented to receive and absorb runoff), wetlands, rain gardens (vegetation planted in natural or artificial depressions) and permeable surfaces [12].

3.1 Role of Blue Infrastructure in restoration of urban landscapes

The development of hydrotechnical infrastructure along watercourses is a reason of disturbances in the continuity of ecological corridors. As particularly harmful in urbanized areas the following activities can be listed: regulation of riverbeds, coastal development, or degradation of coastal environment that prevents the migration of organisms along the water course. As a result of the creation of ecological barriers, habitats are divided and the landscape is fragmented, which leads to isolation of the population of individual organisms. Cities, which have been built on the rivers' banks, use waterways as major transportation corridors, and as a source of potable water and food. Urbanisation has changed the landscape of cities and function of waterways, whereby these are being channelled, paved over and transformed into sewers. Buildings and infrastructure located on the river banks: roads, and industry have dramatically changed the urban pattern, influenced on altering natural flow of rivers and contributed to increase of urban runoff. GI is an important tool for storm water management and ecological restoration of waterways.

GI techniques connected with restoration of waterways include:

- usage of natural retention and absorption capabilities of vegetation to reduce runoff volumes and delay storm water discharges,
- maintaining of natural wetlands and construction of human-made wetlands,
- restoration of bioswales,
- restoration of floodplain forests,
- restoration of rivers, streams and channels,
- integration of rivulets, streams, ponds and marshland areas with Eco-Corridors.

Applications such as bioswales, wetlands and rain gardens help to retain and infiltrate water, reduce storm water runoff volumes and enhance groundwater recharge. Construction of wetlands with dense vegetation contributes to alleviation of storm water pulses, decreasing water velocity and purification of polluted storm water from urbanised areas. Application of GI in the *Staten Island Bluebelt project*, 2003, has incorporated 16 small urban watersheds and isolated wetlands into comprehensive water management plan for New York City. The Bluebelt project combines storm and sewer overflows (CSOs) system with a separate system using restored wetlands with aquatic plants for bioremediation [13]. Among larger investments connected with flood protection, significant examples of GI projects are related to restoration of floodplain forests, which deliver multiple ecological benefits for environment such as: maintaining the water table, preventing erosion and reduction of pollutants by filtering the water.

In 2013, the American Association of Landscape Architects (ASLA) Honor Award was given to the *Ningbo Eco-Corridor*, a 3.3km Living filter. This project creates a comprehensive storm water management system with riparian zones of wildlife habitats, established to purify polluted water from the urban canal system and help to manage storm water runoff. The *Ningbo Eco-Corridor* is also an important element of the city’s recreational and educational infrastructure. The hydrological system of the Eco-Corridor integrates rivulets, streams, ponds and marshland areas planned to create a lowland floodplain habitat for native aquatic species. The entire area was transformed into hills and valleys; valleys to remove pollutants and hills to buffer the urban areas and create vista points for inhabitants [14].

The continuous waterways network is disconnected by roads and buildings which results in isolation of smaller habitats [15]. River rehabilitation has become one of the priorities in water management on
many levels: starting from reconstruction of riparian habitats in river corridors to the creation of new recreational zones with pedestrian and cycle paths. Yangjae stream - one of the first examples of a city stream restoration project in Seoul, (finished in 1997) not only has contributed to the improvement of recreation and biodiversity locally, but also has given an impulse for further rivers and streams rehabilitation and restoration development projects [16]. Among good practices of urban waterways revitalization investments is the transformation of the polluted King Yip Street nullah in Kwun Tong (China) into a vibrant blue-green infrastructure project – Tsui Ping River with environmental, ecological and landscape upgrading. The GI techniques combine enhancing the drainage capacity and providing riverside walkways. On the next step of the Master Plan implementation the new open riverside space – Tsui Ping River Garden will be added. Located also in China, The Nanjing Hexi Waterfront project combines ecological restoration approaches with recreational facilities of the Yangtze River wetlands situated in urban areas. The new wetland park – a 7-kilometer long, with the „eco hotel” located alongside the park has created conditions for improvement of walkability in the district by introducing new waterfront promenades with offices and housing [17]. This experimental project has given the opportunity for local residents to own small plots for growing their own food. Moreover, the urban farming site delivers water and generates power for Nanjing Hexi Waterfront.

In cities across the world, rivers and streams were channelled and their ecological, aesthetic and recreational functions were wasted. On vast areas in many cities, wide river banks together with smaller concrete canals create abandoned landscapes, not utilized for any purpose [16]. These interconnected systems of streams and rivers constitute an important element of GI (table 1).

3.2 Role of Grey Infrastructure in restoration of urban landscapes

Road corridors combine road surface, maintained roadsides and vegetated strips (for example median strip between lanes) (Forman, Alexander, 1998). In open landscape such corridors can change to "roadside natural strips" with native, spontaneously growing vegetation, located adjacent to roadsides [18]. Urban and industrial pollution is associated with the growing urban transport. During the construction of roads, materials, such as debris or other waste materials, enter the soils. The use of road salt or improper fertilization of land used for agriculture also contribute to environmental pollution. Soil degradation is associated with an increase of heavy metals, an increase in salinity and some organic compounds, e.g. petroleum derivatives. Linear road configuration affects the acceleration of water runoff and sediment transport. It increases the risk of flooding and degrades water ecosystems, especially in the network of streams and distant valleys [19]. The construction and functioning of roads combine important phenomena with a negative (direct and indirect) impact on the “natural communication behavior” such as: conversion of adjacent areas to the area, by occupying areas for development or destruction of valuable natural habitats due to changes in water regime and pollution growth. The development of linear infrastructure (roads and railways) is an impenetrable obstacle for many organisms and is a direct cause of high mortality of animals. Roads, constituting a barrier to the flow of organizations, may also paradoxically also create a corridor conducive to the spread of organisms, for example through sunny slopes of road embankments or roadside greenery. On the other hand, ground energy lines constituting ecological barriers are often an observation point for birds of prey. Roads, referred to as the "linear habitat" or "greenway" [18] often create a variety of natural areas, whose existence affects the biodiversity of local ecosystems and species [18,20]. In a highly urbanized landscape, green belts along roads are a particularly valuable reservoir of biodiversity. Trees along roads inhibit erosion processes, protect against wind, accumulate pollutants and increase the aesthetics of the landscape [18,20, 21,22]. Roadside environment, adjacent to a road surface, creates perfect conditions for growing plants with enough light and moisture from road drainage [18]. Roadside vegetation strips, together with natural woody vegetation and agriculture land, form rich and diversified habitats for growing and dispersing organisms widely across the landscape [23]. Moreover, roadside vegetation, acting as a buffer zone, helps in reducing pollution from road surface through filtering and reducing quantity of sediments.
Rebuilding and enlargement of urban roads provide opportunities for revitalisation through GI such as:

- transforming of neglected, abandoned transit lines (railways, highways, motorways), stations and terminals,
- integration of grey infrastructure (e.g. existing highway tunnels, stations, industrial plants) with Green Infrastructure (e.g. green roofs, rooftop garden and green walls),
- integration of Grey infrastructure (e.g. highways, roadways) with Blue Infrastructure (rivers, streams, channels, urban wetlands, bioswales) with GI (e.g. linear parks, open public spaces),
- removing urban highways,
- turning streets into linear habitats [18] with trees, bushes, permeable pavements and rain gardens or greenways with boulevards, sidewalks and multi-use pathways.

Revitalisation in this context is used to describe: transformation of neglected transit lines (e.g. High Line, New York) or abandoned trolley terminals (e.g. Lowline, New York) into new green areas as well as direction of traffic through underground tunnels (Madrid Rio Park) or the 5 kilometres of elevated highway (e.g. Cheonggyecheon Stream) and turning them into a recreational area for pedestrians and bicycles. The contemporary technologies integrate various GI and engineering solutions such as in the case of Lowlines, where passive solar technology together with solar reflector dishes were used to provide light for plants growing below street level [24].

The Madrid Rio Park (Spain), a valuable 9km long linear green space in Madrid, was located on the site of a former highway built on the banks of the Manzanares River [25, 26]. One of the largest revitalisation investments was removing the elevated highway above the polluted Cheonggyecheon Stream (China) to transform site into an urban green corridor with water pumped 11 km from the Han River [27]. The Teheran Eco-Corridor Promenade (Iran) is a large-scale landscape infrastructure revitalisation project, integrating an existing significant highway tunnel with urban ecological infrastructure. The connectivity of the Linear Park, 600m in length and 50m wide, is provided thanks to the construction of an elevated pedestrian bridge above the tunnel. The project assumption is to make area accessible for inhabitants via introduction of a system of underpasses and intersections, diagonal paths crossing the main axis and continuous ramps

Greenery adjacent to roads: trees and bushes, contribute to reducing storm water runoff, improve air quality and mitigate Urban High Island effect (table 1). GI solutions such as rain gardens, using absorption capabilities of vegetation, allow rainwater runoff from roads, parking lots, walkways and roofs, thus stopping water before it reaches the sewer system. Trees and the adjacent landscape can create an important corridor for people and wildlife. Priority in planting trees should be given to native species by identification of their tolerance of polluted urban environments [22]. Green streets enhance walkability thanks to boulevards, sidewalks and multi-use pathways.

3.3 New green linkages (Futuristic Infrastructure) in urban environment

Since 1910 when Chambless proposed a “road-town” concept - being a symbiosis of a city and a village, gardens and agriculture - the idea has influenced later theories and practices of dispersed urbanization along corridors of transport. In 1965, Michael Graves and Peter Eisenman proposed the Jersey Corridor Project – a concept of a twenty-mile long linear city, with buildings connected by rails and roads running underneath, consisted of two parallel strips, (one for industry and the other for green housing), shops and services with parkland located in the middle. Standing six stories above ground, they created the green corridor for open-air cafes and shops, with: restaurants, pools and penthouses on top of the buildings [28].

Countryside in Gauthier’s city creates an open landscape, free from pollution and noise. Owing to controlled development of linear settlement pattern, and limited space linear cities need, nature can
rebirth and biodiversity can increase. The futuristic concept of Gauthier’s contemporary linear city, built at the outskirts of present cities, double interconnected: by efficiently public transportation, distributed on three interconnected levels – Metro for short distances, Suburban Train for medium distances, and High Speed Trains for long distances and by a green belt of a community park located on the rooftop of residential buildings [29]. A multimodal, combined transport and sewage system contributes to delivering goods, trade and waste discharge.

Construction of the giant seawall (13 km in length) in Saemangeum (Korea), situated in the middle of Yellow Sea rim had cut the city from its main nature based attraction – the Yellow Sea. The futuristic project idea is to use the sea wall as the base for linear megastructure, with grand boulevard and transit lines, running in the middle of the construction and buildings, accommodating hotels and housing located above. The main project goal is to create multifunctional green giant structure, supplied with renewable energy produced by photovoltaic panels and wind turbines [30] The investment of Tianjin Eco-city: located 150 km from Beijing and 40 km of Tianjin is announced to be a self-sufficient city with: solar and wind power energy, rainwater recycling, and wastewater treatment. According the project goals it will receive 50 % of water from non-conventional resources. The ecological and functional connectivity in the city will be provided thanks to new Eco-Corridors joining the city districts.

Compact arrangement of above mentioned futuristic concepts, close connections with road network reduce transport costs and necessity to provide additional communication linkages joining city centers with suburban areas. Linear Futuristic Infrastructure is based on public transportation system and, therefore, it contributes to improving quality of environment and wellbeing of local communities (table 1). Housing areas can be easily integrated with outdoor recreational activities such as: bicycle trails, footpaths and parks. Futuristic Infrastructure provides access to new technologies and can help in reducing pollutants and recycling of waste on place.

4. Results and discussions
In Africa and Asia, where urbanization rates are the highest contemporary cities, sprawling on suburban areas, have opportunities to incorporate more green spaces in their future planning. According to data presented by the Chinese Major Association the population living in Chinese cities is expected to reach 75% by 2050 in comparison with 37,7 % of urban population in 2001 [31]. To answer for these huge people migrations across the globe, new urban pattern models have to be considered in planning practices. The questions are in what directions and dimensions contemporary cities will sprawl and how we are able to answer for expectations of future cities inhabitants and provide new housing with access to green areas, recreation, health and services. Green Infrastructure, as „a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services” [32] delivers a tool for urban development plans in macro scale. Green Infrastructure delivers significant benefits to environment and society divided into: environmental, economic and social (table 1). The multifunctional role of GI is particularly valuable in highly fragmented and limited urban environment. Green Infrastructure policies should be integrated with development of urban Grey and Blue Infrastructures. Contemporary GI solutions for cities environment combine horizontal and vertical greening, bio architecture with bio urbanism and create new dimension in urban landscaping. This dimension connects greenery integrated into buildings with green roof, rooftop garden and green walls.

5. Conclusions
Cities create unique ecosystems with ecologically important landscapes such as: riparian areas, wetlands and other urban semi-natural ecosystems [33]. Complexity of urban ecosystems delivering multiple benefits both for people and nature is an urgent topic of nowadays discussion about standards and future of urban planning (34). To understand this greater attention is needed on knowledge of the multifunctional and multiscale role of green linkages in Green Infrastructure.
Although linear cities concept is criticized for being a utopian vision of imposed spatial order, and it shows strong tendency to destroy traditional cities structure, some ideas and guidelines can be introduced to contemporary urban planning. This particularly concerns present transformation of suburbs, endangered of urban sprawl, responsible for rapid decrease of agriculture and natural areas and further fragmentation of habitats. Some answers how to manage with these problems can be delivered due to new, innovative solutions, futuristic visions drawn from, among many other concepts – for example linear cities idea.

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