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GREEN INFRASTRUCTURE: FROM GLOBAL TO LOCAL

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THEME ISSUE

GREEN INFRASTRUCTURE: FROM GLOBAL TO LOCAL – EDITORS' NOTES

MARIA IGNATIEVA, MADELEINE GRANVIK, ANNI VARTOLA AND CLAUS BECH-DANIELSEN

This special issue is based on 11 peer-reviewed papers from the EFLA ICON-LA International Conference «Green Infrastructure: from global to local». The conference had a truly global resonance and attracted some of the world's most recognised scientists and practitioners in urban planning, landscape architecture and design. In total there were 307 participants from 41 countries.

The conference was held in St. Petersburg, Helsinki, Stockholm and Uppsala on 11th–15th June 2012. Locations of the conference were truly Nordic (North-Eastern part of Russia, Sweden and Finland) and its topic «Green Infrastructure» was a very timely and relevant one for all Nordic countries. Particularly, Stockholm, Copenhagen and Helsinki are famous for their well-developed and extended green infrastructures and are nowadays considered as «iconic» positive models.

The main objective of this issue is to raise the attention and awareness among scientists, urban planners, landscape architects and the various cities' administrative bodies on the importance of creating sustainable, green infrastructure in the cities. The current situation of unsustainable development of most cities in the world is further challenged by a range of specific problems relating to their green infrastructure, which is discussed in this issue. The papers presented in this issue cover different themes dealing with theoretical questions of green-blue infrastructure, as well as more practical design and management considerations. Since the topic of green infrastructure is quite broad, it is not surprising that a wide range of scales needs to be addressed: from a large scale of master planning to a fine scale such as research of trees in private gardens and the detailed historical analysis of sultans' palace gardens. The papers represent original research and deep analyses of relevant literature. The geography of places included in the research is quite broad as well: ranging from the West Coast and Midwest of the US and Canada to Nordic, Central European and Mediterranean countries.

This issue starts with a conceptual and theoretical vision of the «Green-blue Infrastructure in Urban-Rural Landscapes – introducing Resilient Citylands» by Per G. Berg, Maria Ignatieva, Madeleine Granvik and Per Hedfors. Here, *Green-blue infrastructure* is declared as a key component in human settlements. The authors have investigated the potential for new interactions between *green-blue*- and *built* structures by using a broad range of international case studies, of both practical and theoretical relevance. *Resilient Citylands* proposes a new concept useful for landscape architecture and planning. It represents a new reciprocal co-evolution for different scales: for urban and rural areas; for human settlements- and natural ecosystems; and for constructed and green-blue areas and elements within urban settings.

The theoretical vision of Green Infrastructure is continued by Nancy Rottle's paper «Urban green infrastructure for climate benefit: global to local» five systems of green infrastructure; social, biological, hydrologic, circulatory and metabolic. These systems provide multiple benefits and may mitigate anthropogenic impacts on climate through reducing greenhouse gases in the atmosphere and helping to reduce the negative effects that climate change will have on urban environments. Rottle presents a powerful North American Low Impact Development approach, dealing with storm water management and incorporation of ecological processes. This paper is supported by famous ecological design projects from North America and Europe.

The paper «Ecological infrastructure: an examination of three Canadian Cities» by Richard Perron and Rob Zonneveld, two representatives from the neighbouring country, Canada, studies three distinct ecological regions, i.e. the boreal forest (in the Precambrian Shield), the tall-grass prairie and the short-grass prairie. Their work can be seen as a classical approach to landscape architecture, working on different scales across the landscape: from a macro scale, long term ecological plan for the city to a series of site specific design investigations and suggestions. Each city has been examined through the design studio process, where a combination of GIS investigations and CAD based design iterations were used as primary methodological tools. The concept of «ecological infrastructure» requires respect and the integration of landscape ecology principles. The paper illustrates quite clearly how design context, understood as the convergence of natural and urban systems, can provide the basis for modeling urban ecological infrastructure.

The theme of transportation and green infrastructure is represented by the paper «Road networks as framework for green infrastructure» by Thomas Juel Clemmensen. Clemmensen looks at the roads not only as an obstacle resulting in fragmentation and barriers, but also as parts of larger networks, which can contribute to creating new green infrastructures and even improve urban landscape porosity and connectivity. Two questions asked in this work are whether it is possible to conceptually relocate road networks in the landscape, and how to consider infrastructure as an opportunity to, and basic component of giving shape to a city or even an entire region. It is not surprising that the case study projects come from the Netherlands and Denmark, with their highly constructed landscapes, and from the US, with its long history of dedication to automobile road networking (national highway system, network of wayside landscapes and parkways) as well as from the UK, where there are some interesting examples of connecting fragmented urban landscapes using road networking.

The theme of networking in this paper is supported by Muhammad Farid Azizul, writing about «Ecological Networks in a Sustainable Landscape, their roles and Impact in the Socio-Cultural Process». This theoretical paper is based on a critical analysis of literature published between 1995 and 2012 across disciplines, which are connected to ecological network-landscape ecology, conservation biology, landscape and urban planning as well as nature conservation.

Also included is a group of papers which are based on the analysis of urban green infrastructure, mostly using a city level scale. «Marginal» Urban Vegetation – the case of Lisbon» by Sara Machado Doesburg and Paulo Farinha-Marquesis calls for the use of an ecological approach to urban planning and management as an essential factor in maintaining the long-term sustainability of ecosystem services. The authors pay attention to «marginal» vegetation, which exists within an officially identified and protected network of green areas. Using satellite images and field work, they have found considerable amounts of such «marginal» areas, which are currently underestimated, but have the potential to become a valuable resource for enhancing the ecological structure of the city.

The Italian example of Catania by Riccardo Privitera, Francesco Martinico, Daniele La Rosa and Viviana Pappalardo, «The role of non-urbanized areas for designing an Urban Green Infrastructure», operates on a city scale and presents an Urban Green Infrastructure (UGI) design approach as a tool for re-defining the role of a green area network as part of the Land Use Master plan. As in the case of Lisbon, Italian researchers try to increase attention to a special category of green spaces, which are usually not part of existing «official» urban green areas – Non Urbanized Areas (NUAs). The authors claim NUA (currently unmanaged spaces) to be an important part of Urban Green Infrastructure. These Non-Urbanized Areas are mainly semi-natural areas, which can be seen as the last remnants of nature within the built up areas that provide a whole range of ecosystem services and, first of all, preservation and enhancement of biodiversity.

Another European case study is presented in the paper by Attila Toth and Lubica Ferianova, «Green infrastructure in the context of rural space restoration and design», investigating rural settlements in Slovakia. This case study has been conducted by using classical methodology, which is a scheme working with three scales: firstly, GI concept for the micro-region Cergát-Váh; secondly, a meso-planning scale consisting of a more detailed concept concerning the cadastral area of the village Tvrdošovce; and lastly, the planning level of a public space design at a fine scale relating to the central part of the village. The proposed design is based on rules of rural space design. This solution will reconstruct lost character and reinforce the local identity of Slovakian rural settlements.

Today, historic gardens are considered a very special type of green area that are highly valued for their cultural, aesthetic and ecological features. Such historic landscapes play a unique role in overall urban green infrastructures. That is why having two papers in this special issue dedicated to historic complexes containing green areas is not surprising. Both papers concern one country, Turkey, and even look at the same city, Istanbul. In «The potentials of Topkapi Palace as a contributor to Urban Green Infrastructure Planning» Pinar Koylu discusses how historic gardens, with their existing endowment of monumental trees and other plant species, can become a core «skeleton» of structured green-blue spaces network, and the preservers of national identity in the modern era of urbanisation and westernisation. In their paper «Through the Historical Landscape to an Urban Green Infrastructure: Themes & Context» Meltem Erdem and Meliz Akyol use a broader approach and analyse the green heritage of Istanbul aiming to understand its potential for the development of the European side of Istanbul. Three relevant typologies were studied: historical parks and gardens, groves and cemeteries. The authors' findings confirm the importance of conservation strategies as an effective tool to control the change within historic green landscapes, but at the same time suggest using contemporary design approaches. Together, these strategies, can create a robust framework for the development of an integrated green infrastructure.

Charles Wade and James Kielbaso's paper «Green Infrastructure: Condition Changes in Six USA Urban Forests» is an example of classical fine scale research of public and private trees in an urban forest in the Midwest cities of the United States. It is a thorough and detailed investigation of size and health conditions of urban forest trees, which can be determined by many factors ranging from the genetics of the individual trees to environmental and anthropogenic factors. This research has a very practical aim and gives researchers, arborists and planners an understanding of the conditions and sizes of the urban trees in the Midwest of the US and also instructs on the suitability of trees for planting.

All papers included in this issue show quite clearly the breadth and interdisciplinary nature of landscape architecture – an umbrella discipline including work on all scales (from the mega scale of region and master planning to the micro scale of individual tree or plant species selection), and based on theoretical and practical knowledge. We hope that the readers of the *Nordic Journal of Architectural Research* will find this wider geographical and scale context interesting, and that it will provide input for the development of Nordic green infrastructures.

We especially want to thank all the reviewers for valuable input.

Maria Ignatieva, Madeleine Granvik, Anni Vartola and Claus Bech-Danielsen

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GREEN-BLUE INFRASTRUCTURE IN URBAN-RURAL LANDSCAPES – INTRODUCING RESILIENT CITY-LANDS

PER G BERG, MARIA IGNATIEVA, MADELEINE GRANVIK AND PER HEDFORS

Abstract

With the *global change* crisis pushing – and new knowledge about sustainability in socio-ecological systems pulling – there presently is a window of opportunity to further our understanding about resilient landscapes. In this paper we focus on *Green-blue infrastructure* as a key component of human settlements. Our main focus is theoretical and conceptual but we also illustrate its values and functions to deliver recreation, preserve biodiversity, create urban structure, support cultural identity, provide ecosystems services and maintain primary production/recycling. We further elaborate on the potential for new interactions between *green-blue*- and *built* structures, discussing international cases of both practical and theoretical relevance. *Resilient Citylands* is proposed as a new concept useful for *e.g.* landscape architecture and planning. It represents a new reciprocal co-evolution for different scales: of urban and rural areas; of human settlements and natural ecosystems[1], and of constructed and green-blue areas and elements within urban settings. We investigate how functionally dense, mixed-use, vibrant, intersensory and contemporary *urban areas* could be combined with cutting edge, lean and efficient *rural areas*.

Key words:
Green-blue infrastructure, Urban-rural interaction, Landscape planning, Landscape architecture, Resilient Citylands, Urban design

Introduction

As the global change crisis and its link to anthropogenic processes unfold (Syvitsky, 2012), it seems urgent and rational to target urban development (Fragkias and Seto, 2012) and its physical resource consumption (Haberl, 2012). An exponentially growing consumption rate in Asian, South-American, Eastern European and selected African Cities, will soon surpass the existing consumption rate in Western global cities in the US, Europe and Australia (Brown, 2009). Global urbanization, in its current state, may be the greatest deciding factor for aggravated hydrospheric and atmospheric perturbations, for adverse effects on the biosphere and for significant geochemical changes (IPCC, 2013; IGBP, 2004). At the same time, a massive depopulation in Western countries' *rural areas* and a deteriorating of rural livelihoods in developing countries are taking place (Brown, 2009). Other trends are severe nutrient loss and soil erosion in global agro-ecosystems (Baskin, et al., 2012; Brown, 2009). All these trends add to severe planetary reverberations: more frequent droughts, floods, changes in atmospheric concentrations of gases and greater variations in temperature, winds and moisture on a global scale (Gaffney and Höppe, 2012). Today, on a *macro-regional scale*, life-supporting areas (ecosystems appropriation) of human habitats add up to an unsustainable amount, up to 1000 times the surface of urban areas in *i.a.* the 29 largest cities in the Baltic Sea Region (Folke, et al., 1997). On *a local scale*, free mobility- and settling patterns lead to excessively resource dependent and sprawling cities (Thwaites, et al., 2007). Other effects are loss of valuable green-blue infrastructure (Berg and Rydén, 2012; UNEP, 2005; Florgård, 2004) and the formation of *edge cities* (Garreau, 1992).

New climate change mitigating knowledge and practices

Over the past decades, an exponential growth of *renewable energy investments* and energy conservation practices have resulted in building expansion in hundreds of global cities (Bokalders and Block, 2010; Wheeler and Beatley, 2008). Similarly, *low-impact and mixed-use* urban planning, design and transformation have been implemented – with green and lean bicycle-pedestrian and public transport infrastructure – in *e.g.* European and South-American Cities (Gehl 2010; Gaffron, Huismanns and Skala, 2005; Wright and Montezuma, 2004). The key role of households' *consumption and lifestyles* for OECD countries is also clarified (Brown, 2009; Åkerman, 2011; Carlsson Kanyama, 1999). International trends in *rural livelihoods* also encompass new development trends, which may contribute to *less resource consumption*, an improved *recycling of nutrients* and *healthier lifestyles* (Karlsson and Rydén, 2012). Efforts are increasing to establish *sustainable agriculture* in *i.a.* the Baltic Sea Region and in the North-American Great Lakes Region (Jacobsson, 2012). International global change researchers and environmental policy teams have started to forward another, potentially even more efficient, supplementary strategic process for mitigating climate change. It concerns there-localization[1] of producer-consumer markets and a call for local and regional as well as urban and rural interaction (Seitzinger, et al., 2012; Granvik, 2012; Berg and Rydén, 2012; Granvik, et al., 2012). The inability to address urgent resources- and environmental problems in urban areas, deteriorating production in rural lands and waters and polluting production methods across the globe, calls for a new strategy: A strategy that thoroughly investigates the potential of uniting urban and rural landscapes and functions.

The potential roles of *Green-blue Infrastructure*, seen from a separate urban *or* rural perspective, are seemingly rational and straight-forward. However, we also foresee problems or challenges with such a separate approach to urban *or* rural development. How can urban and rural dwellers, companies and other stakeholders instead become aware of each other's potential green-blue infrastructure values, functions and resources? How can urban *and* rural recreation, biodiversity, structuring potential, cultural values, ecosystems services and recycling capacities be optimized? How can urban *and* rural perspectives of green-blue infrastructure values be better harmonized (=to create common goals and utilize their mutual strengths)?

This paper elaborates on strengths and possible weaknesses of geographically interacting urban and rural landscapes. Our main objective is to present a theoretical approach and reasons for a modern unification of urban and rural structures, functions and processes based on current technology, landscape planning knowledge and actual best practices. We suggest a new concept – *Resilient Citylands* – and provide site- and situation dependent (contextual) examples and the under laying rationale. Our main research question is: How can a modern co-evolution of urban and rural and of built and green-blue landscapes support more resilient human habitats?

The paper is structured in a logical order, beginning with a historic perspective of green-blue infrastructure and urban-rural systems with special emphasis on landscape architecture theory. This is followed by our own contribution to theory building: identification of six green-blue structure values; definition of the concepts *Green-blue Infrastructure (GI)* and *Resilient Citylands (RCL)*. These topics are addressed by elaborating on different approaches to urban-rural interactions. In the final part we discuss contemporary implementation and visions of *Green-blue Infrastructure* in urban-rural systems by displaying selected global best practices. The paper ends with reflections on the risks and potential weaknesses of the concept *Resilient Citylands* and a final discussion.

1 Re-localization (an antonym of globalization) in the context of this paper means transformation processes for shortening the geographic distances (= i.a. less transport) between different society functions or stake-holders: from global to macro-regional, (i.a. the Baltic Sea Region) to micro-regional, (i.a. the Mälarvalley region around Stockholm) to local, (City) and to local community scale levels.

A historic perspective of Green-blue Infrastructure and urban-rural interactions

During the 7000 years of history of human urban settlements, these areas were often tightly integrated with adjacent food-, fuel-, water- and fiber producing rural landscapes (Sinclair, et al., 2010; Hyams, 1976). Ever since the alleged first urban settlements in the green crescent of Mesopotamia and through out the agrarian and industrial revolutions, rural functions were seldom considered the antithesis of townscape: On the contrary, they were considered a compulsory urban function (*ibid.*).

As industrialization started to replace the predominantly rural societies of the world, cities expanded initially along railways and main roads. They grew to create urban star rays reaching out into the surrounding landscape (Berg, 2010; Geddes, 1904). In the opposite direction, fiber- and energy yielding forest-, productive farmland and fish-rich water landscapes stretched towards the center of cities in the form of green-blue wedges or green ways, forming highly versatile network pathings[2]. The green-blue structures and networks were instrumental for the development of industrial towns. The historic urban and rural interlaced structures, -areas, -energy production, -flows of people, ideas and inventions were *co-evolving* all the way until the beginning of the 1930-ies in central Europe and until the 1950-ies in the Nordic countries (Berg and Rydén, 2012; Saifi and Drake, 2007). A similar development could be found across the globe – and in *developing* countries the urban-rural connection started to break only during the past 30 years. Still almost half the world's population is firmly tied to its connected productive lands and waters.

When the cities grew, their hinterlands were successively exploited, hence they spread across the countryside in all directions. An interesting paradox about the mechanism behind the loss of green spaces was disclosed by Joel Garreau in his book *Edge city* (1992). He showed that while a growing car-dependent population was searching new habitation – preferably in the zone *between settlements and wilderness* – the *green spaces* were successively consumed. The *pattern* of intertwined built and green wedges was successively lost: First in sprawling American subdivisions and later in most cities of the world. Having lost contact with nature, resourceful US citizens ultimately sought new frontiers. This time targeting the far periphery: the *edge* between the city and wilderness. The *co-evolution* of urban and rural (Saifi and Drake, 2007) was breached only during the last 60 years, stimulated by new global mobility-, production- and consumption patterns (Brown, 2009).

Realigning green-blue with built structures

During the past century gardeners, biologists, landscape architects, geographers, psychologists and planners have recurrently forwarded values of green-blue environments as a public interest for human welfare and well-being in cities. Already in the beginning of the 20th Century,

2 In this paper we use the term network pathing (Murphy, pers. comm. June 2013) tentatively to denote systems with alternative connected pathways (green corridors) and nodes (i.a. parks) with vegetated and water ecosystems (c.f. rhizome). Pathing could also refer to i.a. highly versatile built-, traffic-, communications-, technical- and service structure in communities. Pathing originates from computer science where it represents the design of alternative network pathways and nodes for securing a robust flow and storage of data.

first attempts were made in England to extract the magic atmosphere, the rich labor markets and the cultural excellence from the over-crowded, unhealthy and coal smoke-stricken cities. The perceived best parts of the contemporary cities were then combined with the healthy, productive but job-deficient and sparsely populated countryside as seen in Ebenezer Howard's *garden city movement* (Miller, 1989). At the start of the last century, the Scottish biologist and planner Patrick Geddes (1904), and later American planner and architecture critic Lewis Mumford (1961), argued for an integrated built-green approach. This influenced planners world-wide during almost half a century. As traffic jams and resource demanding sub-divisions started to plague Western cities in the 1960-ies and 70-ies, Christopher Alexander (Alexander, Ishikawa and Silverstein, 1977) and Ian McHarg (1969) exhorted world planners and politicians to once again adapt human settlements to their green-blue environments. Unfortunately, the urban sprawl mechanisms are still active and have now spread to new ambitious economies, like *e.g.* China, India and Brazil (Brown, 2009).

In spite of the, admittedly, positive effects of *globalization* on human welfare, a developing resources scarcity crisis (*ibid.*) with increasing prices of *e.g.* oil, minerals and land, may induce a relative re-*localization* of markets. This has already manifested as a relative displacement from longer to successively shorter distances between producers and consumers (Granvik, 2012). Stream-lined urban landscapes, loss of biodiversity and local cultural identity are other negative effects of globalization, which may further trigger re-localization (Ignatieva and Ahrné, 2013).

Built and green interactions throughout Landscape Architecture history

The enlargement of towns in the early years of industrialization was typically related to the development of necessary public green structures. These were firstly designed in English cities in the middle of the 19th century – *i.a.* the Birkenhead Park by Joseph Paxton. Frederick Law Olmsted, in the middle and the last decades of the 19th century, planned a vast number of city parks (*e.g.* Central Park in New York). Within the limits of several cities, he had a pronounced intent to create strong links between everyday park nature and human settlements (Beveridge and Rocheleau, 1998). One positive outcome of Ebenezer Howard's Garden City movement was the concept of *planned* green areas and *connectivity* between the urban, rural and natural landscapes (Miller, 1989). The earlier mentioned planner and biologist Patrick Geddes (1904) created a foundation for a theory in landscape architecture about the dual need of human beings to have access to natural ecosystems[3] as well as to vibrant human culture in the cities. Another founder of landscape architecture theory, Ian McHarg, developed his eco-centric approach to urban-rural interaction (settlement development adapted mainly to ecosystems health and function) in his seminal book *Design with Nature* (McHarg,

3 Here natural ecosystems (stabilized by climate- and edaphic conditions) refer to a macro-regional typology, i.a. tundra, taiga or temperate grasslands – or a micro-regional typology i.a. forests, fields or streams.

1969). McHarg's work was further developed in Anne Whiston Spirn's *The Granite Garden* (1984). Spirn saw the *urban landscape* as an arena for both humans and natural ecosystems. According to Spirn, integrative approaches were first developed in landscape- and urban planning, where both had their roots in landscape architecture. The landscape architecture discipline emanated, in turn, from Olmsted Senior's work and Olmsted Junior's foundation of the world's first school of Landscape Architecture at Harvard University (Spirn, 1996).

Two recent decades of theories on green-built interactions

For more than a century, landscape architecture has carried the torch of built-green interaction theory, research, practice, planning, design and maintenance, with a particularly vivid development during the last 20 years. Ian Thompson's seminal work *Ecology, Community and Delight* (2000) was a strong statement of a modern co-evolution of urban and rural principles with the ultimate goal to create attractive human habitats. Hough (2004) had a closely related approach in *Cities and Natural Process, i.a.* discussing the role of city farming. Lövrie defined green structure and objects as *identity creating town planning elements* (Lövrie, 2003 – see also Qviström, 2008). Ottosson (2007) and Cooper Marcus (1997) investigated the *recreational and healing power of nature* and how to make it accessible for inhabitants in cities and communities. The functions of *rural landscapes* for sustainable livelihoods, heritage and natural resource management, were compiled in the landscape architecture anthology *Landscape and Sustainability* edited by Benson and Roe (2005).

The significance of Place and new theories on Green-blue Infrastructure values

The significance of *context* in the design of well-integrated green-built spaces was outlined in *Site Matters* by Kahn and Burns (2005) and further developed in a critical study of the modernistic city by Thwaites, et al. (2007) called *Urban Sustainability through Environmental Design – Approaches to Time-People-Place Responsive Urban Spaces*. The significance of place for green-built design was also a main issue in Rowe and Humphries' (2012) *educational landscapes*. Modern attempts to formulate a landscape architecture grand theory, typically elaborate on the contextual interactions of buildings, city life and urban activity on the one hand and an overall defining *Green-blue Infrastructure* on the other (see e.g. Murphy, 2005; Deming and Swaffield, 2011). This has in turn influenced a conceptual discussion about a Landscape Architecture City Theory (LandACT) (Hedfors and Florgård 2012; Hedfors and Granvik, 2008). Attempts to define a range of qualities and scales of green infrastructure for the benefit of urban dwellers have been outlined for different contexts with international city examples across the globe. See for instance examples from different continents (The Landscape Architecture Foundation, 2013), from China (Yu, 2012); from Brasil (Herzog, 2013); from the Middle

East (Egoz, et al., 2011); from the European Union – (EC, 2010) and US Cities (Tzoulas, et al., 2007); from Greater Stockholm (Stockholm County Council, 2009); from other Swedish cities (Lundgren Alm, 2001); and from Nordic cities (Florgård and Berg, 1997).

Development of theory and concepts

We will now present our own view of the concepts *Green-blue infrastructure* and *Resilient Citylands*. The definition of *Green-blue Infrastructure* draws on the work already done internationally in order to capture its contemporary essence. After that follows our definition of the new concept *Resilient Citylands*, which is later elaborated and exemplified.

Elaboration on the concept Green-blue Infrastructure

Green (soil-plant systems) or green-blue (soil-water-plant systems) infrastructure are poorly defined in the emerging theoretical literature within the field of landscape architecture. For practice organizations like IFLA (International Federation of Landscape Architects) and IFLA Europe(earlier EFLA) the concept is – however – more and more discussed. An official EU definition was given during a European Commission conference (EC, 2010):

> *Green Infrastructure serves the interests of both people and nature. It can be defined as a strategically planned network of high quality green spaces and other environmental features. It should be designed and managed as a multifunctional resource capable of delivering a wide range of benefits and services. Green Infrastructure includes natural and semi-natural areas, features and green spaces in rural and urban, terrestrial, freshwater, coastal and marine areas.*

In the US, Green Infrastructure (Tzoulas, et al., 2007) has been seen as:

> *A combination of all natural, semi-natural and artificial networks of multi-functional ecological systems within, around and between urban areas, at all spatial scales.*

The European Commission's *DG environment* emphasizes the *spatial structures of natural and semi-natural areas* and environmental features, *which enable citizens to benefit from its multiple services* (EGCA, 2013a). According to the EC, the concept is sorted under «nature and biodiversity», which may seem reasonable as the latter are quite broad concepts. In the following section we suggest, however, that the conceptual hierarchy should be seen as the other way around. In this way, *i.a.* biodiversity is seen as one function among many of green-blue infrastructure. Our definition includes both green (vegetation and its soil system) and blue (its waters and organisms) components. It is based on the Swedish Planning and Housing Authority (Boverket, 2013) and on Sandström and Hedfors (2009) – but also draws on Tzoulas, et al., (2007) and EC (EU, 2013; EC, 2010) definitions and examples. We here suggest a *structural, functional* and *process* aspect (Murphy and Hedfors, 2011) of *Green-blue Infrastructure*: The *structure* of GI defines its components and relationships; the *function* defines the outcomes or products of the GI; and the *process* defines the activities in which the GI is engaged:

> *Structure: Green(-blue) Infrastructure is a system of vegetated and water connections forming a controlled and flexible system (a versatile network pathing – see a tentative definition above) composed by predominantly plant-soil-water green-blue elements, patches/lakes, corridors/rivers, pathways/streams, wedges/bays, streaks/flows, co-defining the morphological matrix of human settlements in urban and rural settings in a range of scales.*

> *Function: Green (-blue) Infrastructure can be characterized by six main functions: (1) offering citizens restoration, health and well-being; (2) securing functional biodiversity in and near human settlements; (3) constituting a fundamental matrix for human settlements' morphologies; (4) co-defining cultural identity and open spaces as public social arenas; (5) providing ecosystems micro-climate regulating services for urban and rural human- and nature habitats; and (6) representing significant life-support and nutrient recycling areas for primary production of food, fodder, fiber and bioenergy.*

> *Process: Green (-blue) Infrastructure is engaged in a dynamic and continuous change of structure and function, which signify living and vital landscapes. GI comprise geological, hydrological and biological processes that operate over various time-intervals ranging from millions of years to instantaneous reactions. Typically such processes are flows, vegetation growth, plant dynamism and habitat succession. Flows include transportation and movement of plants and seeds, animals and fry, microorganisms, soil (as erosion), minerals, nutrients and water (evaporation, transpiration or meandering).*

Resilient Citylands definitions

The concept *Resilience* was originally used in physics and engineering to describe the ability of a material to absorb energy while deforming elastically and releasing that energy when regaining its original shape. It was more widely introduced in the 1970-ies, for describing properties of ecosystems that could be subjected to (climatic or bio-physical) disturbances (changes), resist or adjust to the changing event and after some time interval, regain its original structure and functions (Hollings, 1973). *Resilience* in this work is used in a socio-ecological system context, where such systems are assumed to possess a given *adaptive capacity* to perturbations. These can also be mitigated by humans through environmental observation, learning and altering their interactions within the system in a desirable way (Murphy, 2005).

We suggest that the concept *Citylands* can be understood as human ecosystems including two components. First, a *City* component referring to modern urban landscapes with dense human settlements and second, a *land* component representing (1) modern rural landscapes enclosing and including sparsely populated settlements *and/or* (2) within the dense city, including green-blue infrastructure interacting with urban settlements. *Citylands,* therefore, denote specific socio-ecological combination systems where settlements are *reciprocally and functionally integrated* with green-blue areas and elements. *Citylands* are also conceived in a range of *scales*, from whole regions to single houses with gardens. Our definitions of *Resilience, Citylands* and *Resilient Citylands* are thus:

Resilience = The ability of a living (socio-ecological) system to cope with pressure or disturbances through resistance and adaptation over time and – (for human systems) with the help of observation, learning and creative alteration – regenerate and even further develop its former structure and function.

Citylands = Reciprocally and functionally interlaced urban and rural landscapes, ranging from large-scale regional systems to small-scale built-green-blue combined elements.

Resilient Citylands = Resistant, adaptive and regenerative modern socio-ecological systems/landscapes, for which human observation, learning and creativity can be used for coping with disturbances. Resilient Citylands are reciprocally and functionally interlaced urban and rural landscapes, ranging from large-scale regional green infrastructure systems to small-scale built green-blue elements.

Resilient Citylands taking landscape architecture towards the future

The Resilient Citylands concept emphasizes the *co-evolution of built- and green-blue infrastructures* in future planning of urban or rural human habitats. In order to supply sufficient resources and restorative environments to a majority of urban dwellers anywhere in the world, cities may have to expand their path networks (trails, threads, rays, stripes or streaks), along with and interacting with green-blue wedges, corridors and patches. This can be described as a system of alternative and versatile connections – *network pathing* (see our definition of this term above) *within the landscapes that carry both urban and rural characteristics* – of both green-blue and built elements (*e.g.* Murphy, 2013 *pers. comm;* see also Berg, 2010 and Ahern, 2007). We suggest that the Resilient Citylands concept is useful *e.g.* for landscape architecture research and practice and for explaining a diversity of values in a range of scales of green patterns, -structures, -matrix, -corridors, -patches and -spaces within *urban landscapes*. We also suggest that the *Resilient Citylands* concept can support the development and maintenance of *rural landscapes* both pre-dominantly affected (cultural) or pre-dominantly un-affected through human intervention (natural) landscapes. But even if urban-rural approaches to landscape architecture already exist, they may still have a typical urban or a typical rural focus (see table 1). Below we, therefore, further elaborate on possible differences between urban and rural conceptions of urban-rural interactions.

An urban perspective of urban-rural interactions

An emerging urban perspective of urban-rural interactions has been fuelled by peak oil and similar events, and represents the end of the non-renewable resources era (Brown, 2009). The end of fossil fuel may lead to increased land values and relatively higher prices for locally (and globally) produced food, fodder, fiber, energy and minerals. Increased land values also affect *any* land use issues, for instance how *engineers can erect constructions in the landscape* while *conserving global land and water resources* (see *e.g.* Carpenter, 2011). At the same time, strong world economies are purchasing land in other countries for securing life support for their own growing urban populations (Borras and Franco, 2012). Financial unrest and turbulent markets also trigger demands for *food, water and resources security* in southern hemisphere cities.

Consumers in northern hemisphere urban areas (*e.g.* OECD-countries) increasingly favour*local production of food*. Allegedly a number of reasons for this exist: *i.a.* better control and higher quality; support of the local market; food security; access to fresh food and less distribution costs (Granvik 2012; Queiroz, 2009; Hinrichs, 2003; Halweil, 2002). With currently only a few percent of the local food supporting the larger Western cities (Berg, 2007), cities start to investigate if food and other materials can be produced inside the city, in the urban periphery or in the region where the city is embedded (Queiroz, 2009; Halweil, 2002). An urban perspective of urban-rural interactions thus includes feasibility studies on increasing *rural food and bioenergy production* through an increased co-ordination in new regional and local *urban-rural* markets. In continental Western Europe another trend is to increase the *green areas inside cities*. To some extent this trend aims at increasing urban farming or utility gardens but also aims at increasing park areas for recreation and a range of other purposes (Egnor, Ishikawa and Silverstein, 2009; Florgård and Berg, 1997). Another such classic example is to secure free land between urban agglomerations in order to create identifiable neighbourhoods and green districts (Berg, 2010; Alexander, 1977). The trend to *increase* green areas is partly counteracted by the simultaneous *densification* trend (Berg, Granvik and Hedfors, 2012). In South-American cities like Bogota and Curitiba, a general *upgrading of public spaces* and functions has furthermore led to an increased number of citizens having contact with urban parks and other green areas – which has shown to strengthen both *recreation* and *social cohesion* (Wright and Montezuma, 2004). A particular example of low-impact design of integrated urban and rural functions is highlighted in studies about establishment and maintenance of *lawns* as an ecological and cultural phenomenon (Ignatieva and Ahrné, 2013).

A rural perspective of rural-urban interactions

A rural perspective of rural-urban interactions is also slowly emerging internationally but with diverse starting points (Artmann, et al., 2012). A large share of primary production, rural livelihoods and other rural functions of the world is still based on small family businesses trading within local consumer markets (see *e.g.* Graziano Da Silva, 2013). This is, however, quickly diminishing as large domestic or multi-national companies take over the control of primary production lands and waters. Using mainly centralized manufacturing and refinement utilities, products are sold on global markets (*ibid.*). Slowly rural researchers, authorities, practitioners and to some extent rural dwellers are realizing that arable land prices have already, due to peaking resources, increased over the last five years. This has partly caused local production and local markets to be stimulated (Granvik, et al., 2012).

In the EU's *Leader* projects, rural livelihoods are well defined and developed (Leader Regions, 2000; SOU 2005), but are rarely involved or even interested in urban issues. In the light of coming resource scarcity, rural stakeholders, however, foresee increased urban demand of *rural products and services* from multi-functional agriculture with increased income from *rural tourism* and rural services for urban dwellers (Granvik, et al., 2012; Karlsson and Rydén, 2012; Berg and Rydén, 2012). In the northern hemisphere, *rural recreation activities* (*i.a.* hiking and horse-riding) are offered as a part of rural production (*ibid.*). Another rural perspective of urban-rural interaction is local primary producers arranging *farmers' markets* in adjacent cities. A supplement to other such green jobs in farming, forestry and fisheries would be assisting in the urban maintenance of green areas, winter clearing of snow, sanding, bulldozing in new dwelling areas, pipe constructions, electrical systems installations etc. (*see i.a.* LRF, 2009). Beside primary production, protection of *nature reserves* and conservation of heritage pastoral *landscapes* is another subsidized activity of rural enterprises (Karlsson and Rydén 2012; Artman, et al., 2012). In the rural-urban perspective there is also an expectation and aspiration that the extraction of natural resources (mines, forest products, peat, hydropower) will be better reimbursed by urban consumers and enterprises in the future (*ibid.*).

A strategic boundary zone between urban and rural areas

One potential new feature of *Resilient Citylands* is the development of a new built-green-blue *boundary zone* between predominantly urban and predominantly rural areas (*see i.a.* Ahern, 2007; Moffat, 2003). Due to green/built wedges city morphology, Nordic cities have had markedly long green/blue interface *edge* between settlements on the one hand and glades, meadows, forests, parks, agricultural land, lakes, seas and

Table 1
Contemporary urban or rural perspectives of the values/functions of green-blue infrastructure (GI) (adapted from Boverket[4] (2013) and from Sandström and Hedfors (2009) including potential challenges for its interaction (harmonization) (Seitzinger, et al., 2012; Berg and Rydén, 2012).

Green-blue infra-structure *values and functions*	Urban perspective	Rural Perspective	Questions and challenges for a potential interaction (harmonization) of urban and rural perspectives on GI
1. **Recreation, Health & Social Interactions**	Urban parks and residential green areas are valuable for urban dwellers' recreation	Recreation landscapes (forests fields and waters) valuable for urban and rural dwell-ers	– How can urban dwellers become aware of and guided to rural recreation and rural dwellers be invited to urban green? How can green social arenas be designed/marketed?
2. **Biodiversity protection and development**	Urban species rich-ness and simple biodiversity[5] in parks, gardens and brownfield areas	Nature reserves with high functional biodi-versity[5] embedded in production landscapes	– How can urban and rural ecosystems and biotopes be better connected? How can stable functional biodiverse urban GI systems be established?
3. **Human Habitat structure and function**	GI is one of several urban structuring components and networks. Built struc-tures dominate	GI is the main rural structuring compo-nent (nature, produc-tive, recreation landscapes and nature reserves)	– How can urban and rural infrasystems (green-blue-, transport-, settlements- and service infrastructure) be harmonized? How can urban green be connected with public transit? How can GI network pathings be created?
4. **Cultural Identity**	Characteristic GI (*e.g.* parks) embeds historic urbanand to some extent new sub-urban centers	Open *often small-scale* agricultural landscapes, forests and waters including landscape parks are preserved[6]	– How can green heritage values (in urban parks and pastoral landscapes) pro-grams be co-ordinated between cities, towns and rural communities?
5. **Ecosystems services** (e.g. environ-mental regu-lation and climate change mitigation)	Temperature-, wind-, moisture-, water flows-, water reten-tion-, shadow- and air quality regulatory functions in public parks, green areas and waters	Water-, air-, soil clean-ing-, recycling- dissipa-tion- and en-richment capacity inplant-soil systems – in rural open landscapes, forests, lakes, streams and oceans	– How can rural regions provide its urban areas with efficient climate change protection and adaptation? How can urban and sub-urban GI be optimized to regulate micro-climate, buffer water flows and clean the air which will also affect surrounding rural hinterlands?
6. **Primary pro-duction and Ecotechnology**[7]	Urban agriculture, home gardening, collection & use of compost and munici-pal sewage treat-ment	Agriculture, forestry and fishing. Waste water- and other urban effluent nutri-ents recipient	– How can urban and rural supplementary food- and nutrient production-consump-tion (complete and *clean* recycling) be created and co-ordinated?

4 The Swedish National Board of Housing Building and Planning
5 Simple Biodiversity characterize ecosystems with many or few unrelated species. Functional Biodiversity characterize mature ecosystems with mutually interdependent and adapted species (Odum, 1989).
6 See e.g. the European Landscape Convention (ELC, 2000).
7 In The Swedish National Board of Housing, Building and Planning – the definition mainly targets recycling of nutrients, with little emphasis on e.g. rural or other food production for local urban consumption. In our understanding of this green struc-ture value, recycling includes: primary production lands and waters outside the city; large scale green wedges adjacent to the built-up areas; local city districts and neighbourhoods.

rivers on the other (Berg, 2010; 1993; Odum, 1989). Widening the edge to a broad *boundary zone* or *spatial corridor*[8] could give room for intermediary green areas suitable for neighbourhood recreation (district parks, play grounds, sports grounds, orchards and domestic animal stables). Other potential functions of this zone are peri-urban agriculture with green houses and community gardens (Queiroz, 2009). This fringe is furthermore an interesting strategic zone for a range of other new functions (Berg, 2010; Bokalders and Block, 2010; Gaffron, Huismans and Skala, 2005). These include clean technology production; combined industries including production of food, fodder, fuel and fiber; recycling of waste linked to bioenergy production; other renewable energy production (wind-, photovoltaic-, hydro- and wave power) and energy storage. The urban-rural regional interface could be termed the *outer boundary zone*, whereas the local interfaces inside the city (urban settlements turning towards parks and community forests, fields and waters) could be termed the *inner boundary zone* (Berg and Rydén, 2012).

8 If a city or town could be described as an island, the interface line or spatial corridor would correspond to the shore.

Contemporary green-blue infrastructure practice in urban-rural landscapes

Co-Evolution towards green cities

In Europe, practices of intertwining built and green-blue structures are gradually degrading in Nordic cities – but they are instead developing in central European cities. Stockholm's *green wedges* (Florgård, 2004) and Copenhagen's *green finger plan* (Berg, 1993) are now inspiring Paris, London, Berlin, Rome and Barcelona on how to find a new interaction between urban and rural interfaces, *i.a.* for the *health* and *recreation* of its citizens (Mitchell and Popham, 2008; Stigsdotter and Grahn, 2003) for improving the *ecosystems services* (Elmqvist, et al., 2013; UNEP, 2005) and even increasingly for expanding the *primary production* in, near and across the free land areas surrounding and penetrating the city (Bokalders and Block, 2010; Ebbersten and Bodin, 1997). Below a selection of cases of urban-rural co-evolution systems are presented and discussed.

Urban-rural interactions in practice

A growing number of unique and good practices may illustrate a dawning interest among planning researchers and planning practitioners around the world for contemporary interaction and co-evolution (Saifi and Drake, 2007) of *urban and rural structures, functions* and *processes*. In some practices the contextual focus is on the geographic proximity of urban consumption and its adjacent green belt's rural primary production (table 2). During a world city planning competition hosted by the University of Tokyo 2003 (Itoh, 2003, pp. 198–226), Indian architect Aromar Revi and his India 2100-delegation was granted an honorary award for their 100-year plan of new human settlements in the west-coast Goa-province. In the proposition a «*rurban*» *sustainable urban development* principle was outlined with full interaction between urban and rural landscapes – mainly for the purpose of sustainable local food and water provision and of nutrient- and water cycling. An original idea of the *Caofeidian (Tangshan Bay) Eco-city project in China* was to link adjacent agriculture primary food production with the new settlement dwellers consumption – and via a *Recycling Management Centre* refine and feed back some of the nutrients from the waste-water and organic waste to local agriculture and aquaculture (Zhang, 2010). In the Baltic Sea Region (BSR – defined by the special watershed area of 14 countries), a series of three (2003 – 2013) Interreg funded projects *(Baltic Ecological Recycling and Agriculture – BERAS I, II and III)* investigated the preconditions for sustainable local food production systems intended for adjacent urban markets (Kahiluoto, et al., 2006). In another BSR – *Ecosystems Health and Agriculture* (EHSA) (Jacobsson, 2012) – Sustainable Agriculture for Local-Regional Consumption was investigated both in a BSR context and in the North-American *Great Lakes Region* (*ibid.*). Also, in one of three Sustainable Urban Development projects in the BSR – *Baltic University Urban Forum (BUUF)* – the share of local (adjacent to cities) food to total food consumed was investigated. Western Cities were found to typically have less than 1–2 % local food consumption (up to 10 % for smaller rural towns), whereas Eastern Baltic Cities still had a high share of local life support (up to 60 % local food for the largest cities) (See Berg 2007 and Ebbersten and Bodin, 1997). In a recent national survey in Sweden, it was established that a *re-localization* of food production is supported by many Swedish municipalities and by a majority of consumers in nationwide polls (Granvik, 2012). An international contemporary vital exponent of this growing interest for urban-rural interactions and local food, is the development of *Continuous Productive Urban Landscapes* (CPULs) – where research and practice of urban agriculture design for a number of unique sustainable cities' projects was developed (see *e.g.* Viljoen and Howe, 2006). A development of this idea can also be seen in the newly launched series of *Global Urban Agriculture Summits* (2011, 2013 and next 2014), arranged by the international enterprise Plantagon, asking: how could UN- and national research level practice, -industry and -politics support a crash program for the development of (sustainable) urban agriculture for the life-support of world cities in the future (GUA, 2013)?

Green-blue-built interaction in practice

Urban-rural interactions within the more limited realm of city planning, is mainly expressed as an interaction of urban built- and urban green-blue structures (see table 2). Such interaction is only to a small extent about urban and peri-urban primary production and nutrient recycling. It also represents a range of other GI values such as recreation, biodiversity, ecosystems services, cultural identity and a structural element in the city – see table 1. In the evaluation criteria for the EU Commission's Green Capital Award, three aspects were highlighted (EGCA, 2013a): citizens' access to green recreation areas, green structure share of total urban land-use (as a measure of ecosystems services potential) and the protection of biodiversity and valuable nature areas (Natura 2000 areas). At the same time, neither local primary production for urban use nor urban agriculture inside cities and peri-urban areas constituted, as yet, a main criterion for evaluating candidate cities.

In a comprehensive report for the Institute of Behavioral Sciences and the 22nd International Gas Conference in Tokyo, the role of green-blue infrastructure for future sustainable cities was elaborately presented. The report (*Proposals for the International Competition of Sustainable Urban Systems Design)* described future images for 11 global cities: Vologda – Russia, San Diego and Tijuana – USA and Mexico, Vancouver – Canada, Lin Jing Shen and Tong Ming team – China, Numazno-Mishama and Tokyo – Japan, Goa – India, Berlin – Germany, Buenos Aires – Argentina). Each of the 8 national teams presented a 100-year plan for their contemporary cities' transformation into sustainable cities (Itoh, 2003). The Goa scenario (see also above) was the only case where *urban and rural integration in a micro-regional* perspective was the main focus. In the Vancouver proposal (see table 2), *both Urban-rural* and *green-blue-built* interaction were main features of their 100-year plan. For all other participating cities, green-blue infrastructure was a key ingredient in their scenarios, typically confined to the *urban areas* themselves. International examples of new green-blue infrastructure planning, mainly targeting urban ecosystems services, biodiversity and recreation, have been suggested for Rio de Janeiro (Herzog, 2013), for Middle Eastern cities (Egoz, Pungetti and Makhzoumi, 2011) and are already implemented as new greenways and upgraded park systems in Bogota (Wright and Montezuma, 2004). The *Cheonggyeche on stream* in downtown Seoul is a remarkable case where a 6 km linear riverside park was created when the overarching motorway was removed in the beginning of the new millennium (Landscape Architecture Foundation, 2013). Among the evaluated effects were a dramatic 50 % decrease in traffic-generated air particles, a 5 degrees lower heat island effect and – above all – a re-creational and multi-sensory experience for the 62000 Seoul-residents and 1400 tourists visiting the park everyday.

Urban-rural and Green-blue-Built interactions

A number of contemporary practices (table 2 and examples below) illustrate a more comprehensive view on urban-rural and built-green interactions. Some of the cases are close to our definition of *Citylands*. Green values were highlighted in the winning Vancouver proposal in the above mentioned world competition *Proposals for the International Competition of Sustainable Urban Systems*. Both urban-rural interactions on the *micro-regional* scale *and* green-blue-built structures interaction in different *local* scales within the city realm were mentioned (Moffat, 2003). The European Ecocities project featured seven scenarios of new sustain-

Table 2
Selected International Cases where urban-rural or green-blue-built interactions represented a conscious planning strategy for rendering human habitats more sustainable. Note that some projects have focused on regional (city-countryside) interactions and some more on local (cities and towns) green-blue-built infrastructures. A few cases describe both urban-rural and built-green interaction scales.

Case	Urban-rural (mainly regional)	Built-Green (mainly local)	Reference
Goa 100-year plan in India	A 100-year plan for a strong physical connection between settlement and production lands and waters		Itoh (2003), pp. 198–226)
World Urban Futures		Strategic Longitudinal Sustain-ability Scenarios for 11 world cities – most with green & built interlaced structures	Itoh (2003)
Vancouver Greater Region Cities^{PLUS} 100-year plan in Canada	An award-winning plan for clos-ing nutrient cycles and increasing local production in the whole region	The 100-year urban plan also targeted green and blue elements and structures in the city for multiple purposes	Moffat (2003)
EU Ecocities projects. Plans for seven European City districts.		Strong highlighting of green structure for recreation, ecosys-tems services and biodiversity	Gaffron, Huismans and Skala (2005)
Vauban district in Freiburg in Germany	Interface between urban settle-ment and surrounding fields and forests with orchards, edible gardens, streams and stables	Interaction of four scales of green within the settlement: entrance-, courtyard-, district- and wilder-ness green	Bokalders and Block (2010), p. 581
The Cheonggyecheon river restoration project in South-Chorean Seoul		Former downtown river-branch covered with motorway – since 2003 transformed to a 6 km linear river park.	Landscape Architecture Foundation (2013)
Nantes Green Plan In France	Traditional and contemporary support of local Loire-valley farmers	Advanced Green infrastructure planning for recreation, ecosys-tems services and biodiversity	EGCA (2011b)
Bogota Ciclovia		Bicycle and Pedestrian Network with 25 km greenways through parks and along the river	Wright and Montezuma (2004)
Clichy Batignolles & Jardin Partage, Paris, France		Northern Paris Central Park for recreation, ecosystems services (health) and biodiversity. 100 urban pocket gardens for small-scaleurban food production	Egnor (2009)
Eco Quartier Pfaffenhofen München Germany	Regional Eco-cycling with urban fertile clean soil production – linked to adjacent rural food and fibre- and fuel production	Multi-scale green-blue-built infra-structure integration in mixed-use community	Casselman (2007); EQ Pfaffenhofen (2013)
Nyalenda peri-urban slum in Kisumu, Kenya		Plans for New Green-blue In-frastructure in Suburban Live-lihoods – focusing on water management and temperature regulation with local trees	Brunsell (2003)
TurenscapeHoutan Park in Shanghai, China		Landscape Park transforming pol-luted and degraded landscapes and waters to attractive recrea-tion and purification landscapes	Landscape Architecture Foundation (2013); Yu (2012)

ability districts in seven European Cities – from Tampere in Finland to Barcelona in Spain (Gaffron, Huismans and Skala, 2005). Most of the cities highlighted mainly the recreational and biodiversity rationale of the proposed eco-city green-blue spaces, however, the common goals for greening of the new city districts were more encompassing than that. Four of the goals for ecocities were characteristic of both urban-rural interactions and of green-blue-built interaction: *City in balance with nature, City with integrated green areas, City of bioclimatic comfort, City integrated into the surrounding region* – but also *City with closed water cycles*.

Green Infrastructure values were furthermore emphasized on a regional level as actual *green wedges* in Nantes (EGCA, 2013b). GI values for recreation, ecosystems services and biodiversity were highlighted just as much as the value of preserving traditional Loire-valley agricultural practices for urban dwellers' use. Other EGCA Award winning cities (Stockholm, 2010 and Copenhagen, 2014) have emphasized both urban-rural regional interactions together with city integrated green-blue infrastructure values (*e.g.* recreational and ecosystems services values).

All the aforementioned cases still, more or less, possess an *urban approach* to urban-rural interaction. A fully and mutually informed co-evolution of urban and rural – and of green-blue and built areas – is still largely missing. And it is a reciprocal dependence, where the full potential of urban and rural structures, functions and processes is utilized, that we define as *Resilient Citylands*. In table 3 green-blue infrastructure values and functions were listed and selected and tentative *Resilient Citylands*' goals described. Some of our research questions were also added to illustrate the new concept and the common denominator as a *connected urban and rural approach*. Table 3, therefore, also represents a list of global challenges for landscape architecture. But *Resilient Citylands* structure and function can be exemplified also beyond more obvious green-blue infrastructure values.

Resilient Citylands in a wider perspective

The earlier described cases/examples in table 2 highlight a selection of *green-blue-built* and *urban-rural* integration cases in different scales and table 3 outlines some characteristics for *RCL* solutions – all related to green-blue infrastructure values. The following international (mostly European) cases are implicating a wider perspective of *Resilient Citylands* illustrating selected and characteristic RCL solutions for *e.g.* energy, transport and building:

1. In Japan, USA, Denmark and Germany experiments have been carried out to co-ordinate different distributed renewable energy production systems (Blaabjerg, et al., 2006). The challenge is i.a. to synchronize urban PV electricity and waste incineration heat production with rural wind power, hydropower and bioenergy heat production.

2. In Karlsruhe, Germany, a *Duo-tram* system connects urban public transport with rural regional transit – a system that combine the dual need of rural-urban commuting and intra-urban mobility (Bokalders and Block, 2010).
3. One European Green Capital award-winning feature for Copenhagen (2014 winner of the Award), was the interlinked urban and regional bicycle network, facilitating a zero-emission mobility target in the Greater Copenhagen Region (EGCA, 2013c).
4. Several of Joachim Eble Architects' award-winning sustainability plans for European urban district projects, encompass a *cityland approach* with interaction of green-blue elements in the architecture as well as plans for urban-rural co-evolution (*see e.g.* Eble (2013) about Culemborg, the Netherlands (built), Vauban in Freiburg (built), Altstadt in Tübingen (built), Ostia in Rome (plans), Tianin in Taiwan (plans)).

One of the most advanced building projects under construction with a – in principle – complete *resilient citylands* plan can be found in the new suburban district *Pfaffenhofen* north of München (EQ Pfaffenhofen, 2013). This case contains an urban-rural settlement plan under construction including an eco-housing area, a primary food production area and a local business area. The built area as a whole and its constructed elements are fully integrated with production- and recreation landscapes on four scale levels.

A full *Resilient Cityland approach* was also used for the development of a model district – *Hågaby* in Uppsala Sweden – built according to the UN Habitat agenda (UNCHS, 1996). This settlement features urban *and* rural solutions for seven main resource categories: physical, economic, biological, organizational, social, cultural and aesthetic resources (Berg, 2004; Berg, 2002).

Table 3
A Resilient Citylands approach to six listed key green-blue infrastructure (GI) values/functions (Boverket, 2013; Sandström and Hedfors, 2009). All RCL potential solutions were interpreted to be of *mutual value* for both urban and rural areas, from both a green-blue- and built infrastructure perspective. All suggested RCL goals and solutions are tentative and linked to selected key literature or on-going research (in brackets).

Green Infrastructure Values and Functions	Potential Resilient Citylands(RCL) goals and practice solutions – *with selected Research Questions and references*
1. **Recreation, Health & Social Interactions** (Berg and Rydén, 2012; Berg 2010; Thompson, 2000)	Recreation, healthy environments and social interactions are commonly sought by all citizens in *both* urban parks *and* rural landscapes. *How can urban parks and rural city-near restorative forests, fields and waters be planned and designed to connect in the urban-rural fringe zone? How can such fringe zones be developed for a majority of urban and rural dwellers in several RCL scales (region, city, community – see 3 below)? How can active RCL guidance[9] of citizens be carried out for both urban and rural dwellers' recreation?*
2. **Biodiversity protection and development** (Ignatieva and Ahrné, 2013; Hedfors and Florgård, 2012)	Biologically valuable ecosystems are protected and displayed for citizensin urban parks *as well as* in rural natural and cultural landscapes. *How can RCL green-blue areas and its network pathing– ranging from dense urban centers to sparsely populated rural areas – better be integrated and represented? How can connected species richness and functional diversity be described for urban and rural dwellers, i.e. as highly versatile maps over multi-functional, connected green-blue spaces?*
3. **Human Habitat Structure and Function** (Seitzinger, et al., 2012; Berg, 2010; Bokalders and Block, 2010)	Attractive and functional infrasystems are interlaced and co-planned: built-, green-, transport-, technical- and service infrastructures. *How can an appropriate and efficient reciprocal green-blue-built matrix be realized in Human habitats? How could a transition –* ***from*** *peripheral green belt –* ***to*** *radial green-blue wedges structure in future urban areas – be put into practice? How can systems of green-blue wedges reaching in towards urban centers and built wedges reaching out into surrounding rural landscapes be co-ordinated?*
4. **Cultural Identity** (Ignatieva and Stewart, 2009; Ignatieva and Ahrné, 2013)	Well-defined urban and rural heritage values are made available for all citizens. *How can historic city centers´ buildings and parks be easy accessible and pedagogically displayed for urban-, sub-urban- and rural dwellers? How can valuable heritage-, culturally molded and natural rural landscapesbe rendered easily accessible and pedagogically displayed for all citizens? How can heritage park- and garden design and future sustainability planning be reconciled?*
5. **Ecosystems Services** (environmental regulation and climate change mitigation) (Elmqvist, et al., 2013) (UNEP, 2005)	Urban and rural environments are co-ordinated, in order to make full use of appropriate regulatory ecosystems services. *How can urban and rural green-blue infrastructure help creating more resilient and comfortable human habitats? How can cities, districts and local communities benefit from the temperature-, moisture-, sun protective- wind-, water flows- and air quality regulating capacity of forests, parks, green courtyards-, alleys-, trees-, shrubs-, and soil microbial ecosystems? How can cities, towns and rural communities be adapted for future climatic and environmental conditions?*
6. **Primary Production and Ecotechnology** (Granvik, et al., 2012; Berg, 2010; Casselman, 2007)	A complementary primary production and recycling system is created by combining urban and rural food-, fodder-, fiber- and fuel production capacities. *How can a supplementary system of urban high-value food- (leaf vegetables and fruit) and rural bulk production of (i.a. grain and root vegetables) be created? What is the long-term role of re-localization of food, materials and water recycling? How can urban waste obtain a quality sufficient for fertilizing food crops? How can clean and fertile soil be created from urban organic waste and charcoal – for use in green urban areas and rural primary production? How can a transformation from water- to soil recipients for sewage effluents be achieved? What are the comprehensive roles of urban agriculture in the global food system?*

9 Guidance refer to i.a. signature design of tram-stops and sign-posts, IT-screens and mobile apps guiding urban and rural dwellers to urban and rural recreation.

Risks and potential weaknesses with RCL

This paper suggests that *Resilient Citylands* may be a useful concept for describing a modern version of harmonized and mutually supportive urban-rural landscapes. In general this concept is about production, dwelling, culture, transport and energy and, in particular, for a mutually beneficial utilization of the functions and values of green-blue infrastructure. In this paper we see *re-localization of markets* as an important driver for the formation of *Resilient Citylands*. But as for all innovative conceptions, the new approach may in practice backfire, be misinterpreted or just generate unexpected problems and even threats – see *e.g.* Peter North's elaboration on the geo-political critique of localization as a strategy for abating climate change (North, 2010). Re-localization of *markets* may for instance lead to *higher prices* and a more limited *range of commodities* than what can be offered on a (ideally speaking) perfect competitive market. If RCL mean smaller and more geographically confined local production markets, their *vulnerability* may be greater compared to larger regional or global markets. Local markets can also be seen in a perspective of *protectionism* and may potentially adoptan *authoritarian* local governance (*ibid.)*.

Trying to inform and attract citizens about urban *and* rural recreation or heritage values in the landscape (see table 3), may furthermore not be in line with public preferences. Some people may actually be more or less urban *or* rural. Assuming there is a risk that municipal planners or politicians adopt a static or *universal* view on *Resilient Citylands*' ideal structure and function*,* may furthermore overlook the *contextual* reality in cities, towns and local communities. This may result in an inefficient use of resources. In some areas, it may for instance be appropriate to develop a 10 % local food production or local labour market, in other locations it is more justified to produce 30 % of the local food and 50 % of the workplaces within the micro-regional context (Berg, 2007). The meaning of *local* is also relative. Sometimes it is reasonable to refer to the *community level*, in other circumstances the *macro-region is the appropriate local market* for urban – rural interactions (North, 2010). *Resilient Citylands* is not always suggesting geographic proximity – but is sometimes represented rather by a consciousness among planners about urban-rural connections.

Discussion

In this paper we have elaborated on, and with actual cases tried to demonstrate, how a modern integration of urban and rural areas and of built and green-blue infrastructures may transform human habitats to a state we call *Resilient Citylands*. With increasing global resources scarcity and an aggravated environmental crisis as drivers (IPCC, 2013), we suggest that *Resilient Citylands* may constitute a partly new sustainability focus for landscape architecture. This involves a modern geographic structural, functional and processes urban-rural integration (Seitzinger, et al., 2011) and co-evolution (Saifi and Drake, 2007). A fundamental idea of the *Resilient Citylands* concept is that urban and rural activities can supplement each other in more elaborate, efficient and profitable ways than they do today. We have tried to show that such *Resilient Citylands* interactions can occur on *larger regional scales*, *city scales* or on *local community scales* within towns, city districts or local neighbourhoods. A transformation towards *Resilient Citylands* can be enhanced by*re-localization* of markets – *i.e.* a relative displacement of primary production-recycling systems – from global to macro-regional (*i.a.* the Mediterranean or Baltic Sea macro-regions), to micro-regional (*i.a.* European Union NUTS regions), to city levels and to local community levels.

We have offered a preliminary definition of the structural, functional and process properties of *Green-blue Infrastructure* and we have defined *Resilient Citylands*. We have tried to clarify that Landscape architecture has throughout its history emphasized the strong link between urban and rural functions as well as the reciprocal interdependence and values of built- and of green-blue infrastructure values. Our examples demonstrate a growing international and municipal interest of urban and rural interactions and of green-blue-built infrastructure for a number of reasons: for recreation, to preserve biodiversity, to develop and maintain a functionally efficient and aesthetically attractive human habitat structure, to protect heritage values, to release ecosystems services and to secure a resilient primary production and recycling.

We propose the *Resilient Cityland* concept as a tentative working hypothesis for integrated and more sustainable urban-rural and built-green-blue systems, with its potential *strengths and weaknesses*. Our ambition is to continue our current research and provide nuanced cases, which may enrich and rectify our new preliminary green-blue-built infrastructure concept. We hereby also invite a scientific discussion and an emergent collection of examples which may support, criticize and develop our understanding of what can create truly sustainable human habitats.

We have also with our cases tried to show that *Resilient Citylands* cannot be expected to be universal but probably have a *contextual expression*. Landscape architecture is particularly suited to criticize and elaborate on the *Resilient Cityland* concept, for its utilisation in city-, rural- and community planning as well as for the purpose of design and implementation. Chinese landscape planner Kongjie Yu has over the past decades started to transform the concept of progress in China – from «small-foot» (as in traditionally tied Chinese girl feet) to «big foot» approaches, where landscapes are liberated to invite natural flows and processes – landscapes that are built for settlements that can resiliently master expected climate change induced perturbations and regain their function over and over again (Yu, 2012). Yu has had a notable impact, while introducing these aspects in current Chinese planning, much like Frederick Law Olmsted had in the United States 150 years ago. Yu, renowned also in the global Landscape architecture community for combining Architecture and Ecological infrastructure in Landscape architecture, has a motto for planning resilient human habitats: «Begin with the ecological (green-blue) infrastructure».

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Biographical information

Per G. Berg
Professor in Landscape
Planning
Department of Urban and Rural
Development, Swedish University
of Agricultural Sciences
Address: P.O. Box 7012
SE-750 07 Uppsala, SWEDEN
Telephone number: +46 18 67 25 13
E-mail: per.berg@slu.se

Professor in Landscape Architecture with a special focus on Sustainable Community Development in Urban and Rural settings. He is working at the Department of Urban and Rural Development, Unit of Landscape Architecture, Swedish University of Agricultural Sciences. Expert in the European Commission's European Green Capital Award Committee. His latest FORMAS funded research project is «Functional Density – A critical study on densification as a sustainability strategy in ordinary local Swedish urban townscape areas». The Swedish Institute has financed a pre-study on «Resilient Citylands».

Biographical information

Madeleine Granvik
Researcher and Theme leader in Sustainable Development and Management of Urban-Rural Interactions
Department of Urban and Rural Development, Swedish University of Agricultural Sciences
Address: P.O. Box 7012
SE-750 07 Uppsala, SWEDEN
Telephone number: +46 18 67 19 50
E-mail: Madeleine.Granvik@slu.se

Human geographer from Uppsala University. She holds a PhD in Landscape Planning and is currently a researcher in Sustainable Development and Management of Urban-Rural Interactions at the Department of Urban and Rural Development, Unit of Landscape Architecture, Swedish University of Agricultural Sciences. She is a theme leader in SLU´s Future Research Programme: Future Urban Sustainable Environment (FUSE) in the field System landscapes – from region to urban districts. Her latest FORMAS funded research project is «Functional Density – A critical study on densification as a sustainability strategy in ordinary local Swedish urban townscape areas». The Swedish Institute has financed a pre-study on «Resilient Citylands».

Biographical information

Per Hedfors
Researcher in Landscape Architecture Theory
Department of Urban and Rural Development, Swedish University of Agricultural Sciences
Address: P.O. Box 7012
SE-750 07 Uppsala, SWEDEN
Telephone number: +46 18 67 25 28
E-mail: Per.Hedfors@slu.se

Landscape Architect, Swedish University of Agricultural Sciences (SLU). He holds a PhD in Landscape Architecture and is currently a researcher in Landscape Architecture, with focus on theory, at the Department of Urban and Rural Development, Unit of Landscape Architecture, Swedish University of Agricultural Sciences. He is presently a partner in the FORMAS funded research project «Functional Density – A critical study on densification as a sustainability strategy in ordinary local Swedish urban townscape areas». The Swedish Institute has also financed a pre-study on «Resilient Citylands».

Biographical information

Maria Ignatieva
Faculty Professor in Landscape Architecture
Department of Urban and Rural Development, Swedish University of Agricultural Sciences
Address: P.O. Box 7012
SE-750 07 Uppsala, SWEDEN
Telephone number: +46 18 67 25 08
E-mail: maria.ignatieva@slu.se

Professor in Landscape Architecture, Department of Urban and Rural Development, Unit of Landscape Architecture, Swedish University of Agricultural Sciences. Honorary doctor of St. Petersburg State Forest Technical University, Russia. She did her Master in Landscape Architecture in St. Petersburg and PhD in botany and urban ecology in Moscow State University. In Russia, then in the USA, New Zealand and now in Sweden Maria continued working on the investigation of different urban ecosystems and developing principles of ecological design. Her latest FORMAS funded research project is «Lawns as ecological and cultural phenomenon: searching for sustainable lawns in Sweden». The Swedish Institute has financed a pre-study on «Resilient Citylands».

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URBAN GREEN INFRASTRUCTURE FOR CLIMATE BENEFIT: GLOBAL TO LOCAL

NANCY D. ROTTLE

Abstract

Urban Green Infrastructure can be especially beneficial in addressing climate change challenges to our cities. Five systems of green infrastructure – social, biological, hydrologic, circulatory, and metabolic – provide integrated, multiple benefits. These systems may mitigate anthropogenic impacts to climate through reducing greenhouse gases in the atmosphere while simultaneously helping to reduce the inevitable negative effects that climate change will have on urban environments and populaces. The paper outlines forthcoming climate change challenges and describes the capacity of each of the five systems to provide multiple, overlapping benefits. It then analyzes each system's capacity to contribute to global climate mitigation while diminishing local adverse impacts to urban contexts, supported by relevant projects with examples from North America, Asia and Europe. The paper concludes with propositions for adaptive mitigation and considerations for incorporating green infrastructure in urban planning and design.

Key words:
Green infrastructure, climate mitigation, climate adaptation

Introduction

Climate change has been called the defining issue of the twenty-first century, with cities seen as both solutions for reducing overall greenhouse gas emissions through compact development, as well as the places most dramatically and tragically impacted and therefore most critically requiring adaptive practices. However, for the most part, attention to climate change mitigation has focused on the reduction of greenhouse gas emissions and carbon sequestration at the global scale – most clearly advanced through international agreements such as the Kyoto Protocol – while local climate change policy and plans tend to focus on adaptive responses to predicted climate change impacts, such as sea level rise, water shortages, or compromised gray infrastructure performance. Yet in the urban context at the local level, green infrastructure practices may both protect the overall global climate by mitigating or reducing destructive anthropogenic greenhouse gases while simultaneously providing adaptive buffering from inevitable climate change impacts.

Existing and increasing CO_2 levels in the atmosphere will precipitate inevitable climate change impacts to most parts of the earth. While anticipated impacts vary from region to region around the globe, the International Panel on Climate Change (IPCC) predicts possible scenarios accompanying low, medium and high growth of carbon emissions, with related potential increases in temperatures by the end of the next century ranging between 1.1C and 6.4C. Even with holding CO_2 emissions steady the planet will increase .5C degrees since the greenhouse gases already emitted will remain in the atmosphere and will have a warming effect (IPCC, 2007).

While predicted impacts vary by region, increased temperatures worldwide in both summers and winters are anticipated, with exaggerated effects at the higher and lower latitudes. Temperature rise will cause increased soil evaporation, the likelihood for summer drought, and accompanying demands for water use; in regions that rely upon snowpack for water supply, less winter snow accumulation will reduce the amount of available summer water needed for irrigation, plant survival and human comfort. This change in temperature and water regimes will add stress to ecosystems such as forests, wetlands, and streams and the species that are adapted to existing environmental conditions, reducing overall biodiversity, favoring pest invasions, and especially impacting sensitive species. In addition, higher summer temperatures will be exacerbated in urban areas, where the «urban heat island effect» (UHI) already raises temperatures. In addition to the warmth-retaining mass and surfaces in cities, waste heat emitted from industrial operations, vehicles, and air conditioning raises temperatures in urban areas. The UHI can have dire implications for urban populations, especially the many with vulnerabilities and without mechanical cooling; humans are able to survive only within a narrow range of body temperatures, as became apparent in the

2003 heat wave, or «Canicule», in Europe which was responsible for the loss of over 70,000 lives. Not only is the number of extreme heat days in cities increasing, but they are predicted to cluster in heat waves that disallow the periodic cooling required for human health and survival.

Stronger storms and wetter winters are also predicted with a warming climate, bringing increased flooding as well as river and stream erosion, further threatening human health and biodiversity. Sea levels are conservatively predicted to rise .18 to .59 meters (IPCC, 2007) within the next century, inundating productive lowlands and coastal cities housing a significant portion of the world's population, as well as exacerbating storm flooding and causing sewer back-ups in urban areas. It is worth noting that the 2007 IPCC estimate does not account for potential ice sheet flows or climate-carbon feedbacks, and more recent estimates of sea level rise by 2100 is one to two meters. In a world where over half of the population lives in urban areas, and with this fraction growing, climate change is certain to dramatically impact the lives of significant numbers of people, as well as the organisms and systems upon which they depend. The question is not whether there will be adverse environmental and human consequences, but how extreme they will be.

Despite these predicted impacts and the clear scientific consensus that climate change is at least in part anthropogenic, global attention and action to minimize the intensity of altered conditions and to prepare for their inevitable effects is stalled. Obstacles to action by both the populace and their governments include the gradual timeframe and uncertainty of the severity of future impacts; the enormity, complexity and variability in projected impacts that make future conditions difficult as well as unpleasant to consider; the potential near-term costs coupled with the non-immediacy of the problems; doubt about anthropogenic genesis of climate change propagated by purposeful climate sceptics; stalemates between governments that disagree on the actions that need to be taken; and the generally depressing prospect of so much damage that is being wrought by our individual and collective actions, which discourages many people from engaging the issue. With such looming grand challenges, and so many seemingly insurmountable obstacles, how might Urban Green Infrastructure benefit our global and local climates? I assert that, while it is by no means a panacea by itself, green infrastructure can contribute positively, adding to a suite of practices that must be taken up in order to reduce the severity of climate change in the next century, as well as to aid urban populations in adapting to its inevitable negative effects. In this paper, I argue that Urban Green Infrastructure (UGI) has two inherent attributes that recommend it as an important component in addressing climate change. First, UGI serves multiple functions, making it cost-effective, aesthetic, and desirable regardless of its relationship to climate change, and thereby potentially much less politically charged, costly or unpleasant to undertake. Second, green infrastructure can simultaneously address both *mitigation* – reducing the overall degree of global climate change – and *adaptation,* that is, helping humans to cope with some of the impacts of a warming climate that are already upon us. This paper examines these two perspectives in its contention that Urban Green Infrastructure is an important land-based strategy that should be employed as cities are planned, designed and retrofitted. I define green infrastructure operationally as a set of five systems: social, biological, hydrologic, circulatory, and metabolic. The research question is: What is the capacity of each of the five systems of Urban Green Infrastructure to provide multiple, overlapping benefits, and what are each system's potential for addressing both climate change protection (mitigation) and adaptation? The paper ends with propositions and considerations for employing green infrastructure as a critical strategy for addressing climate change challenges in the urban environment.

Urban Green Infrastructure Providing Multiple Benefits

The definition of green infrastructure has evolved from primarily signifying large scale, undeveloped spaces surrounding communities – greenbelts, greenways and agricultural lands that provide ecosystem services, as first described by Benedict and McMahon (2006)[1] – to its application to cities as articulated by Girling and Kellett (2005): «*the entirety of urban green spaces*» that *«performs a multitude of vital environmental services in cities»*. Green infrastructure is also a term used to signify a natural-systems approach to utilities, which employs natural forms and processes such as detaining and filtering stormwater in vegetated swales and reducing impervious surfaces to increase infiltration; terms such as «high performance infrastructure» (New York City and Design Trust, 2005) and «green stormwater infrastructure» (Seattle, Green Stormwater Infrastructure, 2012) are synonymous to this connotation. A European team reviewed literature on green infrastructure and summarized it in a definition that encompasses urban to rural networks that comprise both built and natural ecological systems, where green infrastructure is: «*...considered to comprise of all natural, semi-natural and artificial networks of multi-functional ecological systems within, around and between urban areas, at all spatial scales*» (Tzoulas, et al., 2007). In this paper I use this comprehensive spatial and system definition, adding to it the recognition that green infrastructure provides services that benefit both humans and other species:

> *All natural, semi-natural and artificial networks of multi-functional ecological and low-impact systems within, around and between urban areas that provide services while promoting the health of humans and their related environments.* (Rottle and Maryman, 2012).

1 Benedict and McMahon first described green infrastructure as «the interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife» (2006, p. 1).

Further, Urban Green Infrastructure can be identified as five critical systems: social, biological, hydrologic, circulatory and metabolic, with all referring to the outdoor spatial and physical environment of the city. I describe each of these systems below:

The **Social System** is comprised of the community outdoor spaces, especially public, that provide places to play, meet, celebrate, exercise, eat, drink, express, debate, and reflect. They are the portions of the public realm that bring comfort, delight, connection and health to urban dwellers; they are the spaces that make us want to live in cities, which in turn aids us in minimizing our personal ecological footprints compared to suburban and rural living. It is a commonly held notion that compact cities are more sustainable than sprawling metropolitan regions, since residents in compact settlements typically consume fewer resources; yet, a system of accessible, highly functioning community spaces is essential to attracting residents from the suburbs and making a city livable and lovable, critical qualities of a truly sustainable city.

The **Biological System** provides spaces and qualities that support multiple species, enhancing a region's characteristic biodiversity. Often built in former biologically rich environments, cities typically degrade ecological integrity and impede critical flows; however greenbelts and continuous tree canopies, riparian corridors and shorelines, large patches of native vegetation, and even small scale plantings and water flows can provide essential ecological connectors through urban areas. Taking steps to fortify the biological health of the urban environment can reduce the inherent urban stresses on life forms, which are exacerbated by the effects of climate change such as increased heat and altered water regimes; urban forests not only provide shelter and food but also act as temperature regulators. Biologically rich landscapes and the species they support also afford human contact with nature in the city, providing significant restorative and educational benefits through these experiences.

The **Hydrologic System** encompasses water as a resource as well as the health of aquatic environments. Five «waters» can be considered for these purposes: clean water source for drinking; stormwater, or rainwater that falls on urban surfaces; greywater, which is water that has been used for functions such as washing and is easily recycled for other uses; black water, or sewage; and aquatic environments. The first four can be seen as resources, reducing demand through reclamation and providing redundant urban water sources. If not managed well, these waters can have deleterious effects on aquatic environments through pollution, scarcity and altered hydrologic regimes, while on the other hand, they can be used to enhance aquatic habitats through ecological design. A green infrastructure approach to the hydrologic system implies that we can apply new ways of harvesting, re-using and treating water, especially as it becomes a scarcity, while also minimizing impacts to and enhancing habitats as well as providing aesthetic amenities.

Considering water as part of a «closed-loop» system where it is recycled and re-used can be a helpful framework for hydrologic resource conservation.

Active transport is the green infrastructure focus of the **Circulatory System**. This system includes cycling networks and facilities, and pedestrian environments that encourage walking and lingering in the urban public realm. If designed well, both of these modes also serve to connect people from their homes to work and school and to public transit nodes, creating safe and more inviting environments and flexible, well-connected networks of movement through the city. Use of active transport rather than automobiles can not only increase health of the environment and atmosphere, but, importantly, can also contribute to human health by engaging people in daily physical activity. Recreational bicycling and walking trail networks are also important parts of the system, significantly adding to a city's liveability and desirability, as confirmed by their current popularity demonstrated by real estate values and sales of housing near to these amenities.

The **Metabolic System** consists of energy-producing elements that have minimal impacts to the Earth's deteriorating climate. In the Urban Green Infrastructure rubric this includes elements such as small-scale energy generators that harness natural processes and which can be used in the urban environment, such as wind turbines on buildings and in parks, solar hot water heating and cooling, and photovoltaic mechanisms. Such generators can also potentially send energy back to the grid. Importantly, this category also features the urban food system, which supplies the food that we metabolize for our personal energy with minimal atmospheric impacts of transport, processing and packaging. The urban food system includes urban and community gardens, farmland on the urban fringe, and farmer's markets that bring local food from the grower to the consumer.

While each of these systems can provide numerous human and environmental benefits, the hallmark of Urban Green Infrastructure is its multifunctional performance. Where traditional infrastructure typically addresses a single system with a sole function, green infrastructure most often serves multiple functions and provides more than one ecological service. An example of this multi-functionality is urban forests, which simultaneously yield several benefits: delivering climate control through shading buildings, streets and people; providing habitat for birds and other arboreal species; reducing stormwater runoff and erosion by intercepting rain and evapotranspiring it; improving air quality by removing particulates; and enhancing the aesthetics, spatial definition and comfort of urban community spaces. Like urban forests, other green infrastructure features – on scales from park systems, to pedestrian and cycling streets, to living roofs – address multiple systems and values simultaneously. In this way, they are cost effective approaches to not only solving environmental issues, but also providing the amenities that people enjoy and want to support. Green infrastructure systems are also often less expensive than their gray counterparts; a study by American Rivers and partner organizations determined that green infrastructure techniques can be less costly to implement while also reducing stormwater treatment, energy, flooding and public health expenses (American Rivers, et al., 2012). If the finances now spent to build and maintain gray infrastructure such as pipes, vaults, and transmission lines, to repair flood damage, and to provide health services related to sedentary lifestyles and contaminated water were instead spent on implementing green infrastructure, our cities could be rendered more ecologically sound, healthful for people, and environmentally legible and delightful.

A corollary to the affordability of green infrastructure is that it often augments rather than replaces gray infrastructure, reducing scale costs and providing redundancy in a system that therefore lends it resiliency in severe situations. For example, cities may still require pipes to carry the highest stormwater flows in heavy storms, but the use of rain gardens, street trees and permeable surfaces can reduce the size of these expensive pipes and vaults and decrease the number and severity of flooding events. Similarly, allocation of street lanes to cycling and safe, enjoyable pedestrian environments can reduce the wear and tear and accompanying costs that vehicles generate, while also providing an alternate mode of mobility when traveling by motorized means might be constrained by weather or catastrophe. With such redundancy, if one system is hindered another can take over without losing essential function, imparting resiliency in a city's infrastructure.

With these multiple overlapping benefits, it can be seen that regardless of political persuasion or climate change beliefs, it is advantageous to plan, design and implement Urban Green Infrastructure to render cities safe, livable, and healthy, with potential secondary benefits to the global atmosphere and towards resiliency to climate change impacts.

Addressing Climate Change Mitigation and Adaptation

In their 2007 article Swart and Raes posited, *«the question is not whether the climate has to be protected from humans or humans from climate, but how both mitigation and adaptation can be pursued in tandem»* (p. 301). Discovering and implementing methods for adapting to climate impacts while also reducing the severity of those impacts – e.g. mitigating the degree of human-caused climate change – is a critical planning principle to address climate change in the built environment. The IPCC defines *mitigation* as «*anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases,*» while *adaptation* is the «*adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities, that is, how organisms can cope with the actual impacts of climate change such as increased heat, floods, drought, and rising seas* (IPCC, 2007, p. 869). Practices that protect the climate, especially through reduction of greenhouse gases, tend to affect the global environment, while adaptive strategies are more likely to operate at the local level.

In his book *The City and the Coming Climate* (2012) Brian Stone argues that the IPCC definition of mitigation lacks inclusion of land-based strategies that can help to minimize climate change impacts, and contends that such strategies are significant in their potential to decrease the overall severity of climate change as well as its deleterious impacts on human health and well-being, going so far as to say *«land-surface changes are the single most effective option available to cities to counteract the very real threats of climate change in the next half-century»* (p. 99). Robust systems of Urban Green Infrastructure provide land-based strategies that will typically simultaneously address both mitigation and adaptation, and therefore this rubric provides a powerful and easily deployed conceptual tool for guiding planning and design policies. Below I examine each of these systems separately to evaluate if and how they might help to protect the climate, and how they can help humans adapt to climate change impacts. I first examine each system's capacity to *mitigate* the severity of future climate change, primarily through reduction of greenhouse gases, and then survey the capability for green infrastructure to decrease or help humans *adapt* to the negative effects of irreversible impending climate patterns.

Climate Change Mitigation

First, in examining the Social System for its ability to protect climate, I have reasoned in the preceding section of this paper that community and open space supports livable, compact urban form. Such compactness of settlement is required to feasibly support public transport systems and can generate close-knit social communities, enabling people to drive less and thereby reduce carbon emissions. Providing access to amenities such as gathering spaces, play areas and contact with the natural world in the urban context attracts people to choose this compact form, to live in cities, generating smaller individual «ecological footprints» that can be achieved through shared residential housing as well as from use of public transit and active transport. Open space advocate Mike Houck from the Portland Green spaces Institute has reversed Thoreau's famous aphorism about wilderness, quipping, *«In livable cities lies the preservation of the world.»* Cities such as Amsterdam and Copenhagen have recognized the import of green space in their «finger plan» growth planning, with both cities designating urban development to occur along fingers of transit corridors separated by generous green space in the «webbing» between the urbanized fingers, providing easy access to open spaces from cities and towns. Copenhagen's 1947 Regional Plan (or «The Five Finger Plan») is based upon goals that the public should be able to easily access nature as well as transportation infrastructure. A contemporary summary of the plan describes its intent that «*People should have the possibility to enjoy forests and lakes, agricultural landscapes, rivers, streams and fjords and still benefit from the close proximity to the city centre.*» (Copenhagen Capacity, 2012). Contemporary Vancouver, B.C. is a model of a dense residential city center with ample open space, from large forest reserves to small pocket parks, connected by a continuous public shoreline and bicycle trail, which together with protection of views between thin residential towers provides the context for an exceptionally high quality of compact urban life.

The Biologic System directly contributes to climate mitigation through carbon sequestration in soils and vegetation, and indirectly by cooling buildings and cities so that fewer fossil fuels are used for air conditioning. Mature, large trees have been found to proportionally sequester more carbon than newly planted small trees (Nowak and Crane, 2002). One 12" diameter tree sequesters an average of 17 pounds of carbon per year (equivalent to an average of 63 passenger car miles), while a 30"

Figure 1
Vancouver, B.C. Canada is regularly rated one of the world's most livable cities, with high-density podium towers, carefully planned views and connected green spaces and a continuous public shoreline.
PHOTO: NANCY ROTTLE

diameter tree will sequester 92 pounds of CO_2 annually, or equivalent to the carbon emitted in 337 vehicle miles. Planted areas, including the organic components of soil, and green roofs can also contribute to carbon sequestration in the city. A study of a dozen extensive (thin substrate) green roofs over two years found that the carbon dioxide sequestered in both above and below ground biomass averages 375 g carbon per sq. meter (Getter, et al., 2009). In addition to removing greenhouse gases from the air, a large tree shading a western wall can save 268 kWh of electricity per year in the Midwestern US, and 3,430 kBtu annually for heating and cooling (McPherson, et al., 2006), with concomitant reduction in carbon emissions that would otherwise be produced through burning of fossil fuels to produce that energy. The vegetation and soils in green roofs and walls can also help to reduce energy consumption in buildings by insulating them from heat, cold, and solar radiation. One study modeling energy consumption in Houston buildings found that green roofs in that city could reduce natural gas consumption by 11 %, due primarily to cooling (Sailor, 2008).

Carbon is also stored in the wetland, stream and «green stormwater» environments of the Hydrologic System, both above ground in the bodies of aquatic plants, and in the organic, humus-rich wetland soils that retain carbon. Additionally, use of green stormwater infrastructure can significantly reduce the CO_2-intensive manufacturing process of concrete catch basins, pipes and vaults, while infiltrating water and using the microbes in soils and plants to treat water close to where it falls can reduce energy required to pump stormwater to a receiving water treatment plant. In a study of energy used to treat wastewater in Illinois, it was estimated that 1,300 kWh of electricity is required for treatment of each million gallons of wastewater (NRDC, 2009). When stormwater is harvested for onsite re-use, energy required to pump potable water from afar can also be significantly reduced. The energy to convey, treat, and distribute water in Southern California is calculated at 12,700 kWh per million gallons of water used (California Energy Commission, 2005); replacing transported water with that from water harvested from rainwater, graywater (such as air conditioning condensate) and wastewater could significantly lower that carbon-generating energy footprint.

Seattle's Residential Rainwise program is an example of simultaneously reducing stormwater in the combined sewer system while also promoting rainwater harvest and re-use. Residents living in prioritized combined sewer basins are eligible to receive monetary assistance of up to US$ 3.50 per square foot of impervious surface managed by installing rainwater cisterns to collect and hold rooftop water and by collecting runoff in «raingardens» that infiltrate stormwater which would otherwise flow to the wastewater treatment plant (Seattle Rainwise, 2012).

In the Circulatory System, the carbon reduction benefits of walking and cycling compared to driving personal vehicles are obvious. A conservative estimate of the amount of CO_2 emissions saved through cycling rather than taking car trips in the EU is 11 million tons (European Cycling Federation, 2011). Well-designed pedestrian environments also encourage use of public transit. The environmental conditions of the «walksheds» around transit stations can encourage or deter use of buses, trolleys and trains: streets that are human-scaled, safe, protected from unpleasant elements of weather and noise, and that offer comfort, interest and delight best support walking and transit use. Cycling facilities such as bicycle parking, and buses and train cars that accommodate bicycles, further support the use of active transport for commuting. Copenhagen's traffic division prioritizes the bicycle as the form of urban transport, with over 50 % of all trips within the city taken by bicycle (City of Copenhagen, 2011a). With over 35 % of commute trips taken by bicycle, the region's planners have instituted Cycle Superhighways connecting regional towns to the city, to raise the mode split in further favor of daily bicycle trips to work and school. New York City's closure of over a mile of Broadway has been enormously successful in accommodating and spurring greater pedestrian and bicycle use in the center of Manhattan. Within the first year after street improvements were made, not only did pedestrian use increase while injuries were reduced, but travel speeds for vehicles also improved (New York City, 2012). Such shifts in conditions to favor walking and cycling can significantly reduce the carbon emissions generated in a metropolitan region.

Energy production by alternative local sources in the Metabolism System also has clear climate benefits. Well-functioning small scale, in-place energy production such as solar and photovoltaics, micro-hydro, wind turbines, and heat from burning urban forest waste can be used efficiently without loss of energy from transmission, with ample reduction in greenhouse gas emissions potentially achieved compared with burning coal and oil. Climate protection can also be significant through sourcing food – which provides human energy – through local urban agriculture systems compared to industrial agriculture; fewer «food miles» and less fossil fuels used for pesticides, herbicides and packaging produce fewer greenhouse gases, while support of local agriculture through farmer's markets, allotment gardens and farmland preservation measures can preserve and build carbon sequestering soils.

Providing opportunities for residents to grow food, to engage in urban agriculture, and to purchase locally produced agricultural products in an accessible urban food system can therefore contribute to climate mitigation. Seattle's «P-Patch» program and its numerous Farmer's Markets provide such an example of a robust local food system. The city's P-Patch program makes available over 75 community garden spaces located throughout the city's urban neighborhoods which residents rent to grow food and flowers, with over 20,000 pounds of excess produce donated to local food banks in 2011 (Seattle P-Patch, 2012). The most recent «Upgarden» has been built upon the top of a 1960s parking garage in the city center, providing over 30,000 square feet of gardening space for neighborhood residents. The City also sponsors several market gardens, where gardeners, many who are immigrants, grow produce that is sold as community supported agriculture (CSA) subscriptions to augment personal incomes (Seattle Market Gardens, 2012). Over a dozen farmer's markets spread throughout the city provide access to local food while supporting livelihoods of urban and rural small-scale farmers.

Figure 2
Seattle's new «Upgarden» is a community garden created on the roof of a 1960s parking garage in the city center, with a vintage car serving as a planter. The garden is one in a system of over 75 urban community gardens.
PHOTO: NANCY ROTTLE

To summarize the above analysis, practices within each of the five green infrastructure systems can effectively contribute to climate change mitigation, lowering the amount of greenhouse gases in the atmosphere and therefore potentially easing the future adverse conditions that climate change will produce. With such practices taken up worldwide, and combined with other significant measures to reduce greenhouse gas emissions, we might expect to cope with low-emission rather than high-emission scenarios, which vary dramatically in anticipated temperature and sea level rises.

Climate Change Adaptation

Next, this examination takes a similar approach to evaluating the value of each of the five green infrastructure systems for climate *adaptation*, briefly assessing each system's utility in mollifying local and regional impacts that are predicted to occur, whether within the current concentrations of CO_2 in the atmosphere in low-impact scenarios, or with an increase in atmospheric greenhouse gases that will result in higher-impact scenarios. Incorporated in these analyses is the likelihood of a robust green infrastructure system to imbue resilience in a metropolis, which will be required to cope with extreme events such as high heat – already an issue with growing urban heat island effects – as well as the gradual degradation of ecosystem health.

First, can the Social green infrastructure system help us to adapt to, or minimize the consequences of climate change? If the global population continues its predicted pattern to inhabit cities, then social space may provide significant benefits, especially in aiding the urban populace to cope with extreme heat events. Without air conditioning – which many will lack due to the cost of energy, or blackouts precipitated by extreme heat – outdoor spaces may provide refuge from the stifling heat that can accrue in indoor spaces, and therefore save lives. Social space may also facilitate neighborhood residents in coming to know each other, thereby building community strength that is critical in coping with catastrophic events such as high heat, flooding, and power failures. Interpersonal relationships can be especially important to the elderly and infirm who rely on special services to survive; attention from neighbors in the absence of these services can be a matter of life and death. In the European heat wave of 2003, it is thought that many elderly died not only as they lacked air conditioning to cool nights, but also because their families were away on holiday and therefore unable to check on them (Stone, 2012).

Many cities are incorporating water features in new public parks and plazas, recognizing the aesthetic draw of water as well as the relief it provides in high summer heat. For example, Jamieson Park in the city center of Portland, Oregon overflows with families and children playing in the shallow water fountains on warm sunny days, serving as a hub for this new urban residential neighborhood. In Copenhagen, Islands Brygge waterfront park is an achievement by local residents to claim outdoor recreational space on the harbor, serving as a living room for the dense residential district, and its floating swimming platform has become a popular draw and icon for the city's renowned public life culture.

The Biological System has great capacity to aid cities in coping with the impacts of climate change, especially in mollifying heat island effects and increased stormwater impacts, for both human well-being as well as survival of cool-temperature species such as salmon. Forests, trees, riparian zones, and green roofs and walls generally cool and add moisture to the overall environment. A number of studies confirm that trees can reduce outside temperatures significantly; McPherson, et al., found the variation between green/non-green city centers to be as much as 9 °F (2006). Irrigated green roofs can help to cool air and building temperatures, through evaporative cooling and reduction of surface albedo, providing relief in heat events. A study for Toronto estimated that greening 50 % of the surface area of the city's downtown flat roofs with irrigated green roofs would produce cooling of the city by approximately 2 degrees Celsius (Liu and Bass, 2005). Cooling the overall environment can reduce the amount of air conditioning needed for individual buildings, with the double benefit of both climate mitigation and adaptation. In a study to assess potential adaptation benefits of green infrastructure over the next century in Manchester, England, the University of Manchester developed computer models for future climate change scenarios which indicated that adding ten percent tree cover in urban areas could maintain urban surface temperatures at or below 1990

Figure 3
Jamieson Park in Portland's Pearl District provides an urban gathering space that is especially popular with children on hot days. The urban park spaces in this new downtown district invite families to live in a more compact, urban setting.
PHOTO: NANCY ROTTLE

levels. In contrast, the study predicted rises of 1.7 C degrees by 2080 with only maintenance of the current tree canopy, or, worse still, a 5+ C degree rise if ten percent of the tree coverage were lost in the town center, even for a low-emissions future scenario. In that same study, models indicated that greening all roofs would maintain temperatures below 1990 for all scenarios and land cover types, as opposed to temperatures as much as 7.6 C higher if roofs were not greened in the town centers, in the high-emissions scenario (Gill, et al., 2007).

Urban greening also provides significant potential benefits for supporting biodiversity in the face of climate change, both in its provision of continuous habitat along continental and regional migration routes for seasonal species, and in enhancing overall biodiversity within cities. In addition to reducing higher temperatures caused by the urban heat island effect, connected, diverse and especially native vegetative habitat will generally contribute to native species' health, helping to build resilience to stressful new conditions caused by climate change. Such resilience may include resisting negative impacts of exotic and pest invasions. Riparian vegetation in connected stream, lake and river corridors will help cool water, to help salmon and other cold-water species to survive. Connected corridors of canopies and ground level vegetation not only cool cities, but also provide shelter, food, nesting and movement opportunities for birds, mammals, amphibians and insects that are stressed by both urban conditions as well as climate change impacts. Green roofs may also aid in providing habitat: a study in Berlin found 7 % of regional species on one small roof (Kohler, 2006), while in Greater London researchers found 10 % of species classified as «nationally rare and scarce» on the city's green roofs (Kadas, 2006).

Hydrologic green infrastructure – sometimes called «Green Stormwater Infrastructure (GSI)», «Low Impact Development (LID)» and «Sustainable Urban Drainage (SUDS)» – can be especially effective in helping people and their environments to adapt to climate change impacts. Green stormwater practices that strive to infiltrate rainwater where it falls will help cities to cope with increased precipitation and storm intensity, manage flooding, and reduce pollution and temperature stresses to aquatic environments. As summer climates become hotter and drier, water harvest and re-use will become more important both for direct consumption and to maintain vegetation so that it survives and can provide full climate-mitigation and adaption functions. Collected and re-used water can replenish or reduce demand on limited water and energy resources, assure adequate water supply for domestic, industrial and agricultural needs by providing a redundant source in times of shortages, and forestall need for costly and often environmentally damaging water supply plant expansions.

The range of possible forms of green stormwater infrastructure is limited only by the imagination. Biological systems can be used to clean water, to minimize stresses that polluted water impinge on aquatic environments and to allow reclaimed water to be re-used as a resource. Houtan Park in Shanghai, China, is an example of a park design that moves severely polluted water through a series of wetland pools, cleansing the water from a Grade V to a Grade II, after which it is used to irrigate the park (Landscape Architecture Foundation, 2012). In Portland, Oregon and Seattle, Washington, streetside «raingardens» are used to detain, infiltrate and clean dirty stormwater from vehicle-traveled surfaces before it drains into streams, rivers and bays. In two years of monitoring of Seattle's «SEA Streets» these biofiltration swales reduced the amount of runoff by 99 %, while a second design using cascading ponds on a steep hillside was found to substantially reduce pollutant levels in the stormwater (Horner, Lim and Burges, 2004; Chapman and Horner, 2010). Urban forests are an important component in green stormwater infrastructure in temperate and tropical climates, since trees help to intercept, absorb, and evapotranspire rainwater, as well as facilitate infiltration of rainwater into the soil. A study on the effects of tree canopy in the US Pacific Northwest estimated an average of 30 % reduction in stormwater runoff due to interception and transpiration of conifer trees (Herrera, 2008). Green

Figure 4
Houtan Park in Shanghai, China, purifies polluted river water in a series of wetlands so that it can serve as an urban amenity as well as be re-used to irrigate the extensive plantings in the riverside park. Design by Turenscape.
PHOTO: NANCY ROTTLE

roofs have been shown to retain and evapotranspire 40–80 % of annual precipitation, depending upon roof depth, substrate, and climate (Carter and Rasmussen, 2006; Deutsch, et al., 2007). In the Manchester study cited above, Catherine Gill and her research partners projected that increasing tree cover and adding green roofs would reduce projected higher stormwater runoff, though not sufficiently to handle all of the anticipated future increase in precipitation due to climate change (Gill, et al., 2007).

In the Circulatory green infrastructure system, active transport not only mitigates climate change through reducing carbon emissions, but also can influence immediate local conditions by reducing the substantial waste heat burden that motor vehicles contribute to the urban heat island effect. In addition, air pollution is exacerbated by heat, so walking and cycling instead of driving may help to lessen the unhealthful conditions that extreme heat events produce. Indirectly, active transport can provide resiliency to a city coping with climate change impacts: walking and cycling provide a form of transport redundancy that can be undertaken even in times of fuel shortages, storm damage or other catastrophic events. Engaging in active transport can also build personal resilience to cope with climate chaos events through the documented benefits of physical and mental health enhancement that are gained through

Figure 5
Streetside «Street Edge Alternative (SEA Street)» biofiltration raingardens in Seattle have proven to both detain and infiltrate water as well as cleanse it of pollutants.
PHOTO: NANCY ROTTLE

regular exercise. Walking and cycling, and the environments that support these forms of movement, also foster conviviality in the public realm and therefore interpersonal and cultural ties, building the social resiliency that is necessary to ensure that all are cared for in extreme events. Building the infrastructural networks that support active transport also can enable all citizens adequate mobility, promoting a more democratic and therefore potentially more resilient society.

While green infrastructure components in the Metabolic System may be most effective in reducing climate change through reduced carbon emissions, elements in this system can also foster resiliency through providing alternative energy supply, whether to cope with increased temporary demand – such as cooling needs during heat events – or seasonal reduced supply, such as when hydroelectric flows become low through drought. Similarly, while local food systems can reduce carbon emissions, they also enhance supply in times of shortages that might be caused by extreme or unexpected climate patterns, supplementing food sources from other regions that might be impaired by storm or drought. Here again, the social resiliency formed through community gardening and local farmer's markets can become an important factor in helping people to cope with local disasters and shortages wrought by climate change.

Analysis

Table I summarizes the above analysis of the capacity of green infrastructure to mitigate climate change (or, protect climate) at the global level, and to help the human populace and other species to adapt locally to the inevitable impacts of increased greenhouse gases in the atmosphere. It can be seen that implementation of each of the five green infrastructure systems can contribute to both mitigation and adaptation. Moreover, many of the components of these systems can provide multiple benefits, such as urban forests and green roofs helping to reduce energy use needed for cooling while also providing habitat, or use of collected water to generate electricity while also reducing demands on potable water supplies. Additionally, many of the system components can be spatially combined: for example, community space can support urban forests, green stormwater treatment, habitat, and pedestrian and cycling networks if planned and designed well.

Table 1
The table summarizes the analysis investigating the capacity of each of the five green infrastructure systems to mitigate and/or provide adaptive advantages to climate change impacts.

	Mitigate – Global (reduce energy usage, store carbon)	**Adapt – Local** (reduce stresses of extreme weather & resource shortages, community resilience)
Social: Community Space		
Urban Amenities support Compact Form	x	x
Urban Social Space, Nearby Nature	x	x
Circulatory: Active Transport		
Pedestrian Environments, Connections to Transit	x	x
Cycling Networks	x	x
Hydrological: Five Waters		
Water Supply: Harvest and Re-use (rain, greywater, blackwater)	x	x
Green Stormwater Treatment – Biofiltration, Green Roofs, Tree Canopy	x	x
Aquatic and Coastal Environments	x	x
Biological: Habitat		
Urban Forests, Connected Habitats, Corridors	x	x
Habitat Patches, Green Roofs, Green Walls	x	x
Metabolism: Energy		
Local Food Systems: Community Gardens, Urban Farms, Farmers' Markets	x	x
Small-scale Energy Production	x	x

Discussion: Adaptive Mitigation

While many adaptive strategies can be employed to help the human race cope with the impacts of climate change within growing urban populations, many of these strategies may only exacerbate the situation, producing ever more greenhouse gases which will then precipitate more dramatic changes and more severe conditions to which we must then find adaptation mechanisms, in a downward spiraling feedback loop. For example: coping with higher temperatures will require more energy-intensive air conditioning, and add more waste heat to the urban environment; lack of potable water supplies will stimulate energy-intensive desalinization; and flooding from bigger storms will suggest that larger (greenhouse-gas emitting) concrete detention and conveyance systems be built. Those who are able may elect to move out of hot cities to the countryside, triggering increased burning of fossil fuels for transportation and heating. Some adaptive actions will have secondary negative impacts – for example, coastal cities may build high levies along their shorelines for protection from rising seas, severing their populace from the elements that both cool the air and provide high quality livability, and, adding insult to injury, reducing shoreline habitat and biodiversity and the aquatic resources they support.

Therefore, it is paramount to identify actions that provide local protection from climate change impacts while also serving to minimize future impacts through reducing greenhouse gas emissions. Brian Stone calls these actions «*adaptive mitigation*»: *«climate management activities designed to reduce the global greenhouse effect, through the control of gaseous and/or land-surface drivers, while producing regional benefits in the form of heat management, flood management, enhanced agricultural resilience, or other adaptive benefits.»* (2012, p. 147).

Adaptive mitigation also implies that climate protection efforts should not exacerbate the adverse immediate impacts of climate change. While exceptionally dense cities may have decreased fossil fuel consumption in the short term, without the cooling advantages of urban greening they may become untenable without heat-producing and carbon intensive artificial air conditioning. In the same vein, some «compact» urban form patterns such as tall towers may block sunlight and cooling breezes, or generate excess turbulence at their bases, creating inhospitable conditions for good outdoor community space, and thereby potentially inhibiting the social cohesion important for resilience in extreme climate events.

Copenhagen's recent award-winning Climate Adaptation Plan is exemplary in setting out integrated strategies that will equip the city to cope with existing and predicted storm intensity and resultant flooding, while also providing climate mitigation benefits. These strategies feature green-and-blue infrastructure improvements, including continuous corridors of gardens, parks, nature areas and schoolyards, living roofs, facades and parking lots, planting of broad-crowned street trees, incorporating water storage in parks and courtyards, and expanding green transport links such as vegetated off-road bikeways. These adaptive features are presented as opportunities to simultaneously raise the quality of life for Copenhageners, recognizing that «*a green approach may have a broad and wide multidimensional effect, and can solve several problems of climate adaptation, as well as improving Copenhageners' health and well-being.*» (City of Copenhagen, 2011b).

From the above analysis it should be clear that green infrastructure offers multiple forms of adaptive mitigation. Each of the systems possesses the capacity to simultaneously contribute to climate protection as well as adaptation to climate change impacts. Still, the systems and their components need to be carefully integrated into the urban environment, and considered for their contributions to both climate change mitigation and adaptation. The appropriate quantity, placement and design of applied green infrastructure must be incorporated with adaptive mitigation in mind. Too much green in a city might compromise compactness, whereas not enough would be ineffective. Design solutions must be region and place-specific; for example, stormwater treatment, water harvesting and urban greening in arid regions look and function very differently from that of temperate and tropical climates. And of course, detailed study, design and application of evidence-based design is necessary, to understand and model the potential success and actual environmental services that green infrastructure can be expected to provide in future climate conditions: for example, stormwater calculations need to take predicted future storm patterns into account; plant species able to thrive in future conditions should be included in planting schemes; and designers need to be aware that some trees species can accelerate ozone formation in high heat events. Still, green infrastructure should be among the measures used in the first line of defending our global climate, and in promoting the health and survival of citizens who must deal with the acute conditions that inevitable changed climatic patterns will instigate. Brian Stone (ibid., p. 102) suggests that: «*[Tree planting] will come to be viewed as a down payment on the massive program of climate management soon to be undertaken by cities – the beginnings of an inland seawall to guard against the rising tide of heat.*» With its inherent efficiency, multiple benefits, affordability, quality of life advantages, and dual effectiveness of addressing both climate mitigation and adaptation, the integrated systems of Urban Green Infrastructure are vital tools to employ as we confront the climate change challenges ahead.

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Biographical information

Nancy Rottle
Associate Professor
College of Built Environments,
Address: Box 355734,
University of Washington, Seattle,
WA 98195-5734.
Phone: +1.206.685.0521
E-mail: nrottle@uw.edu

Nancy Rottle, RLA, is an Associate Professor of Landscape Architecture and Director of the Green Futures Lab at the University of Washington, where she teaches ecological design and conducts research on urban green infrastructure. She is the co-author of a 2011 text *Basics Landscape Architecture: Ecological Design and co-editor of a special edition of Places Journal, Climate Change and Place*. Her research and design work have won numerous awards and she has lectured in North America, China, New Zealand and Europe.

Current Research

Current research projects include testing of stormwater quality treatment in multifunctional urban waterfront spaces; green wall and water harvesting design, construction and monitoring; investigation on climate benefits of green infrastructure; leadership on regional green infrastructure planning; and pedestrian and cycling infrastructure design and communication.

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ECOLOGICAL INFRASTRUCTURE: AN EXAMINATION OF THREE CANADIAN CITIES

RICHARD PERRON AND ROB ZONNEVELD

Abstract

This paper examines the idea of ecological infrastructure within the context of three Canadian cities located in three distinct ecological regions i.e., the boreal forest (in the Precambrian Shield), the tall-grass prairie and the short-grass prairie. Each city was examined through the design studio process using a combination of GIS investigations and CAD based design iterations. The paper illustrates how design context, understood as the convergence of natural and urban systems, provides the basis for modelling urban ecological infrastructure, beginning with a macro scale long term ecological plan of the city and resolved through a series of site specific design investigations. Three approaches to designing green infrastructure are proposed: colliding infrastructures, designing for succession and regeneration, and designing for capture and inertia. Examples are presented for each approach.

Key words:
Ecological Infrastructure, research by design, colliding infrastructures, infrastructures of succession, infrastructures of capture

Introduction

The discussion that follows is based upon a methodology that treats design as research; a form of what Donald Schön would call reflective practice or knowing in action (Schön, 1987). This means paying attention to the phenomena that emerges, that is questioned, and that is tested through design inquiry. It is an approach that places as much importance to generative inquiry as it does to analytical inquiry. Following from Groat and Wang it is possible for the researcher to focus upon the design process and results both during the design activity and as a form of reflection after the fact (Groat and Wang, 2002). It is important for landscape architecture to find its own epistemological ground, balancing generative and analytical inquiry rather than following epistemological models developed for other disciplines. Landscape architecture educators should be finding new ways to exchange ideas about creative inquiry.

In the winter of 2012 students in the Department of Landscape Architecture at the University of Manitoba undertook a studio themed «Ecological Infrastructure» (Schröpfer, 2012; Shannon and Smets, 2010). As a form of generative research we were interested in questions regarding the nature and variability in how urban ecological infrastructure could be realized in different ecological/cultural contexts, with different development patterns, industrial histories and post-industrial possibilities. Each of three urban contexts would present unique problems, and design solutions would emerge in response to local sets of urban pressures and ecological potentials. As a pedagogical exercise the studio integrated macro and meso scale geographic information systems analysis with meso and micro scale design development using 3D spatial modelling applications.

The work was conducted in two phases. Phase 1 involved a study of the urban contexts and the development of large scale urban strategies based upon ecological design principles (Bullivant, 2012; Newman and Jennings, 2008). The strategies are attempts to integrate urban and ecological processes (Niemelä, 2011).

Phase 2 of the work involved meso scale design projects influenced by principles of integral urbanism (Ellin, 2006). Through our analysis we characterize approaches to designing urban infrastructure according to agencies (rather than content), which, herein, we define as colliding infrastructures, infrastructures of succession, and infrastructures of capture. Ecological infrastructure is understood in terms of landscape processes rather than objects of spatial occupation.

In the studio we began by asking «What is an urban ecological infrastructure, and, what are reasonable goals and objectives in designing and developing such an infrastructure?» Rather than working from existing definitions, we believe that designers should be seeking the definition as part of the design research inquiry. Concepts and working definitions of «ecological infrastructure» would emerge according to contextual characteristics determined by existing landscape processes.

Summary of contexts and strategies: Studio Phase 1

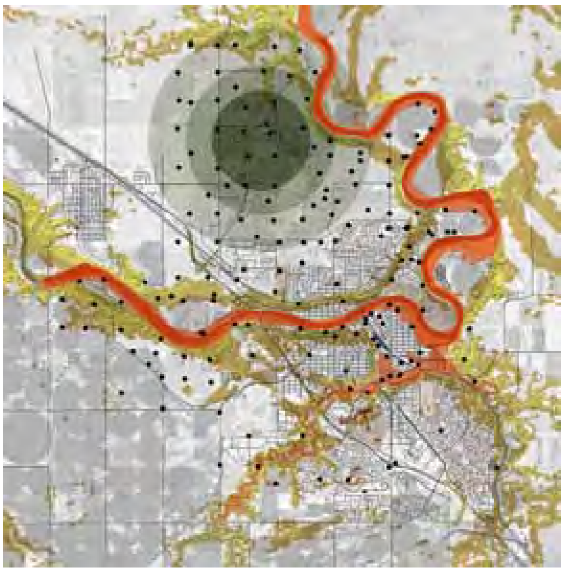
Three cities were included in the study, Winnipeg, Medicine Hat and Thompson. All three cities are located in what are called the 'Canadian Prairie Provinces', however each city is found in a unique bioregion (Lewis, 1996). All three cities could be characterized by shifts or predictable shifts from industrial to post-industrial conditions (Berger, 2008) and the emergence of wasted or liminal landscapes, or drosscapes (Berger, 2006). For each of the city's ecological infrastructure would be considered in terms of the emerging urban conditions, for Medicine Hat this meant an urban growth strategy, for Winnipeg this meant reducing ecological fragmentation, and in Thompson this would be about post-industrial revitalization.

Context Medicine Hat

Medicine Hat, a small city (population 60,000) in the Province of Alberta, is situated in a short-grass prairie region. The city is characterized by dramatic river cuts (coulees) through the semi-arid short-grass prairie landscape. Medicine Hat is referred to as the «Gas City» because of a long history of natural gas extraction that has resulted in a spotty landscape mosaic with buffered gas wells distributed across the city (figure 1). Agriculture production in the region is dependent upon water drawn from channelized mountain streams. Rivers running through the city are prone to flooding due to rapid runoff of melt water in the springtime (figure 2).

Figure 1 (left)
Spotty landscape mosaic of Natural Gas wells distributed throughout the city. Large buffer to the north indicates a development boundary surrounding industrial developing fertilizer.

Figure 2 (right)
Landscape characterized by patterns of irrigation; pivot irrigation green circles (west), rolling irrigation characterized by banded mosaic (east).



Medicine Hat Growth Strategy

An urban growth strategy should take the ecological infrastructure into account. The strategy (figure 3) for Medicine Hat includes:

- Restriction of development in the industrial zone of northwest, allowing for the establishment of a long term recombinant ecological development (Meurk, 2011);
- Expansion of a «no build area» based upon topography, soil condition, and flooding;
- Diversion of major traffic route around the city, to develop a more pedestrian and bicycle friendly environment;
- Development of a «green network» throughout the city, building upon coulees and expanding riparian zones, restricting development within the coulee network;
- Challenging the suburban mosaic by linking to green network;
- Creating didactic environmental experiences to reconnect the people to the water;
- Simulating flood conditions to assist in the propagation of native species in controlled flood plain;
- Highlighting green house production and managing water use;
- Build upon the potential of the distribution of natural gas well sites by beginning of a patchwork of urban forestry.

Figure 3 (left)
Residential development (beige) between major green corridors. Commercial development integrated into green zones, broadening of green zones.

Figure 4 (right)
Typical short grass prairie coulee condition

Context Winnipeg

Winnipeg is a mid-sized city, population 730,000, located in the Province of Manitoba. Situated in what was originally a tall-grass prairie, the City of Winnipeg may be characterized as topographically flat and prone to flooding due to the confluence of two significant waterways, the Red River and the Assiniboine River, (mitigated by major water diversions projects including the Red River Floodway[1]). The studio group focused their attention on the area bounded by the Red River and its floodway.

1 http://www.floodwayauthority.mb.ca/home.html

Winnipeg: reducing ecological fragmentation

Like many North American Cities, Winnipeg has developed in a piecemeal fashion, first as an amalgamation of a number of small communities, and later as through suburban growth designed by property developers. Coordinated spatial planning at the scale of the city was, for the most part, limited to functional zoning and transportation planning. Large scale ecological infrastructure planning has yet to be undertaken in any serious manner. This studio project began with an examination of the City's current master planning and transportation documents, and considered what an integrated ecological master plan (Shannon and Smets, 2010) based upon principles of landscape ecology (Forman, 2006; Forman and

Figure 5
(top left) Winnipeg Study Site, approximately 27,500 hectares, eastern third of the City of Winnipeg; (top center) «blue infrastructure» site bounded by bounded by the Red River to the west and the floodway diversion project to the east; (top right) «Hard infrastructure», major roads, electrical ROW, rails and regional centers; (bottom right) proposed ecological infrastructure primary flow diagram; (bottom left) highlighting regional centers and residential areas.

Godron, 1986; Dramstad, Olson and Forman, 1996) might begin to entail. This is of course a complex problem and the subject of much current research (see for example Palazzo and Steiner, 2008; Newman and Jennings, 2008; Tiberghien, Desvigne and Corner, 2009).

Figure 6 (left)
Diagram indicating existing opportunities for major «green corridors» linking existing patches within the city and to the region.

Figure 7 (right)
Winter prairie at the edge of the city.

A working definition of ecological infrastructure was proposed: *Ecological Infrastructure is the organizational framework that meshes ecological processes and ecosystem services into the urban fabric*. Following from this definition a number of design goals were identified:

- Design ecological infrastructures to frame growth around regional mixed-used centres as identified by City planning documents
- Re-construct conventional infrastructures (such as road, rail and electrical right of ways) to incorporate natural processes in the city
- Identify vital ecosystem services and incorporate their functions and processes into ecological infrastructure
- Indicate areas of opportunity, where human and natural processes intersect, to allow for hybrid processes to emerge.

In pursuing these goals urban ecological fragmentation emerged as a primary concern. This fragmentation developed as a result of suburban growth patterns, and functional zoning and transportation models that, often neglected or destroyed existing ecological structures. A strategy was developed to reduce urban ecological fragmentation by:

- Reconnecting the suburban mosaic;
- Developing an «opportunistic» approach to ecological infrastructure, that takes advantage of
  - linear features that have become available through the abandonment of rail transportation routes, electrical transmission right of ways,
  - «neglected» lands that have resulted from industrialization, and
  - «day-lighting» covered riparian areas;

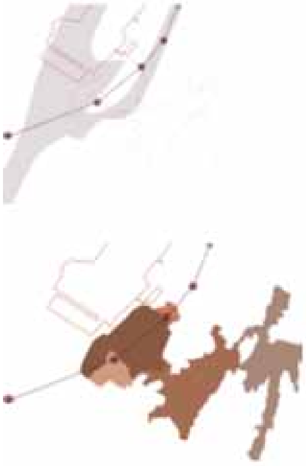
- Linking the patchwork of parks, greenways and urban forests;
- Connecting the green urban network, parks, playgrounds, forest, riparian corridors, vacant lands, etc., to the wider regional network;
- Examining the role of the residential «yard» in the green urban network;
- Considering how shifting industrial conditions may become critical to a green infrastructure, such as developing critical green nodes or green stepping-stones upon abandoned or underutilized industrial lands.

The city scale design approach that would include the establishment of a series of extended corridors (building upon the linear features described above) that would connect the inner city to the periphery. These corridors would be designed to reinforce existing ecologically sensitive urban fragments including riparian corridors, tall grass prairie patches, urban oak savannah, and prairie «parkland» forest patches.

Figure 8
Winnipeg has long been a central hub for rail transportation and is often characterized as a winter city.

Context Thompson

Thompson was conceived and later constructed as a planned community in 1957 (now with a population of 12,829) situated in the Boreal (Taiga) forest biome of northern Manitoba. The city's origin stems from the need to house and support an adjacent nickel mine and smelting operation. The urban footprint is in stark contrast with the Boreal forest (predominantly coniferous trees (particularly spruce) wetlands, granite outcrops and thousands of freshwater lakes and rivers). Mining interests have since waned and the community currently has refocused itself as a regional trade and service centre of northern Manitoba.



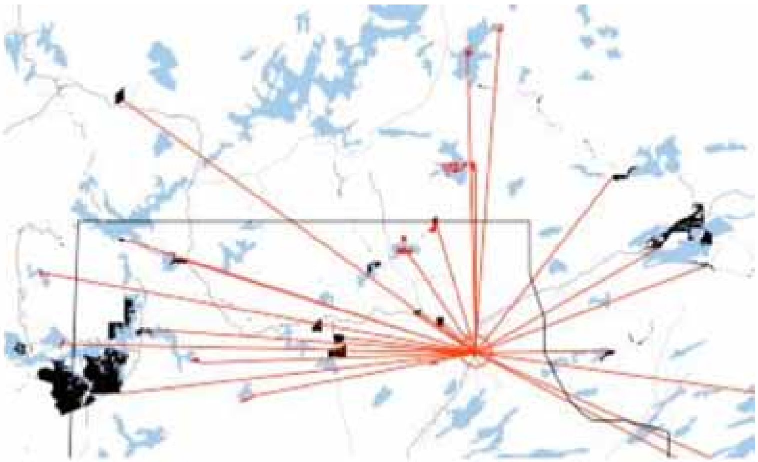


Figure 9 (left)
The proposed strategy is staged and considers the direction of future urban growth towards abandon mine site (bottom image). Development is based upon sub surface mineral deposits (upper image) and predicted economic expansion.

Figure 10 (right)
At a regional scale Thompson performs as a regional «Hub of the North». The circle locates Thompson with First Nation communities (black colour).

Thompson Post-industrial/Urban Revitalization Strategy

A strategy was proposed to consider not only the consequences of the post-industrial sites and services but to adapt the urban infrastructure to meet the current needs (Berger, 2002) of Thompson as the 'Hub of the North' and servicing the surrounding (remote) communities. The strategy, as determined by the students and the design brief, is to consider ecological infrastructure and what this means for a hinterland community. The strategy for Thompson includes:

- Adapting to the phased closure of the mining operations: smelter and refinery closed in 2015, reclaiming the mine site and remediation of the tailings pond, and, continued exploration and mining practices migrating away from the current town site;
- Expansion of the city to the north of the existing town site (and Burntwood River) integrating existing infrastructure and limitations (soil characteristics and ecological sensitivity);
- Develop a secondary commercial core along access road to airport; and proposed that new residential areas reflect the existing urban form where development radiates from institutional cores (education, medical and governmental facilities) and are connected primarily with a pedestrian pathway system;
- Development of an interconnected ecological network within the city and surrounding area by improving connections between forest patches and improving patch ecological structure and function;
- Improve connectivity (transportation) and flows between Thompson and surrounding communities with minimal obstructions to regional ecological flow.

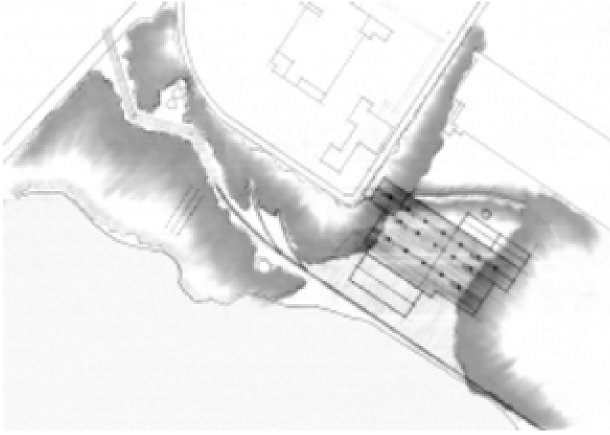


Figure 11 (left)
Photograph of mining operation. Modified image from: http://www.findthe postalcode.com/location.php?province =MB&location=Thompson

Figure 12 (right)
Illustration of natural corridor passing through mining site as part of a post-industrial design scenario.

Ecological Infrastructure at a meso scale: Studio Phase 2

In the examples that follow a number of design approaches to ecological infrastructure have been developed. Through the work, three design approaches have emerged that characterize the foci of the projects: colliding infrastructure, design for succession, and systems of capture. The approaches are described briefly below with examples drawn from each of the cities under investigation. The design has taken into consideration qualities of hybridity, connectivity, porosity, authenticity and vulnerability. These qualities, as described by Nan Ellin, are meant to serve as «guideposts» for developing an integral urbanism (Ellin, 2006).

Colliding infrastructures

Perhaps the greatest impediments to the urban ecological infrastructure are other conventional infrastructures such as roadways, buildings, etc. Conventional infrastructures may be developed directly on the landscape, or as sub-surface conditions and even as above surface phenomena. But in each case these infrastructures may restrict or impede flow of organisms; and are resistant to natural landscape dynamics due to ongoing management practices. These conventional urban infrastructures are usually linear in nature but can occasionally take on patch like or matrix like patterns.

The long linear nature of roadways and railways, systems designed for the movement of water, systems of electrification or natural gas may all limit and determine, in different ways, ecological design possibilities. The corridor like nature of these infrastructures is what allows them to work while also contributing to their potential for limiting other activities. Conventional infrastructure corridors share some functional similarities with ecological corridors of serving as habitat, conduit, filter, barrier, source and sink.[2] For example, conventional freeway and rail corridors are primarily designed as conduits of materials or machines (often machines that carry people and materials). As conduits they usually consist of inorganic materials and systems of movement that filter out or-

2 Douglas, I. and Sadler, J.P., *Urban Wildlife Corridors: Conduits for movement or linear habitat*. The Routledge Handbook of Urban Ecology. New York: Routledge, 2011, p. 278–279.

ganisms or act as barriers that prevent the movement of organisms. But, the design of ecological urban infrastructures may be thought as ways of mitigating the impacts of these other movement systems, of reducing barrier effects, of increasing the porosity of linear systems, and of acting as strategic sources of organisms and materials for serving a wider hybrid urban ecology. As linear systems, ecological infrastructure may be thought of as colliding with other infrastructure networks, and the challenge for landscape architects has to do with finding opportunities in such collisions.

The colliding infrastructure approach is illustrated in three different design studio examples described below. The first example describes conventional infrastructure in the linear form. The second example examines a patch like industrial infrastructure. In the third example the conventional infrastructure (covers a large area through industrial processes and takes on the form of a small matrix (or extensive patch). In each case ecological impediments are mitigated and ecological opportunities are considered in terms of their design potential.

Corridors: transportation and barriers to flow

(student Dustin Dilts)

The City of Winnipeg, Manitoba, was established as a result of the development of the railway and the rail transport continues to act as a determinant of ecological flow within the city. Winnipeg is home to two major railway yards (the CP (Canadian Pacific) Yards and the CN (Canadian National) Symmington Yards) that separate the city between north and south. Large railways yards are often adjacent to industrial developments and, or, sites of low lands due to excavation required for the building up of the rail beds. These railway yards often act as barriers of flow for human and non-human organisms fragmenting the city according to functional industrial desires.

Connection

Conversely, railways and roadways may act as «through» corridors[3] for species movement due to their width, the associated buffers and the irregularity of their usage. Since these corridors are human-made they are unnatural habitats, however their maintenance and disturbance regimes may be considered as landscape ecology design problems. Although highly managed, rail corridors often act as contiguous linear features of open space in a city. Railway corridors may be the only places where native grasslands persist.[4] In a tall grass prairie region like Winnipeg railways may be considered as potential corridors connecting remnant prairie patches.

The linear nature of rail corridors provide less opportunity for *convoluted* boundary conditions and may limit energy exchanges between the corridor and its surroundings. Design consideration involving rail

3 Through Corridors include roads, power lines, gas lines, railroads, dikes, livestock routes, horseback trails, walking paths and animal paths (Forman, 2006, p. 159).

4 Forman, 2006, p. 172.

and road corridors should take into account the shape and nature of the adjacent landscapes where rail corridors and adjacent land work together modifying the shape attributes of corridors and patches.

One of the most dramatic instances of the restriction of ecological flow occurs when rail infrastructure intersects major roadways. Major intersections between railways and roadways are often resolved using underpasses or overpasses. But the intersections of unnatural corridors should also be considered in terms of the contiguous flow of organisms. The intersections of railways and roadways may be thought of in terms of the intersection of ecological corridors, as nodes forcing the diversion of flow, or as possible sinks for organisms.

In this design proposal the focus was upon the intersection of railway and roadway corridors. Lowlands adjacent to rail-yards are treated as an important part of the urban wildlife habitat. Berms along the rail-yards are designed to limit the impact of the rail activity on the wetland, while providing a viewing area for the passer-by to experience the rail-yard activities. A proposed land bridge and associated earth works project limits corridor fragmentation by directing the flow of organisms over the roadway along the rail corridor.

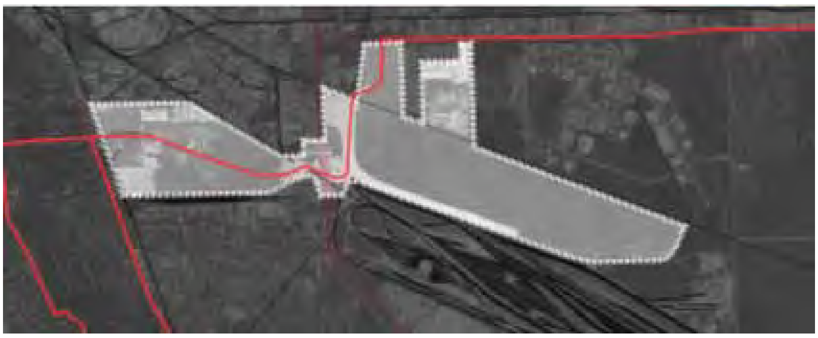


Figure 13 (left)
Greenway crossing major highway and railway. Vacant land associated with rail yard development used for the expanded greenway.

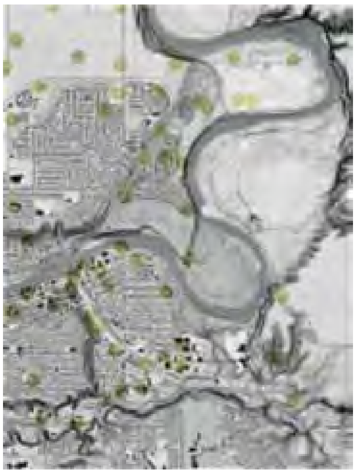
Figure 14 (right)
Fibre-reinforces plastic (FRP) honeycomb structures (inset) have been used in highway bridge decks. New composite materials and honeycomb structures for infrastructure is an ongoing area of engineering research.

Patches: industry sources of opportunity

(student Kristen Struthers)

The City of Medicine Hat, Alberta is often referred to as the «Gas City» because of its long history as a source of «sweet (low in sulphur)» natural gas. The extraction of natural gas in the City itself has resulted in a patchwork of gas wells distributed throughout the region (figure 1). Due to the nature of the gas extraction process, 100 meter protective buffers have been established associated with each of the approximately 1500 gas wells distributed throughout the city. This has resulted in a regular shaped mosaic of «green» patches of varying quality distributed «randomly» according to the subsurface geology. As a surface condition, theses patches provide unique opportunities for a distributed system of protected natural environments.

In this design proposal entitled «Capture and Disperse», a mechanical seed dispersion system on the sites distribute seed mixtures (vary according to specific soil conditions) as a deliberate response to the release of methane gas occurring as a result of the gas extraction process. Tree and shrub planting occurs in the buffered areas to contain the dispersed seeds and structure the site (plantings vary according to soil and other conditions, so for example, Shubert Chokecherry and Green Ash are planted in highly urbanized areas). On the one hand the act of seeding serves as a commentary to the negative impacts of industrialization, while increasing the likelihood of maintaining what might otherwise become an isolated patch condition. It is anticipated that over time the plant material would extend beyond the patch itself. Seed mixtures vary according to a number of site specific details such as soil condition, aridity, and urban micro-climatic considerations.



In this scenario the patch is treated as hybrid ecological/industrial artefact that *collides* with its adjacent urban setting (commercial areas, suburbs, dense urban features, etc.). The fact that the natural gas extraction occurs in an urban setting allows for the establishment of unique, albeit potentially isolated patches to emerge. Forman indicates that the five corridor functions «are exactly the same as the five functions performed by patch boundaries or edges» (Forman, 2006, p. 155). The individual patches are designed to respond to a number of conditions such as the intensity of urbanization, whether it is found in a coulee or a short-grass prairie, area, the soil type, etc. Each set of conditions offers unique possibilities for the patch agency as source, sink, habitat, filter or barrier. So for example, the patch may act as a barrier to urban growth, and a sink for invasive species, a xeric habitat, or a filter of human activities. Since these unique patches are designed to artificially self-seed they become the source of organisms that could be encouraged to spread into the greater urban ecological matrix.

Figure 15 (left)
Seed dispersal mechanisms attached to methane extraction systems.

Figure 16 (Middle)
The city of Medicine Hat is built on a variety of different soil conditions. As the buffers are apparent throughout the city, the diversity of soil conditions and the possibilities each soil type affords should be evident in the design intervention.

Figure 17 (right)
Typical plan and section with sandy area with loam soils, low moisture retention and high erosion potential, seed mix is drawn from local short grass prairie varieties.

New matrix: post-industrial restoration
(student Marie Levesque)

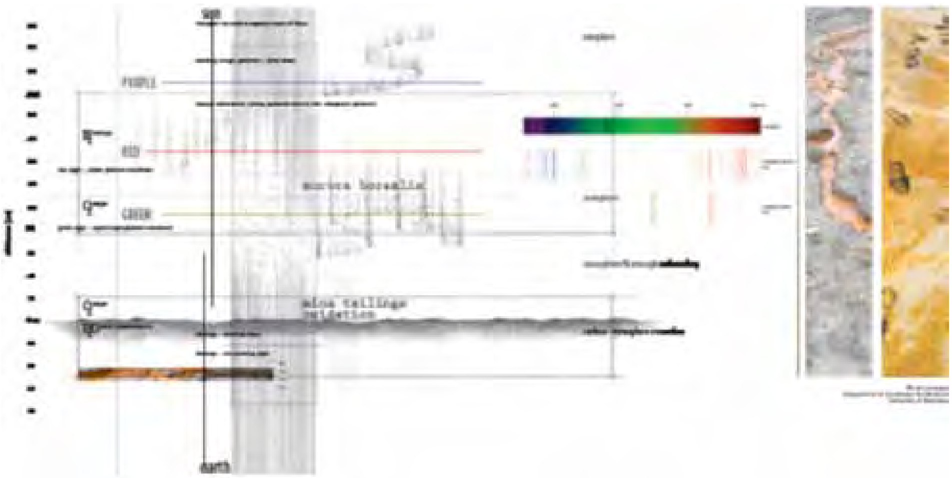
Thompson, Manitoba, is a northern community developed around the mining industry. Located within the boreal forest, the surrounding landscape is characterized by primarily deciduous forests and rocky outcrops. Mining activities in the area have played a significant role in reshaping the landscape. Large industrial processes like mining may be though of as redefining the underlying landscape matrix[5]. Forman defines the matrix as «the background ecosystem or land-use type in a mosaic, characterized by extensive cover, high connectivity, and/or major control over dynamics» (Forman, 2006, p. 39). In the case of mine site the surface area coverage of the disturbance is larger than the City itself. These are human-made unnatural habitats that have a significant control over the local landscape dynamics.

5 In this case matrix is considered to be a relative term. Within the context of the boreal forest the area that we are considering may be thought of as a large disturbance patch in the more expansive forest matrix. Within the context of the city itself the same disturbance patch becomes a dominant (relative to the size of the adjacent city) part of the urban matrix.

Figure 18
Mine Tailings.

The mine site includes three large unique landscape formations that are the result of the mining process: large open pits, slag piles, the obsolete manufacturing infrastructure, and the tailings ponds. As a form of ecological design inquiry on post-industrial sites such as this one, we are concerned with either re-integrating the post-industrial landscape into the boreal forest matrix, or examining the new potentials of the reshaped landscape. In the first project (examining the tailings pond) the emphasis was on the latter approach.

The City of Thompson has a direct physical relationship to the mine site and may be able to take advantage of the emerging landscape condition. Although common mining practice involves the restoration of mined lands, wherever possible, the post-industrial condition may be treated as a rare opportunity for the creation of an unique or hybrid «ecology».



In the project the student became fascinated with an «alien» surface condition that emerges from the mine tailings. She would «equate» this emergent landscape with the material assemblages of the Aurora Borealis, a process about the coalescence of minerals and the optical potentials. In the creation of this hybrid ecology, a new electrical and hydrological infrastructure would be embedded into the emergent landscape as the industrial process reaches its conclusion. These conduits of light and steam sit within the mine tailings to celebrate a new beginning.

Figure 19
Mine tailing and Aurora Borealis association study. Several forms taken by the northern lights have been used to guide the intentions of the site choreography, including both steam and light as the instruments. Aurora rays, homogeneous bands and arcs, horizon glow, suspended patches, rayed arcs, and rayed bands are some of the most recognizable forms of atmospheric displays of the northern lights.

Succession and regeneration

The complexity of urban systems, the human competition for resources and the extent of disturbances within the urban setting gives cause for considering urban ecological infrastructure as a means of dealing with shifting mosaics, and the events or agents associated with changes of patches, corridors and species populations. In the dense urban settings of the studio investigations the shifting mosaics appear to be characte-

Figure 20
Pressurized and heated water will be forced through tiny perforations in the expandable pipes, positioned at grade with the existing tailings surface. As more tailings are generated and disposed of on the site, the pipes will be covered, allowing for steam-atmosphere mixing at and just above the surface of the tailings.

rized by remnant patches, regenerated patches, introduced patches and disturbance patches. Remnant, regenerated and introduced patches can be susceptible to relatively rapid change with rapid succession, whereas disturbance in the form of landscape management will slow down the rate of succession. When such disturbances are removed the rate of succession will likely accelerate (Forman and Godron, 1986).

Cities by their very nature involve ecological disturbances. Most notably are disturbances caused through human interventions. As land uses change, new opportunities to increase the rate of the shifting mosaic may emerge. In urban environments ecological infrastructure may be thought of in terms of potentials for supporting landscape succession, of directing change and of influencing a shifting mosaic. In the examples that follow, three design proposals were developed based upon principles of designing for cyclic succession, heterotrophic succession (primary energy source is non-photosynthetic organic matter), and point succession.[6]

6 The discussion of succession should not be limited to patches since corridors and matrices will also be subject to succession.

Figure 21
Succession in the boreal forest.

Cyclic succession: Of Clay and Water

(student Amy Whitmore)

Probably the most easily understood means of succession is cyclic succession. (see Forman and Godron, 1986, pp. 64–65). To design ecological infrastructure that encourages cyclic succession may mean that we are engaged in designing ways of deliberately affecting landscape processes, influencing the agencies of place.

In the project «Of Clay and Water» the designer recognized that changes in the hydrological regime act as limits to the cycles of succession. By stopping the possibility of flooding we have inadvertently inhibited the regeneration of the cottonwood, thus causing a break in the successional cycle. The design includes the development of artificial retention ponds along with integrated irrigation systems to artificially induce flooding into the cycle of succession.

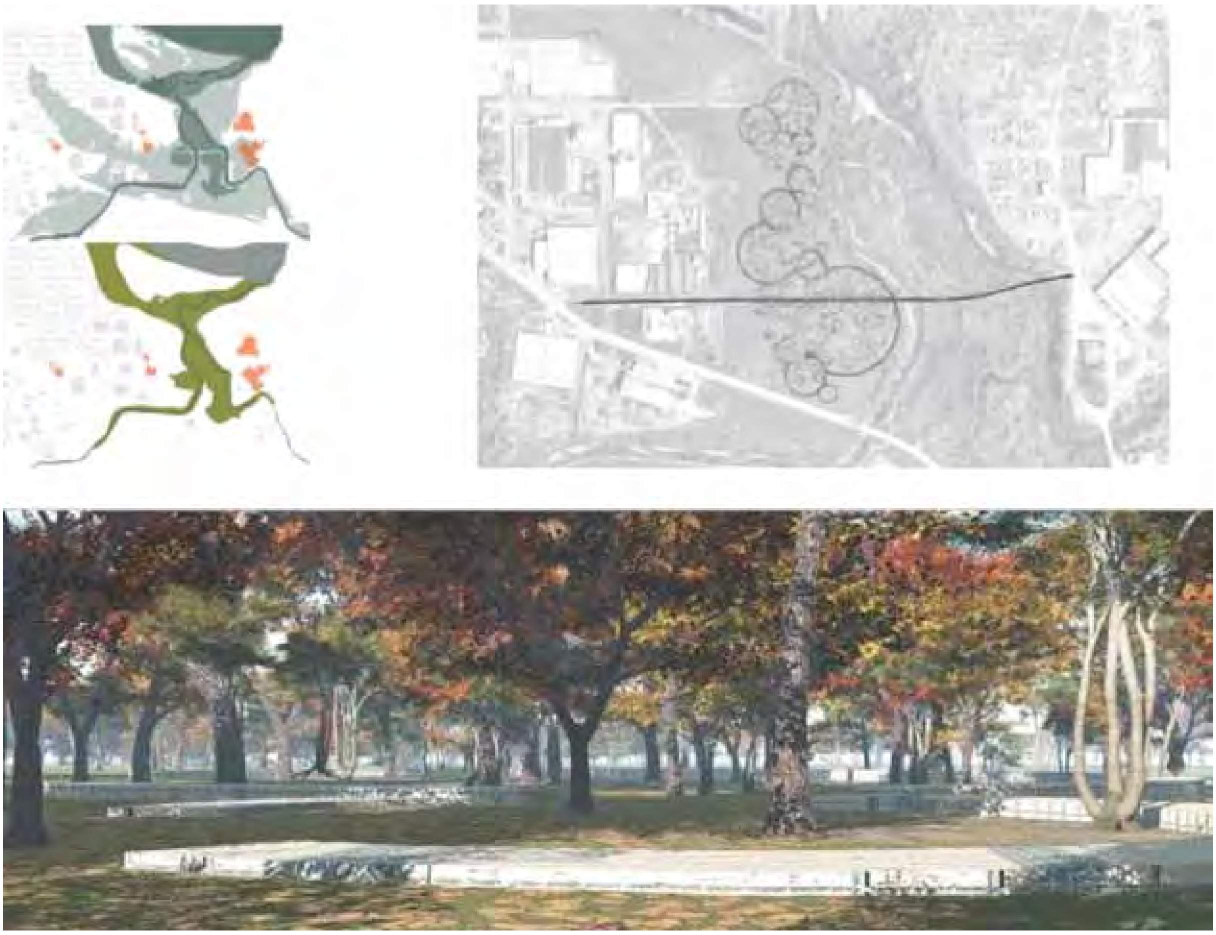


Figure 22
Top left, maps of flood plain and Cotton wood tree stands; top right, plan of water control system; below, rendering of the cottonwood park and retention ponds during a dry period.

Point succession: Vestige Metamorphosis
(student Vincent Hosein)

«In point succession the climax community is a mosaic containing patches with species of earlier successional stages.» (Forman and Godron, 1986, p. 65) Expansive linear corridors such as Winnipeg's hydro electric right of ways cut through a wide swaths of landscape intersecting several «green» patches and may provide the basis for building off of a point succession mosaic. These corridors have had limited urban impact, although they have been under a regular management regime and serve as informal pedestrian pathways. Still, these corridors continue to provide remnants of endangered species (www.livingprairie.ca) such as those found in the original tall-grass prairie mosaic.

The project Vestige Metamorphosis, is a design for an existing urban electrical corridor that is about to be decommissioned. The design brings about a new hybridity taking advantages of human made vestiges of the hydro-electric towers, but also vestiges of ecological communities. The design reinforces woodland, tall-grass prairie, fescue prairie, wetlands and aspen parklands, while recycling the materials of the towers by creating a series of ecozone specific follies along the newly created greenway.

Figure 23
Typical prairie vegetation, from left to right, Prairie dropseed (*Sporobolus heterolepis*), Paper birch (*Betula papyrifera*), Western prairie fringe orchid (*Platanthera praeclara*), Big Blue Stem grass (*Andropogon gerardii*).

The point succession approach to design is meant to strengthen nodes along the path in strategic locations encouraging interconnectivity of the corridor acting like a spine through the city. The follies serve as both attractors to the nodes as well as ways of protecting sensitive habitat.

Figure 24
Computer rendering of hybrid landscape.

Heterotrophic succession
(student Curtis Krul)

In heterotrophic succession «the primary energy source is non-photosynthetic organic matter», much of which can be found in the organic human and non-human animal waste or in the vegetative biomass such as a fallen log in the forest. In the project *City Center*, heterotrophic succession underpins a new urban park design. This project is meant to be a subtly didactic exposition of urban energy flow while facilitating the conversion of human waste. Working from the classic ecology text *Energy Basis for Man and Nature* by Howard and Elizabeth Odum, the designer develops a model and

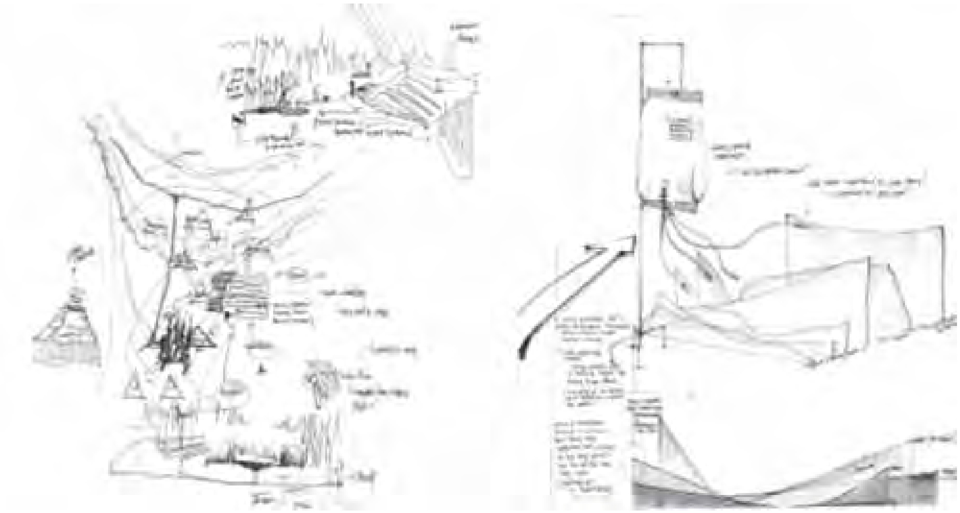


Figure 25
Sketch studies modelling the energy flow of heterotrophic succession design.

structures a design that maps the heterotrophic processes (hydrolysis, acidodegisis, acetogenesis, methanogenesis, digestion, symbiotic photosynthesis, etc.) to the physical infrastructure that supports it. In their discussion on succession Odum and Odum state that species «collectively maintain soils, establish nutrient storages, set up pathways of processes, store information for inheritance, etc. In general, where succession starts with a low initial state there is a period of mass growth with low diversity, followed by diversification and great variety.» (Odum and Odum, 1981, p. 111) Following from this the work concentrates on the growth of one of nature's basic infrastructures, and a fundamental building block of the boreal forest, lichen.

Capture… inertia

The final three examples of designing ecological infrastructure come from approaches that can be characterized as being about deliberate accumulation, gathering, capturing or to put it another way, of engaging and playing with the principle of inertia (from the Latin meaning idle or lazy). Design for inertia («the resistance of any physical object to a change in its state of motion or rest, or the tendency of an object to resist any change in its motion»[7]) is thought of as finding ways to limit system functioning and/or the rate of change in a system. This may be, for example, about increasing biomass accumulation, or concentrating and containing system materials. Inertia may be about the regulation of affect, the regulation of system characteristics that increase frequencies, rates of flow, rates of change, or even momentum within a system (i.e. population size times rate of population growth). Inertia may also be considered in terms of other assemblages, of for example, the accumulation of a cultural past, and a slowing down of our frenetic urban tendencies. Design for inertia may be slowing down one function so that another function can take root. Design for inertia may be about introducing disturbances that are strong enough to slow things down so that new functions may become established.

7 http://en.wikipedia.org/wiki/Inertia, also «inertia» may refer to an object's «amount of resistance to change in velocity» (which is quantified by its mass), or sometimes to its momentum, depending on the context. (momentum = mass x velocity).

Design for inertia, may be about resetting systems within a metastable context, or it may be about deliberately invoking system instability, causing the system to find its own new metastable equilibrium (Forman and Godron, 1986, p. 431). The infrastructure for this kind of design will vary vastly, but may be best characterized as interfering with or deliberately destabilizing system functioning.

Filter, the industrial watershed

(student Taylor LaRocque)

This project is a response to pollution in the South Saskatchewan River attributable to a number of sources including: agricultural and municipal return flows, surface runoff, pesticides, phosphorous, sedimentation, and the accumulation of nitrogen. Infrastructure was designed that not only captured sediment for phytoremediation but would also serve as a collector for people to reconnect to the wetland to other areas of Medicine Hat, and to make the area not only a destination, but part of the community's life.

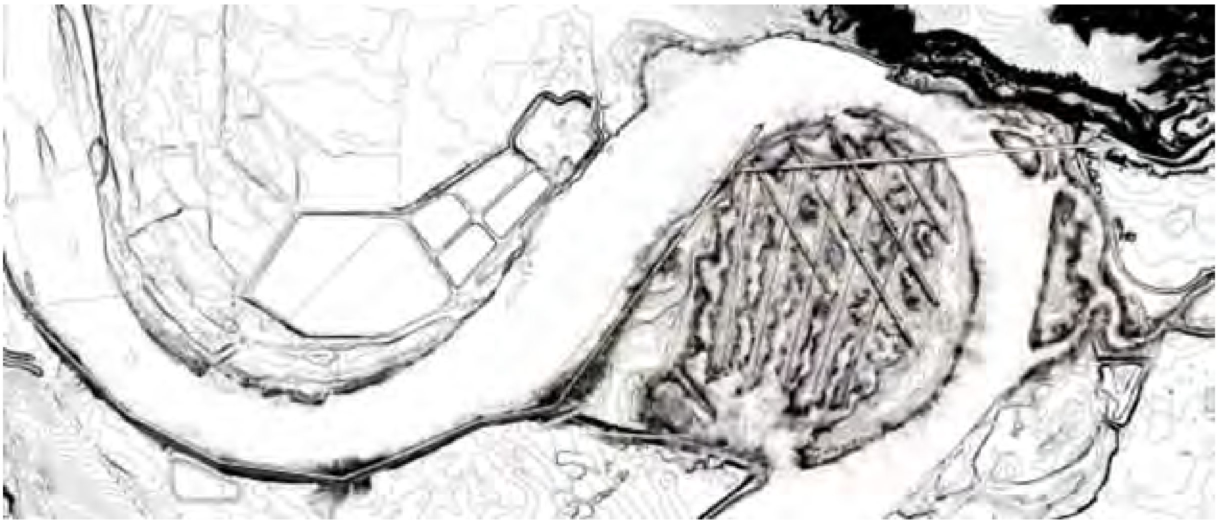


Figure 26. More than just a functional wetland, the River Walk is a reminder that the river is important to the vitality of the city and the province, and it is a resource that should be not only drawn from, but also celebrated and protected.[8]

The treatment wetland incorporates several of methods of wetland design described by (France, 2003)[9], while catering to the specific conditions of the South Saskatchewan River in Medicine Hat. The design considers the transition of the wetland through the year, from low levels during the early spring and fall, to the highest levels during the month of June. The wetland is designed to withstand this seasonal flooding, as well as abnormal flood events. It consists of an inlet, sedimentation forebay, interior segmented channels, a micro pool and outlet. The wetland serves to remove contaminants such as phosphorous and nitrogen, as well as various sediments. By targeting various types of river water pollution, the treatment wetland both improves water quality and educates the public about the quality of their river. By exposing the process of water treatment, citizens of Medicine Hat can approach the river and observe

8 Laroque, Taylor, Medicine Hat Studio Book, Draft Version, p. 159 (unpublished).

9 Robert L. France, 2003. Wetland Design: Principles and Practices for Landscape Architects and Land-Use Planners.

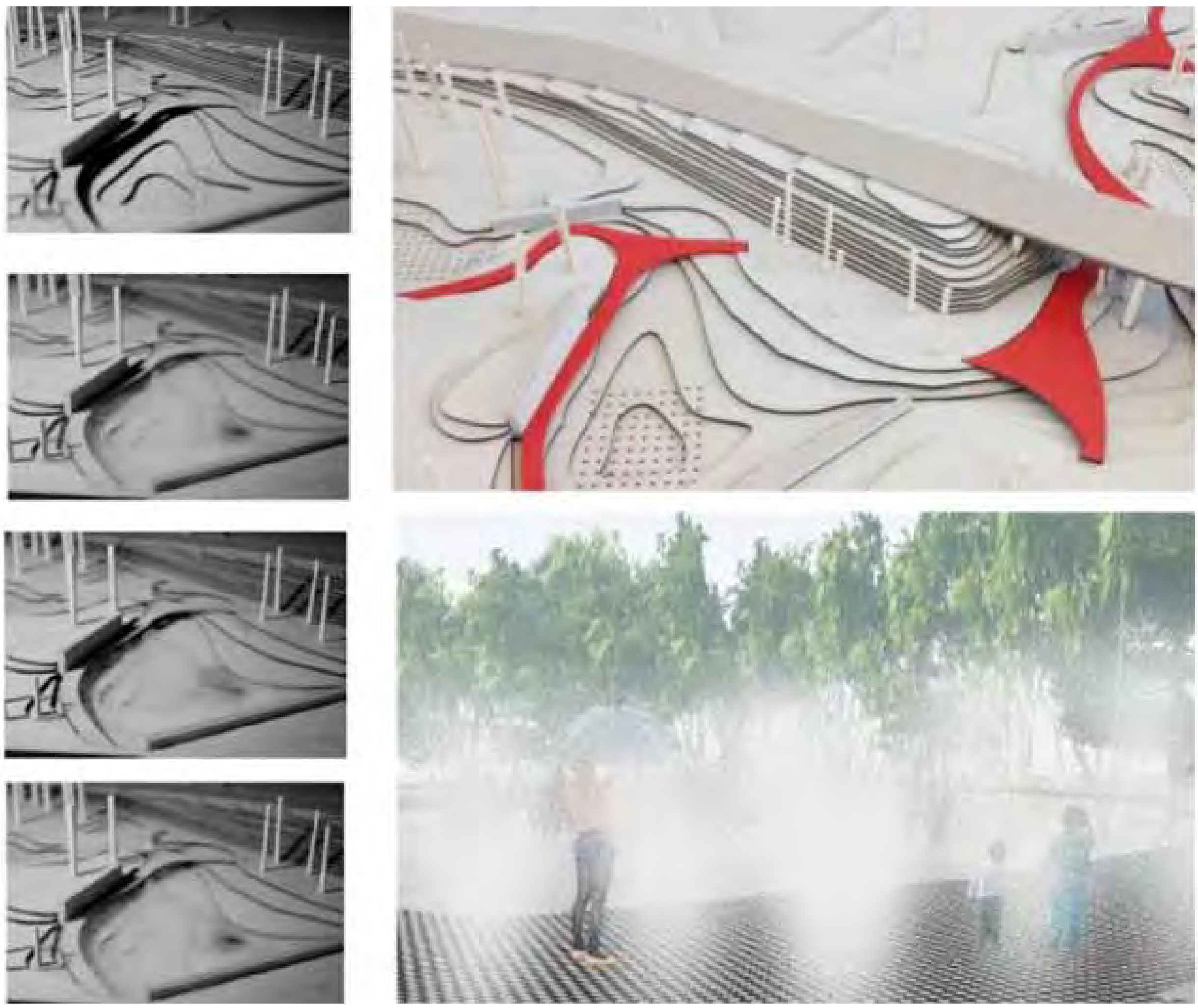
the treatment cycle firsthand. At certain times of the year, the wetland can even be entered for a more immersive experience.

Assemble and Disperse: Infrastructural Hybridity
(student Trent Workman)

Each spring the City of Winnipeg collects approximately 5,000 truckloads of grit from the streets of the city in the form of sand, salt and debris. Over the winter months this grit helps to add traction to roads but by spring it is collected and deposited in the landfill. This design proposal posits the re-use of sediment in combination with over-flow water from the combined sewer and drain system on a site adjacent to the Red River, beneath a vehicular overpass.

Combined sewers and drains have a tendency to over-flow approximately eighteen times per season in Winnipeg. The design exposes the drainage hydrology in the form of bioswales designed as a system which integrates a regional trailway, the railroad and hydro corridor allowing excess water to flow to this under-utilized site. The collection of these

Figure 27
Models simulating soil build up and visualization of steam in park.



elements is imagined as a process of land-forming through a cause and effect relationship. This relationship is explained as a process of primary, secondary and tertiary settings based on three forms of operation: assembly, accumulation and aggregation. Each operation has implications upon further settings affecting the way in which subsequent settings react to their new situation. This project maps the cause and effect relationship of a landscape in process.[10]

10 Workman, Trent, *Ecological Infrastructure Studio Book*, Draft version, p. 159 (unpublished).

The living inertia of an abandoned mine
(student Noman Syed)

The last example illustrates the idea of the cultural potential that can be found through the play with industrial inertia. In each of the three examples the students engage the potential of abandoned mine site through the re-invention of the by-products of industrialization. In the design revisits and decomposes the mining process and gathers the memories of the industrial process through a series of symbolic gardens. Here is the memory of the industrial infrastructure itself that is captured and celebrated.

Figure 28
Metaphors of the mining process, clockwise from top left, milling, bedrock profile, mining waste, nickel product.

Discussion

The examination of designing with ecological infrastructure in three Canadian cities located in three separate ecological regions has revealed three primary insights. First is the ambivalence of understanding ecological infrastructure. The necessity of framing perception and intentions at various scales, in this case at macro and meso scales as well as locating the urban patch (or patch work) in a specific landscape matrix affects our understanding of how we perceive, design for and use ecological infrastructure. Ambivalence is understandable as the convergence of natural and urban systems, along with intentionally hybrid systems, is complex and associated with ambiguities of the relationships between humans (and their built world) and nature.

The second insight is the recognition of three design approaches emerging from the student work: colliding infrastructure, design for succession, and systems of capture and inertia. The collision between urban infrastructure (including ecological infrastructure), ecological processes or systems and human activities is evident in the student inquiries into corridors and patches. Accepting new ways of perceiving existing and hybrid conditions are necessary for encouraging new urban ecologies. Without new perceptions the conventional and less inspiring systems remain. The idea of succession has also been reconsidered to acknowledge principles of cyclic, heterotrophic and point succession. This opens design opportunities to provide affect (ecological and cultural) in otherwise conventional circumstances. Design interventions become more responsive to otherwise hidden or neglected natural processes. Students also considered challenging inertia by 'interfering with or deliberately destabilizing system functioning'. This was accomplished through recognizing existing systems and creating interventions that assist in naturally occurring (or previously existing) functioning systems such as a constructed 'industrial' wetland; in constructed human systems as exemplified by redirecting road grit from landfills into an engaging hybrid landscape; and celebrating industrial by-products, slag piles, open pits, and abandoned buildings which otherwise are covered over, removed, or ignored.

The third insight is pedagogical. An investigation into urban ecologies of three separate cases using surfacing definitions is challenging. Exploring the ambivalence of human and natural ecologies as well as learning new analytical and graphic software (GIS and 3D graphics) occasionally pushed students (and staff) outside of normal comfort levels. However, this process resulted in urban design solutions that challenge (unproven) convention and reconsider the relationships between natural and human ecologies. In the end, new ways of perceiving ecological infrastructure adds to the discourse, ultimately improving, culturally and ecologically, the urban situation.

Acknowledgement

The work described herein was the result of one term of studio work in the Department of Landscape Architecture, University of Manitoba. Three cities were investigated and proposals were developed at a macro scale by small groups of students. Individual students then developed meso scale design proposals. Students working on Medicine Hat, Alberta, included Kevin Handkamer, Taylor LaRocque, Kristen Struthers, Amy Whitmore and Megan Wilson. Students working on the study of Thompson, Manitoba, included Amanda Blick, Sara Brundin, Curtis Krul, Marie Levesque, Stephanie McKichan, Sarah Mitchell, Leah Rampton, Kajsa Strom and Noman Syed. Students who worked on the City of Winnipeg projects included Lia Abolit, Dustin Dilts, Vincent Hosein, Shannon Loewen and Trent Workman. The authors are indebted to the students for their insights and their design contributions as illustrated throughout the paper. All images are from the authors or students. The only exception is figure 11 which is a modified image from the public website: List of Postal codes in Thompson, Manitoba (http://www.findthepostalcode.com/location.php?province=MB&location=Thompson).

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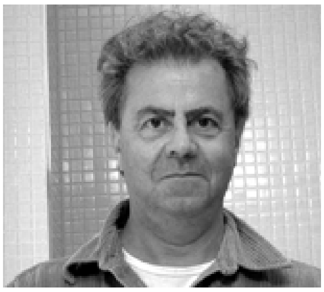

Biographical information

Professor P. Richard Perron, Ph.D.
Department of Landscape Architecture, Faculty of Architecture
Address: 201 John A. Russell Building , University of Manitoba, Winnipeg, MB R3T 2N2 Canada
Telephone : 204-474-6449
E-mail: perron@cc.umanitoba

Professor Perron teaches in the Graduate Department of Landscape Architecture and the Undergraduate Program of Landscape + Urbanism. His research is in areas of Ecological Urbanism, Landscape Urbanism, Integral Ecology, Actor Network Theory and design infomatics.

Biographical information

Robert Zonneveld, Ph.D.
Department of Landscape Architecture, Faculty of Architecture
Address:201 John A. Russell Building , University of Manitoba, Winnipeg, MB R3T 2N2 Canada
Telephone : 204-474-6449
E-mail:
robzonneveld@hotmail.com

Rob obtained his Ph.D (2012) from Lincoln University, New Zealand where he studied issues of globalization, authenticity and staging in small town tourism using a performance metaphor. Rob is currently an instructor at the University of Manitoba.

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ROADS BELONG IN THE URBAN LANDSCAPE

THOMAS JUEL CLEMMENSEN

Abstract

Roads are often associated with a fragmentation or splintering of landscapes and their natural connectivity; particularly in relation to 'green infrastructure' they are often considered problematic elements that rupture and barricade. Conversely, as part of larger networks, roads can be considered important elements in the creation of new, 'green infrastructures' that can qualify urban landscapes in terms of improving their overall porosity and connectivity. This argument will be unfolded and substantiated in this article through theoretical reflections which conceptually re-locate road networks in the urban landscape, supported by relevant reference projects that illustrate the potential of road networks as a platform for 'green infrastructure'.

Key words:
Green infrastructure, urban landscapes, road networks, landscape architecture, urban planning

Introduction

In spite of being a characteristic feature of all urban landscapes, road networks seldom attract much attention among architects involved in urban planning and landscape architecture. One reason can probably be found in the dominance of the zoning approach to planning, where road planning easily becomes isolated and reduced to a matter of traffic management and transport economy (Clemmensen, 2008a; 2008b). Another possible reason could be, as suggested by Christopher Sawyer, that road networks like other infrastructures are conceived 'outside' the more visually oriented domain of landscape architecture at a much larger and more abstract territorial scale. This is not to say that infrastructure does not operate within the landscape, it obviously does, but rather that it does not originate there. According to Sawyer, infrastructure is conceptually located elsewhere and thus is not strategically accessible to landscape architects working only in the realm of landscape. As a consequence infrastructure often becomes something landscape architects work around rather than engage with and alter (Sawyer, 2004).

If Sawyer is right, how can we as landscape architects engage with road networks in profound ways that move beyond the purely visual and pictorial? Is it possible to conceptually re-locate road networks in the landscape? In the following, these questions will be addressed by discussing different understandings of landscape and its relation to infrastructure and it will be claimed that 'roads belong in the urban landscape', a claim that echoes John Brinkerhoff Jackson's essay *Roads Belong in The Landscape* (1994). Furthermore, it will be argued that road networks can be considered important frameworks for creating new 'green infrastructures' that can qualify urban landscapes in terms of improving their overall porosity and connectivity.

In order to strengthen this argument three different 'sites' that relate to contemporary road networks, and which hold potential in relation to the development of 'green infrastructures' in urban landscapes, will be presented: The *roadside* will be described as a parallel network with a capacity to connect otherwise isolated fragments – an idea which references the concept of the parkway. The *super grid* will be presented as a pertinent way to organise the interface between 'urban' and 'rural'. Last but not least, the fine network of minor roads – the *sponge* – will be described as a platform for site-specific development without 'fracture'. The potential of each of these sites will be exemplified by reference projects working in a cross-disciplinary field between landscape architecture and urban planning.

Infrastructures and landscape

How should we understand the relationship between infrastructures and landscape? This question has occupied Sawyer who employs a distinction between *landscape* and *territory* as a basis for his considerations. As explained above, according to Sawyer, it is not easy for landscape, when considered as a concept related to visual perception, to accommodate infrastructure, as the latter is imagined in relation to a larger and more abstract territorial scale. This does not mean that infrastructure does not operate in the landscape, it clearly does, but rather that infrastructure does not originate there. At the conceptual level, infrastructure is located outside the landscape and is thus not strategically accessible to landscape architects who solely work within the landscape domain; this means that infrastructure to a greater extent becomes something immovable and 'difficult' that they work around rather than work with. This lack of coupling to the conceptual plan of infrastructure means, according to Sawyer, that landscape architects continue to be very much occupied with the visual qualities of the contrast between infrastructure and landscape, or *the machine in the garden*, as Leo Marx describes the desire to accommodate infrastructure in the landscape (Sawyer, 2004).

With regard to making infrastructure strategically available to the landscape architect as something to work with and not just around, there are, according to Sawyer, a number of important approaches that can briefly be summarised as follows: 1: in order to better understand the space in which infrastructure operates, traditional boundaries between city and country have to be broken down; 2: a recognition of the fact that infrastructure often exists in a conflict-ridden field between divergent interests, which necessitates the ability to be able to mediate between these interests; 3: a more comprehensive level of observation, which addresses territory and makes infrastructure visible and understandable; 4: obtaining a better understanding of landscape by shifting the focus from the shape of the landscape to the processes that generate its form (ibid.).

Gary Strang, who describes infrastructure *as* landscape, presents a similar set of considerations concerning the relation between infrastructure and landscape. In relation to the way Leo Marx, in 1964, presented the idea of 'the machine in the garden', Strang observes that current conditions create a situation in which the machine becomes inseparable from the garden; or in which the garden and the machine are completely intertwined (Strang, 1996). In doing so, Strang does not refer to the formal characteristics, but to the functional integration between infrastructure and a constructed landscape, which relies on infrastructure for its preservation. In spite of the fact that we rely on these constructed landscapes, our attitude to the underlying infrastructure, according to Strang, has, to a higher degree, been characterised by denial rather than by respect. Most often architects are given the task of hiding, screening and camouflaging infrastructure in order to maintain an image of the pristine natural surroundings of our past; only very rarely are they asked to consider infrastructure as an opportunity for, and a basic component of, giving shape to a city or an entire region (Sawyer, 2004).

The applicability of this relationship to the road network is confirmed by observations from the Netherlands, a country otherwise known for its highly constructed landscapes. Michelle Provoost is puzzled by the way Dutch motorways are built with a view to adapting to and harmonising with the landscape, as if the two were polar opposites, the one artificial, and the other natural. In contrast to this, Provoost claims that the construction of roads can be seen as an opportunity for shaping an entirely new city or a new landscape (Provoost, 2002). Poul Meurs makes a similar point when he has problematized the way discussions in the Netherlands are characterised by out-dated arguments that do not take into consideration developments in the relationship between the road network and urban development. According to Meurs, the task is no longer to adapt the road to the landscape, but to design a landscape of mobility in which infrastructure; urban development and landscape are combined (Meurs, 2003).

In seeing infrastructure as landscape, Strang argues for an approach that attempts to render infrastructure and the natural landscape coexistent, performing several different functions. He would like architects to be more like farmers who depend on the architecture of natural systems; similarly he would like infrastructure to be more like well-functioning fields which are used not only for food production but fulfil several different purposes, such as, for instance, providing a seepage surface or a resting place for migrating birds. By thinking in supplementary functions, public infrastructure, with its relatively large budgets for construction and renovation has, according to Strang, a huge potential for improving urban areas and regional landscapes on a scale that architects usually only dream about (Strang, 1996).

The aforementioned considerations concerning the relationship between infrastructure and landscape affect important aspects of a more contemporary understanding of landscape. Whereas Sawyer's contraposition of landscape and territory contributed to identifying a distinction between the visual and the procedural, Strang's description of infrastructure as landscape contributes to identifying a distinction between the artificial and the natural. According to James Corner these oppositions are tightly interconnected. Corner describes how our understanding of landscape is characterised by a pictorial or scenographic impulse, with the result that the physical appearance of the landscape is, over time, separated from the causes of its shape. In this way the artificiality of the landscape is masked over time and gradually comes to appear as something natural (Corner, 1999b). Corner is critical towards this connection between landscape and 'nature', because the result will be that the landscape functions as an antithesis to the urban; an additional aspect or supplement derived from a nature which exists outside and which has no buildings, technology or infrastructure (Corner, 2006). In order to improve the foundation for a more critical arrangement of the shaping of landscape, Corner wishes to direct attention towards the processes, which are involved in the creation and transformation of the actual landscape. This means that the visual aspects will be toned down compared to the productive aspects – what landscape can do, and how it works over time, become more important than the appearance of the landscape. In this perspective, the landscape is to a greater extent seen as an active instrument for the enrichment of culture than as a passive product of culture (Corner, 1999a).

The qualification of urban landscapes

Before explaining how road networks can be considered important frameworks for creating green infrastructures that can qualify urban landscapes, it needs to be clarified what 'qualifying' means in this context and how that is related to a more contemporary meaning of the concept *landscape*. Here the thoughts of John Brinkerhoff Jackson (1909–1996) and Thomas Sieverts, who both have been involved in the study of urban landscapes through a lifetime, seem appropriate.

John Brinkerhoff Jackson has described landscape as a synthetic space or a man-made system of spaces superimposed on the face of the land, which functions and evolves to serve a community (Jackson, 1984). In relation to this definition, Jackson distinguishes between three types of landscapes: Landscape One which refers to the very complex and changing landscape of the early middle ages, a landscape without memory or vision regarding the future; Landscape Two which is rooted in the renaissance and which refers to a landscape of clear and permanent borders; and Landscape Three which refers to the contemporary every-day landscape characterised by characteristics of Landscape One as well as Two. On the one hand, Landscape Three continues to be dominated by the understanding of landscape connected with Landscape Two, which, due to its emphasis on the visual and its insistence on homogeneous spaces and unambiguous boundaries, has difficulties accommodating and recognising the vitality and diversity of the everyday landscape as a quality. On the other hand, the everyday landscape is similar to Landscape One with regard to its informal nature, its lack of interest in history and its basic utility-oriented and unscrupulous use of the environment (ibid.). This tension can, for instance, be seen in the so-called Danish Motorway Tradition; in this tradition the visually oriented adaptation of the road to the landscape (Two) is increasingly compromised by a new everyday landscape (Three) containing different types of areas designated for commercial use, which, in the words of Marcel Smets, are created on the basis of their own mercantile logic (Smets, 2001). According to Jackson, it is essential to the qualification of Landscape Three that Landscapes One and Two find their balance and that, in this respect, it becomes possible to define a landscape which can accommodate the variability of everyday life as well as the political infrastructure of a stable order. This, however, demands that we let go of the out-dated forms and ideas connected with Landscape Two (Jackson, 1984).

Thomas Sieverts has a similar approach to the concept of balance; he describes the process of qualifying urban landscapes as a development from an 'impossible order' to a 'possible disorder' (Sieverts, 2007). In connection with this, Sieverts describes how this approach to qualification is an intermediate position between two professional 'camps' – either passionate opponents or euphoric supporters of the development of urban landscapes. The opponents represent a fundamental rejection of the forms which the current dynamics of urbanisation assume, and insist on retaining the idea of the traditional centre-oriented European city with its clear contrasts: centre – periphery, developed – undeveloped, significant – not significant. This is all very much reminiscent of Jackson's characterisation of Landscape Two. Conversely, the supporters celebrate the non-specificity of the urban landscape and see the lack of identity as a liberating factor. From their point of view urban potential is enabled by the fragmentation of landscape, where uncertainty and openness promise unlimited freedom and opportunity. In this way it is reminiscent of Jackson's characterisation of Landscape One.

Sieverts position on qualification originates in the work of Vera Vicenzotti, who has described how the term wilderness is used as a metaphor for the urban landscape with both negative and positive connotations. For the opponents (the conservatives) the wilderness, and its disorder, represents a threat to the existing order and it's meaning; for the supporters (the progressives) the wilderness represents a detachment or liberation from inherited understandings of order (Vicenzotti and Trepl, 2009). This nuanced approach makes it easier to understand how Sieverts, in his description of a movement from an impossible order to a possible disorder, expresses to a greater extent a desire for a new order which has been freed from conservative conceptions of order (a feature of Landscape Two) rather than an actual desire for disorder (a feature of Landscape One). In this way the approach to qualification, which Sieverts is a representative of, can be seen as an attempt to formulate new possible orders, based on the fragmented character of urban landscapes rather than impossible ideals; orders that recognise and incorporate a degree of disorder that is a consequence of the autonomy and self-organisation that seems to characterise its development.

Road networks and the qualification of urban landscapes

What role can the road network play in relation to the qualification of urban landscapes? When landscape is understood and approached as a synthetic space or a man-made system of spaces superimposed on the face of the land, the road network can be described as an integrated part of the landscape. In his essay *Roads Belong in the Landscape* (1994) Jackson reminds us that roads should not only be identified with movement between places, but that they are places in themselves and will always be involved in the development of the landscape – in the modern landscape no other space has been so versatile.

When seen in relation to Jackson's idea of qualifying Landscape Three through a sort of balance between the qualities that characterise Landscape One and Two, the road network holds a special potential. On the one hand, the road network, in a literal sense, forms a basis for massive self-organisation, related to the 'system of automobility' (Urry, 2005), and thus contributes to creating the conditions for the growth of a highly complex and changeable landscape – a landscape somewhat similar to Landscape One. On the other hand, the vast majority of the road network is part of public infrastructure and is planned, managed and administrated by public authorities, the same authorities which, from the absolutism of the renaissance to today's governmental planning apparatus, have been setting out visions for a landscape with clear and permanent boundaries – a landscape somewhat similar to Landscape Two. For instance, it is evident when reading The National Planning Report for Denmark 2010 that the Danish government wanted 'a clear boundary between city and country' (Miljøministeriet, 2010). Such an objective could rightly be described as 'good intentions' against 'incontrollable cities' (Nielsen, 2008), but it is also true that public planning continues to hold the potential to protect urban landscapes against excessively utility-oriented use. In this way road networks seem to take a special position in relation to the ability to mediate between the qualities that characterise Landscape One and Two. The fact that in many European countries the greater part of the road network is still the responsibility of public authorities and is a public domain opens an opportunity to involve the road network as a tool for planning-related efforts to qualify urban landscapes. However, this presupposes that the road network is seen as more than a purely traffic-related and transport-economic affair. The first important aspect in relation to the architectural strategic potential of road networks is, consequently, concerned with a consideration of additional functions for road networks, so that they, in the words of Gary Strang, may become similar to well-functioning fields which serve multiple purposes. It would thus become possible to take advantage of the relatively large budgets for construction and renovation already connected with road networks, and increases the yield from these public investments.

Another important contribution to the architectural strategic potential of road networks is related to the transgressive nature of road networks. Crossing various zones and other administrative boundaries, road networks exist as an infrastructure for the system of automobility and as an organisational fabric for the system of spaces, which, according to Jackson, constitute the landscape. It is precisely the fact that networks use organisational logics different from those of zone planning which opens up new possibilities for breaking with the rigid thinking linked to Landscape Two. Based on Sievert's description of the qualification of urban landscapes as a movement or shift of focus from an impossible order to a possible disorder, road networks might be considered as organisational platforms for a possible (dis)order based on different ordering principles than those related to zoning. When seen in relation to the crucial role the development of modern road systems have played in relation to supporting the integration of urban and rural environments, which characterise urban landscapes (Clemmensen, 2008a), it seems natural to see the organisational properties and characteristics of the road network as an alternative or a supplement to the rigid ordering principles of zoning.

Possible sites of architectural intervention

As indicated in the introduction, the zoning approach to planning has not left much room for ideas about spatial organisation based on networks. This lack of attention apparently recurs when it comes to the way architects consider 'sites of architectural intervention'. For example, Keller Easterling has described how architects seldom defines sites of architectural intervention in a way that will permit exploration of organisational or network architecture, and calls for greater attention on the relation between organisational procedures and the production of space (Easterling, 1999). In a similar way, one could call for a greater attention on the relation between the organisational properties of road networks and the production of space in urban landscapes. Which organisational principals can be identified and what are their potentials in relation to the qualification of urban landscapes? In particular, what might improve their degree of connectivity[1] and porosity[2], both of which can be identified as key objectives in relation to the qualification approach to urban landscapes (Clemmensen, Daugaard and Nielsen., 2010)? In an attempt to answer these questions we will revisit three well-known sites. The answer is neither unequivocal nor exhaustive but should be regarded as a conceptual opening and an attempt to illustrate how road networks could function as framework for green infrastructure.

The wayside as parallel network

Benton MacKaye (1879–1975), who was deeply engaged in American planning in the first half of the 20th century, developed the idea of the wayside as a special partition within planning with active boundaries

1 Interconnection between the different elements in urban landscapes is essential if they are to function as coherent domains reflecting common interests. This becomes increasingly important as urban landscapes accommodate both global elements that follow global rules and local elements that serve the living and working worlds of the local area (Sieverts, 2008, p. 263). Connections that function across scales or levels of influence and double coded zones that work as 'glue' between different elements have the capacity to support the connectivity of urban landscapes.

2 Bernardo Secchi and Paola Viganò use the term 'porosity' to explore and question how different spatial structures can absorb movement and change: «Porosity varies in different materials, and is a function of their make-up, structure, form and design.» (Secchi and Viganò , 2009, p. 29) Porosity contains and combines two sets of objectives: reducing barriers in urban landscapes, and improving their permeability in order to ensure unhindered flow for pedestrians and cyclists as well as flora and fauna. The overall purpose is to maintain an openness and 'availability towards changing collective and individual rhythms' (Viganò, 2007).

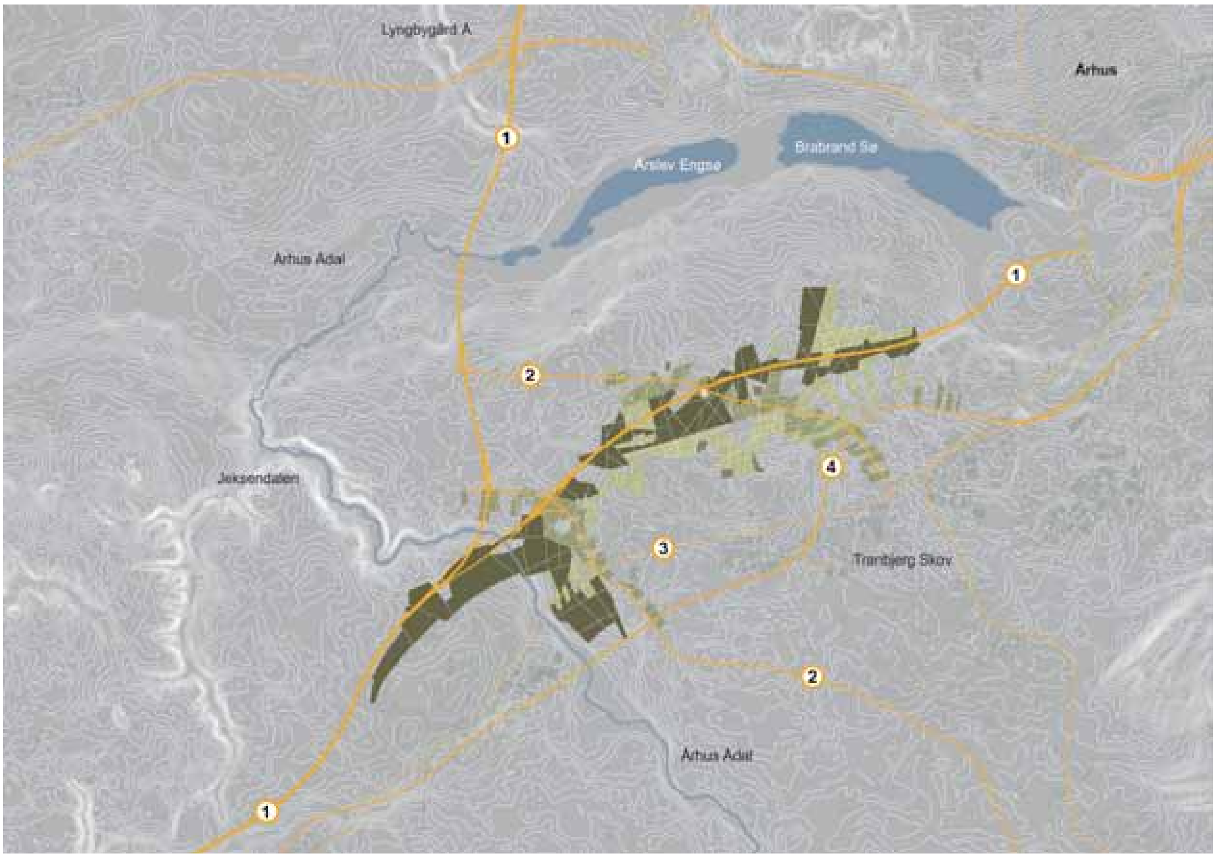
and an extensive organisational range. According to Mackay, the ribbon of neutral no-mans-land adjacent to all major roads, also known as the 'right of way', could be considered to be a critical conduit between towns and wilderness or recreation and could be designated in ways that affected all the surrounding land as well as the experience of driving on the roadway. The creation of a national highway system automatically resulted in the parallel formation of a diverse national network of wayside-landscapes (Easterling, 1999). Similar considerations are found in the concept of the American parkway – the idea of parallel networks in a linear park-landscape. For example, William Whyte (1917–1999) saw great potential in the American parkway in terms of creating new spatial and recreational connections. Yet unlike MacKaye, Whyte had a more visual-aesthetic appreciation of landscape and his recommendations have largely supported the goals of environmentalists and preservationists as cautions against wasting or abusing land (ibid.). This demonstrates how the concept of the parkway was never fully developed, and to a large extent has been reduced to a matter of creating scenic roads in contrast to the dirty reality along the American highways.[3]

The idea of the wayside as a site of parallel landscape networks might hold an even greater potential today, as the diffuse and complex patterns of everyday life in fragmented urban landscapes does not seem to be matched by a corresponding degree of connectivity and porosity; intensively cultivated fields, major roads with limited access, and isolated urban enclaves are increasingly posing a challenge. The wayside with its large interface could potentially be an important site of exchange between the many disconnected elements. It could also serve as an additional ecological network, which, together with the existing network, will form a more comprehensive and fine-meshed system, integrating and connecting a greater variety of environments.

The project *GREENfrastructure – skovrejsning i infrastrukturelle og bynære landskaber* (2004) serves as an inspiring example of the potential of a parallel landscape network in relation to motorways (figure 1). In this project Stefan Darlan Boris develops an alternative afforestation concept which breaks with existing tendencies to use afforestation in a kind of screening or camouflage strategy. Instead of being a background, Boris brings the forest into the foreground as a mediating element in dialogue with the surrounding landscape on three different levels: *The Forest*, *The Forest Park* and *The Forest Garden* (figure 2). *The Forest* represents the intention of creating an overall continuous landscape network to benefit biodiversity, and it is planned as natural forest with a low cultural imprint. *The Forest Park* is designed in a way that supports the visual qualities of the landscape and is given a moderate cultural imprint. *The Forest Garden* is thought of as a site in close dialogue with the activities in the local everyday landscape, which in time will have a high cultural imprint (Boris, 2010). In this project, the motorway is transformed

3 John Brinckerhoff Jackson was critical about this trend, which stood in stark contrast to his own understanding of the landscape as a living and dynamic place: «You may gather that I am not enthusiastic about the current beautification program. I am not. I recognize the goodwill and patriotism of its instigators, and I recognize the need for order and control in the American landscape. But I am convinced the basic philosophy of this crusade is little more than a collection of tired out middle-class platitudes about the need for beauty, greenery and the wickedness of bad taste.» (Cited in Easterling, 1999, p. 118).

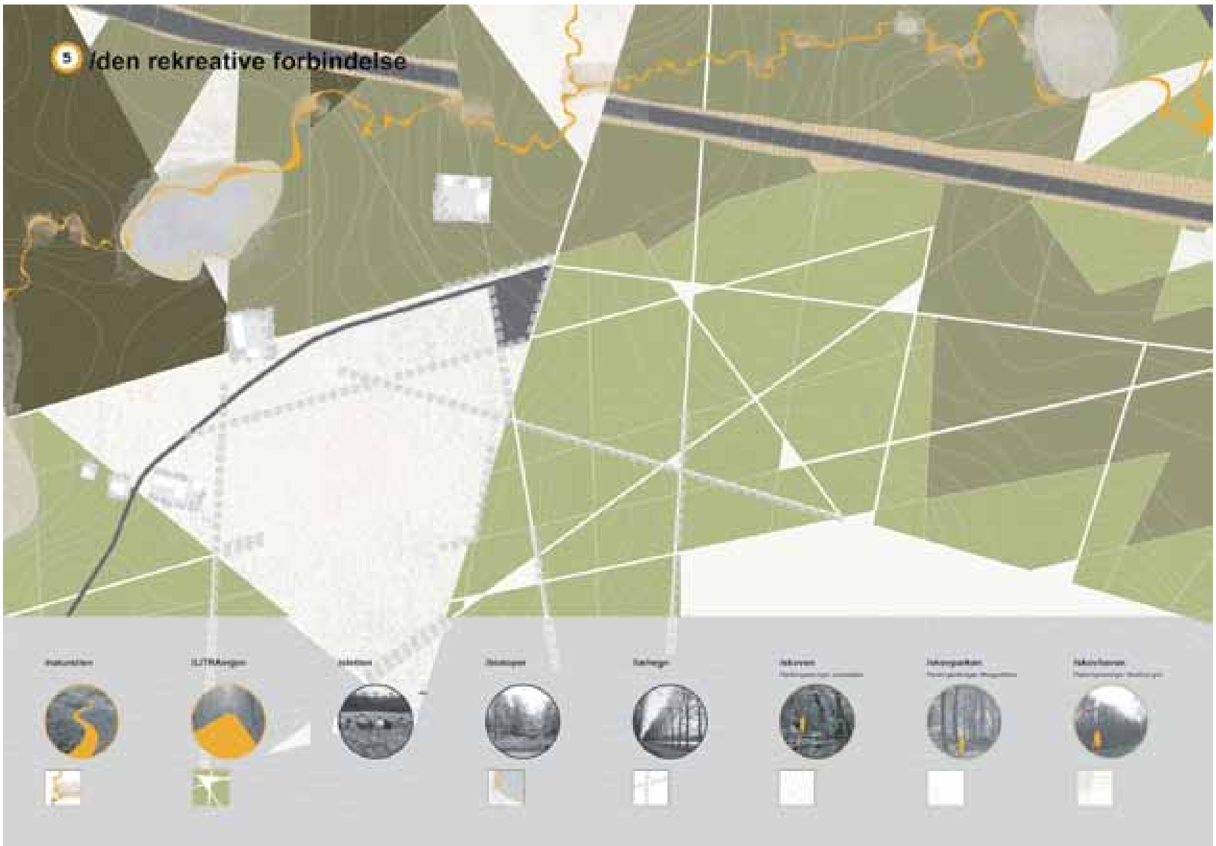
from a potential barrier to a central spine in a linear park, which uses the wayside in an attempt to turn the back into the front. The wayside is not only utilised as a physical connection and a framework for future development, it also becomes the site that renders the surrounding urban landscape accessible as a meaningful place (figure 3). In this way the project represent a line of thinking with great development potential in relation to the concept of green infrastructure.



The super grid as urban-rural interface

Another important site for architectural intervention is linked to the structure of road networks and its influence on the organisation of the city. According to Albert Pope, it is possible to identify two fundamental forms of organisation – the open *grid* and the closed *ladder* – which respectively create the foundation for a continuous centrifugal development or a discontinuous centripetal development. In the latter case, the city is developed as a number of independent urban forms defined in contrast to the surrounding space. In relation to this distinction between grid and ladder, the *super grid* can be defined as an hybrid form of organisation where the closed ladders are inscribed in an overall open grid – a combination of continuous centrifugal development or a discontinuous centripetal development (Pope, 1996).

Figure 1
Overall plan from the project GREEN-frastructure – skovrejsning i infrastrukturelle og bynære landskaber (2004) in which Stefan Darlan Boris develops an alternative afforestation concept that breaks with existing tendencies to use afforestation in a kind of screening or camouflage strategy. In this project the wayside is utilised in the creation of a parallel landscape network in relation to a motorway southwest of Aarhus, Denmark. The numbers on the plan refer to the hierarchy of roads, which is used to inform the design. The three different green colours refer to the three different levels in the project: The Forest (dark green), The Forest Park (green) and The Forest Garden (light green) (Stefan Darlan Boris).



One of the finest examples of the use of the super grid in the organisation of a larger urban development is found in the 1969 master plan for the English new town of Milton Keynes (figure 4–5). Here the overall grid secures equal accessibility across the entire area and minimises the risk of traffic blocks, the ladders secure placid environments without through traffic and easy access to recreational qualities at a lower level. With this combination the inhabitants gain a freedom to move across the area and harness all of its qualities – each inhabitant has the freedom to combine his or her own unplanned neighbourhood (Rasmussen, 1994). A linear network of parks, which secure important connection across the area, also supports this freedom.

Like other urban development plans from the same period, the master plan for Milton Keynes has since been criticised for promoting urban sprawl and car dependency, and planning schemes that utilise the road network to combine qualities associated with urban and rural environments seem to have disappeared. However, the reality of today's urban landscapes reassembles the kind of urban life that the master plan for Milton Keynes was intended for; the car has become the preferred mode of transport and most people move around freely and assemble their own 'neighbourhood' as they see fit. The most significant difference seems to be that it happens without an overall plan or vision.

Figure 2
Detail plan from the project GREENfrastructure – skovrejsning i infrastrukturelle og bynære landskaber (2004). Instead of just being a buffer between the motorway and the surrounding urban landscape, locating the forest in the background, Boris brings the forest into the foreground as a mediating element in dialog withe the surrounding landscape on three different levels: The Forest (dark green) represents the intention of creating an overall continuous landscape network to benefit biodiversity and is planned as natural forest with a low cultural imprint. This part of the green infrastructure helps connecting existing biotopes in the urban landscape. The Forest Park (green) is designed in a way that supports the visual qualities of the urban landscape and is given a moderate cultural imprint. The Forest Garden (light green) is thought of as a site in close dialogue with the activities in the local everyday landscape, which in time will have a high cultural imprint (Stefan Darlan Boris).

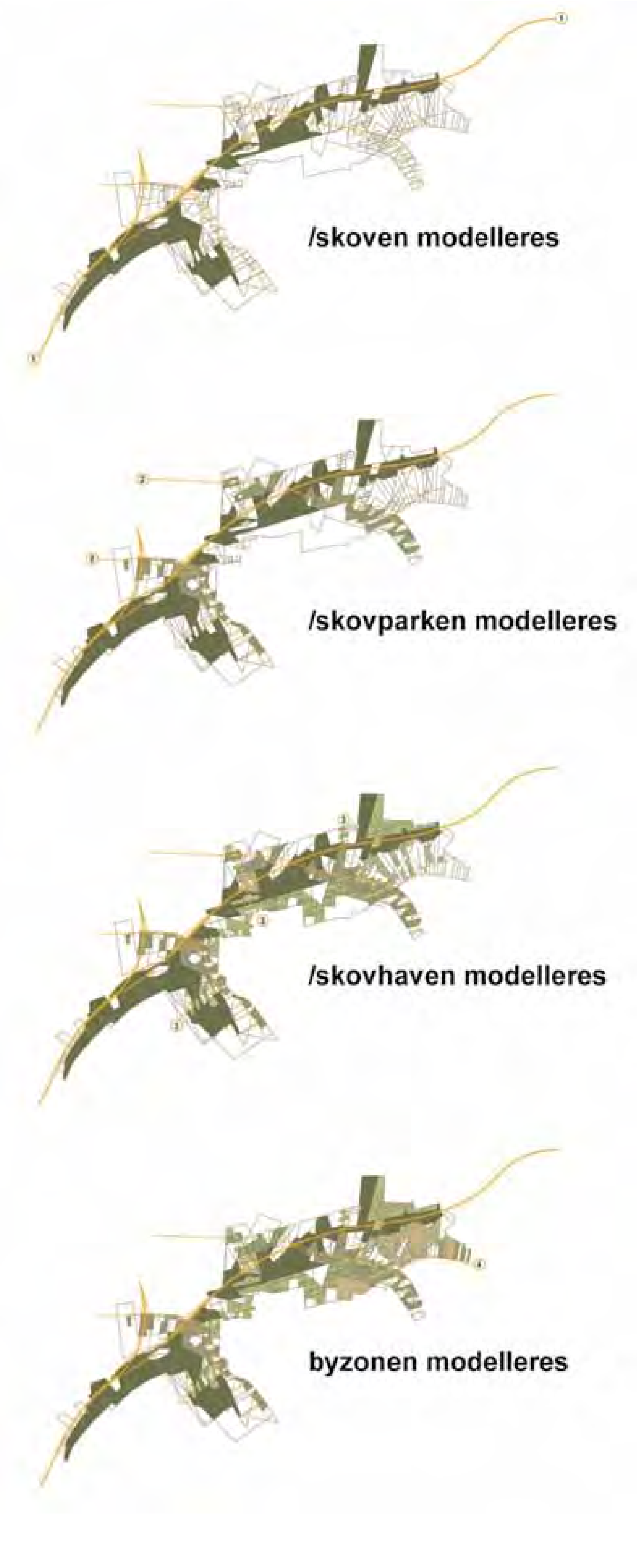


Figure 3
Diagrams from the project GREENfrastructure – skovrejsning i infrastrukturelle og bynære landskaber (2004) explaining the different stages in its development. From the top: The Forest is shapes, The Forest Park is shaped, The Forest Garden is shaped and new areas for urban development are shaped.
In this project the wayside is not only utilised as a physical connection and a framework for future development, it also becomes the site that renders the surrounding urban landscape accessible as a meaningful place (Stefan Darlan Boris).

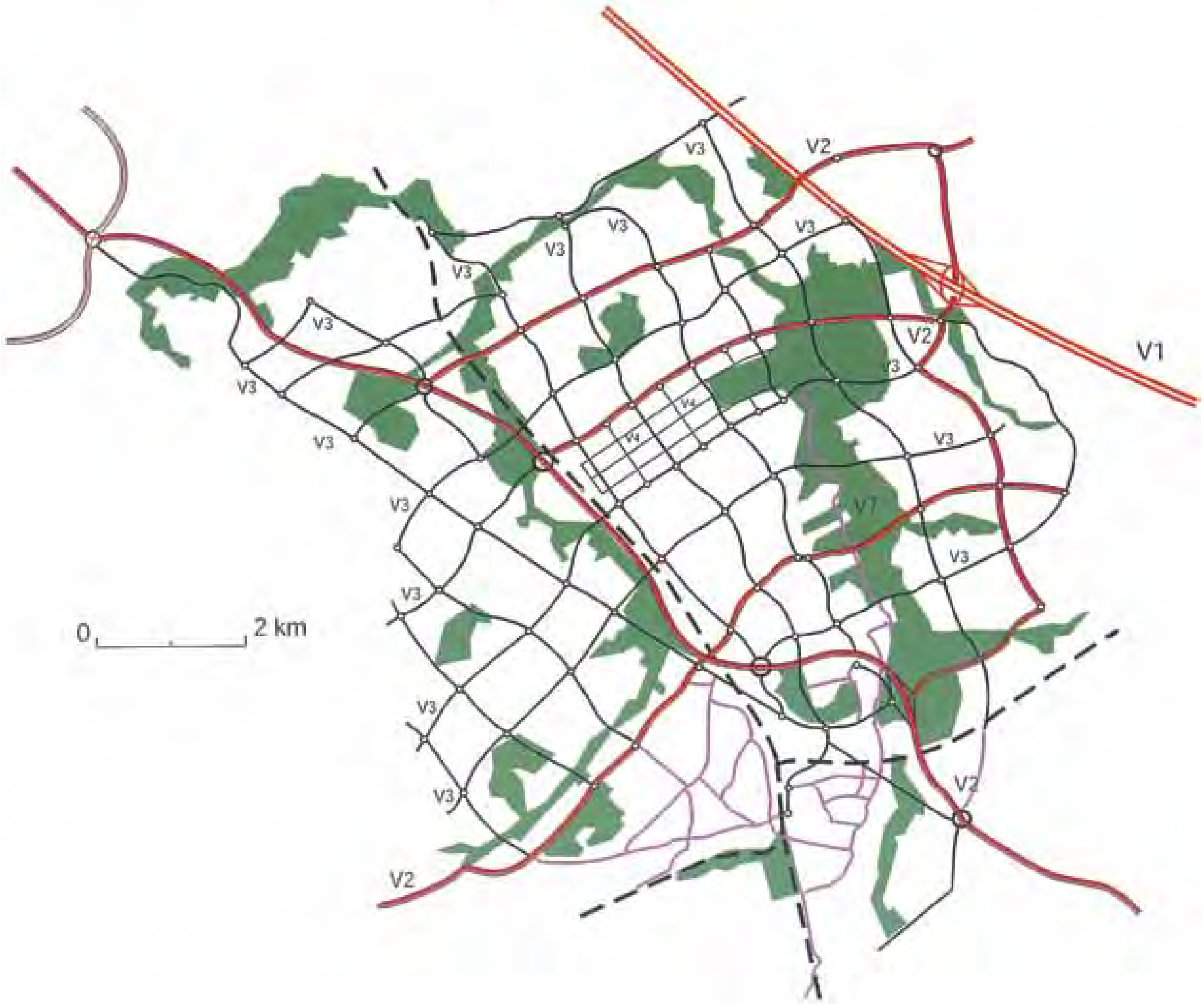


Figure 4
Illustration of the road layout and green infrastructure in the master plan for new town Milton Keynes in England (1969). The new city is organised and structured around a so-called super grid (shown in black/V3), which is intended to give the inhabitants maximum freedom to move across the area and harness all of its qualities (Philippe Renoir).

In this respect, the super grid could be an appropriate organisational framework for today's urban landscapes – a way to organise the urban-rural interface in more qualified ways. As part of my PhD-project *Vejnettet og det urban-rurale landskab* (2008), this idea was tested in an exercise concerning a small section in the growth region of East Jutland, Denmark. The main idea was to illustrate how future urban development and expansion of the road network could be organised in a way that benefits, rather than compromises, the connectivity of urban landscapes. Instead of solving existing and expected traffic problems through a continued expansion of the motorway system, it was proposed to upgrade and expand the network of secondary roads to forms a super grid, which could support the diffuse commuter pattern in the region (figure 6). Similar to the master plan for Milton Keynes, the super grid is also used as a framework for green infrastructure – structures which support the urban-rural interface – in this case by utilising the space in between the 'closed ladders' and the 'open grid' in order to protect environmentally sensitive areas of river valleys from development and secure ecological and recreational connections. In each of the superblocks surrounding

Figure 5
The vision for new town Milton Keyens (1969) was to develop a city which was greener than the surrounding landscape. This meant that 20 % of the site was devoted to the development of an extensive green infrastructure, which should secure important landscape connections ahead of the actual urban development. Milton Keynes also became known as the 'Forest City' (Walker, 1994) (MKDC).

the river valleys, the existing tertiary roads are converted into a network of recreational connection with restricted motor traffic. Future development is oriented towards and directly connected to the secondary roads of the super grid in order not to compromise the river valleys as an important green infrastructure.

The 'sponge' as local connector

In relation to the project *Water and asphalt – the project of an isotropic territory* (2006), Bernardo Secchi and Paola Viganò have studied the fine-grained infrastructural networks that characterise the 'territories of dispersion' in Italy. These networks, which are both ubiquitous and isotropic but also site-specific and adapted to the local geography and culture, are characterised as 'sponges' because of their sponge-like structure. In relation to their studies, Secchi and Viganò identify a problem in the way these 'sponges', which are often developed and expanded gradually over a long period of time, are increasingly regarded as being insufficient compared to contemporary needs and ideas of efficiency. New urban and infrastructural initiatives often ignore the inherent qualities of the 'sponge' by introducing a different logic based on hierarchisation, fragmentation and homogenisation (Viganò, 2008).

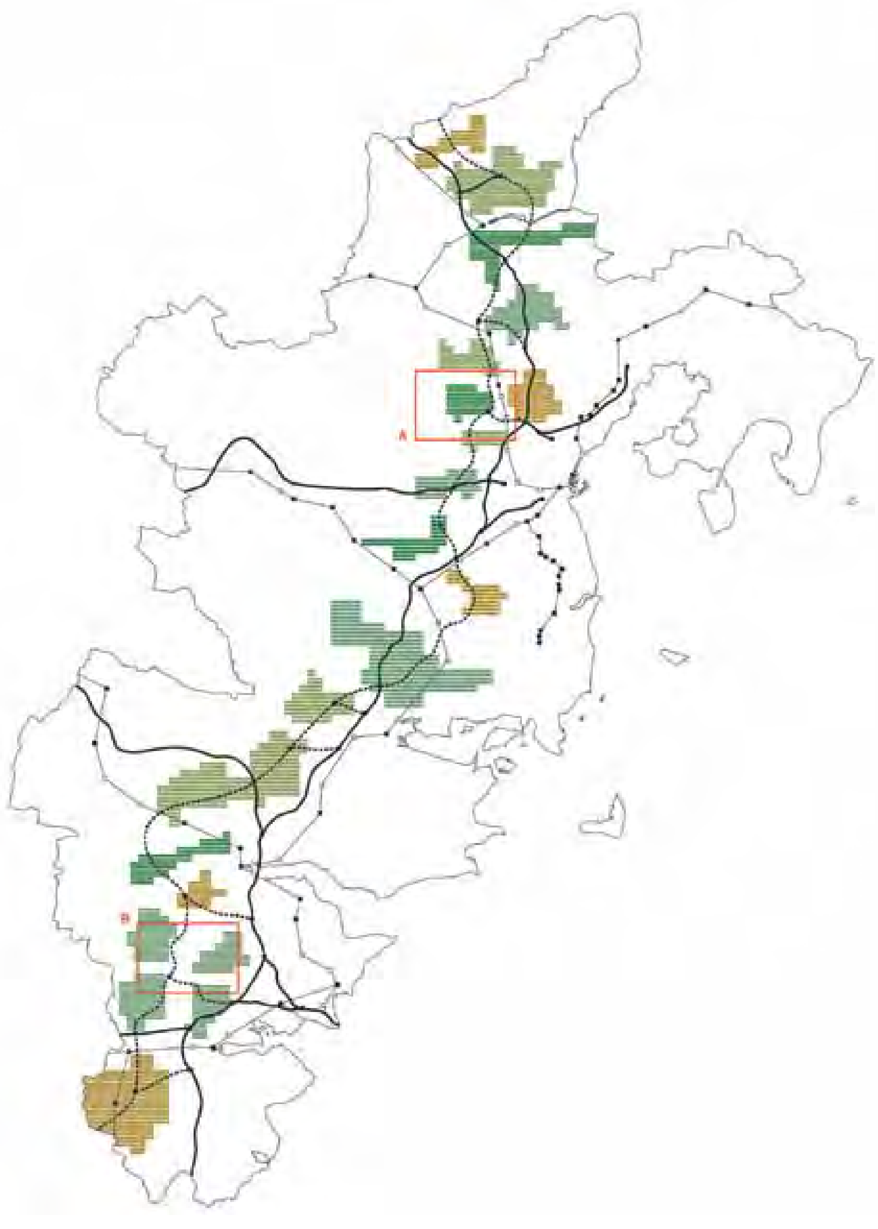
In Denmark, these sponge-like infrastructures can be identified in the fine-grained network of minor roads which connects the countless houses, farms and villages in rural areas. Today, many of the areas with dispersed settlements are part of larger urban landscapes, and the fine-grained network of minor roads constitutes an important connection

Figure 6
The super grid as organisational framework for new green infrastructure in urban landscapes. This idea was tested in an exercise concerning a small section in the growth region of East Jutland, Denmark, as part of the PhD-project Vejnettet og det urban-rurale landskab (2008). The main idea was to illustrate how future urban development, afforestation, and expansion of the road network could be organised in a way that benefits rather than compromises the connectivity of urban landscapes. Instead of solving existing and expected traffic problems through a continued expansion of the motorway system (top map – blue lines), it was proposed to upgrade and expand the network of secondary roads to form a super grid (top map – red and black lines), which could support the diffuse commuter pattern in the region. Similar to the master plan for Milton Keynes, the super grid is also used as a framework for green infrastructure. The super grid is used to both organise the planned afforestation in a forest network (middle map), which in some areas can be colonized by new urban enclaves, and to transform tertiary roads in the river valleys into a network of recreational paths (bottom map) to protect the environmental sensitive valleys from further development (author).

between the diversity of different locations. At the same time, there is a tendency for new road infrastructure and single-family housing developments to be organised in way that ignores and compromises the qualities of the fine-grained network of minor roads, apparently because these interventions, as pointed out by Viganò, follow very different logics.

Based on these considerations it makes sense to recognise the fine-grained network of minor roads – the sponge – as an important site for architectural intervention in relation to the qualification of urban landscapes. By utilising the specific qualities of the 'sponge' in relation to the on-going transformation of these landscapes, it becomes easier to create site-specific development without 'fracture' – development which is based on what is already there and has worked for years (ibid). In this way, the 'sponge' addresses a central problem in urban landscapes; that of au-

Figure 7
Schematic plan from the project Byudvikling og trafikal infrastruktur i Østjylland (2007), which was an exploration into new concepts for the organisation of future urban development and transport infrastructure in the growth region of East Jutland, Denmark. According to this particular plan and concept, the future urban development is concentrated in a number of new urban landscapes (green and brown colours) in relation to an infrastructural spine with two parallel motorways (thick black lines) with one motorway being new (dotted). Areas marked with a red square were subject to a more detailed proposal (see figure 8) (author).



tonomous new systems new systems being super imposed on existing systems without any form of exchange that contributes qualitatively to the landscapes (Sieverts, 2007).

This type of approach can be identified in the concept and schematic plan for the organisation of the growth region of East Jutland, Denmark as described in *Byudvikling og trafikal infrastruktur i Østjylland* (2007). In this project future urban development is concentrated in a number of new urban landscapes in relation to an infrastructural spine with two parallel motorways (figure 7). Two examples illustrate how new urban landscapes could be organised in relation to the existing conditions, and one of these implement a form of organisation which utilises the existing fine-grained network of minor roads. In this example, this network is linked directly to the motorway by a loop, which will dramatically increase overall accessibility to the area. Part of the 'sponge' forms the basis of a number of linear housing developments which, in combination with an extensive afforestation program, can be expanded and subdivided (figure 8). By utilising existing infrastructures, important connections between new and existing developments in the area are secured, and the green infrastructure of new housing developments is woven into the existing landscape and forest structure. In relation to the green infrastructure of the new housing development, the 'sponge' makes it possible to optimise the length of the fringes of the forest – a highly valued quality for housing.

Figure 8
Illustrations from the project Byudvikling og trafikal infrastruktur i Østjylland (2007), which explores how the fine-grained network of minor roads – the 'sponge' – can be utilised in the organisation of a new urban landscape. The new motorway (thick red) connects to the existing road network (orange) by a loop (thin red). New developments are proposed along existing roads (light grey) and future forest roads (light green). New forest (green) is proposed in relation to existing forest (dark green) (author).

Conclusion

The three cases above all address the link between the organisational properties of road networks and the production of space, in particular in relation to the concept of green infrastructure. They illustrate how road networks can be conceptualised as a framework for green infrastructures which can qualify urban landscapes, mainly in relation to the creation of structures that can mediate meaningful connections between the different systems within urban landscapes. In this way, roads can become elements associated with porosity rather than fragmentation.

The three cases also indicate that earlier ideas and visions about the relationship between infrastructure, landscape and territory might gain a new relevance. For example, it has been suggested that architect Frank Lloyd Wright's (1867–1959) comprehension of the importance of the road network in *Broadacre City* (1935) completely anticipated how most people today use these networks (Dupuy, 2008). The parallels between Wright's ideas about life in *Broadacre City,* where the only real centre were the family's individual home, and the way life unfolds itself in contemporary urban landscapes can be striking. However, there is at least one very important difference; the widespread carpet of urban landscapes in contemporary Europe as well as North America is not the result of comprehensive visions and master plans created in the minds of architects and planners. On the contrary, they are the result of countless decisions, visions, plans, dreams, etc., which in a positive way reflect the diversity of free and democratic societies.

This is not to say that we cannot learn something from these cases in which transport infrastructure is integrated in the way 'city' and 'landscape' are being conceptualised and planned. The fact that huge parts of the road network continue to be constructed without architectural visions of the organisational dimension suggests the importance of developing new perspectives which can match issues of traffic management and transport economy. By regarding the road network as a structural tissue, which, for better or worse, has been involved in the evolution of urban landscapes, it becomes possible to develop visions retrospectively. Visions, which are about seeing the potential in the existing road-conditions, and which, on this basis, create the framework for green infrastructures, can qualify urban landscapes by increasing their overall connectivity and porosity. To do this, architects need to challenge road planning as an autonomous discipline.

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Biographical information

Thomas Juel Clemmensen
PhD., Associate Professor
Aarhus School of Architecture
Address: Norreport 20,
8000 Aarhus C, Denmark
Phone: +45 893 603 06
E-mail: ethomasjuel.clemmensen@aarch.dk

Thomas Juel Clemmensen (b. 1973) is educated as an architect, holds a PhD in architecture and is a member of the Danish Landscape Architects Association. He is an Associate Professor at the Aarhus School of Architecture, where he teaches and carries out research in the fields of urban planning and landscape architecture. His main research interest is how landscape architecture can inform and improve current transformation processes in cultural landscapes. Publications include articles in the Journal of Landscape Architecture and the Nordic Journal of Architectural Research. Alongside his academic career, Thomas works as an independent consultant.

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EXTENDING THE ROLES OF ECOLOGICAL NETWORKS IN A SUSTAINABLE LANDSCAPE

MUHAMMAD FARID AZIZUL

Abstract

The ecological network concept has emerged in the past three decades in response to growing expectations of a balance between conservation and development in human-altered environments. This spatial concept has developed to facilitate the connection of critical ecosystems to the protection and restoration of biodiversity. As the concept is a societal construct, it is important to frame the roles and functions of spatial conservation tools within a socio-cultural point of view in order to fully realize the benefits of such kinds of landscape structures. This paper reviews and critiques literature across disciplines – landscape ecology, conservation biology, landscape and urban planning and nature conservation – published between 1995 and 2012. It places an emphasis on the viability of the multiple services needed in the planning and implementation process. Included is a commentary on whether ecological services, as an indicator of value, sufficiently capture the socio-cultural dimension. A range of challenges and issues remain however, about how to integrate biodiversity conservation with other sustainable uses of the landscape. Examining this issue in the context of a socio-ecological system serves to promote a better understanding of such an intricate relationship. This paper suggests potential research directions that could help address these challenges.

Key words:
Ecological network; greenways; socio-cultural process; ecosystem services; socio-ecological system; sustainable landscape.

Introduction

One of the most significant current discussions in biodiversity conservation and planning is the Ecological Network (EN) concept, which has arisen in response to habitat loss and fragmentation. The development of the concept is a result of land use intensification, which has been recognized as a primary threat to biodiversity survival in a man-dominated landscape (Forman, 1995; Cook, 2002; Bennett, 2003; Jongman, 2004; Hellmund and Smith, 2006; Opdam and Wascher, 2004). The threat has resulted from the clash of anthropogenic activities and dynamic natural processes (Hobbs, et al., 2008) which has resulted in habitats becoming smaller and more isolated, and thus unable to support habitat structure and ecological processes (Bennett, 2003).

More recently, literature has emerged that offers contradictory findings about the traditional approach in conserving biodiversity through protected areas (PAs). Such measures of conservation are not considered viable in a rapidly changing world where biodiversity protection should be incorporated into the wider landscape and be ecologically, economically and socially sustainable (summarized in Crofts, 2007). Several authors have emphasized that these PAs are not viable in the long term (e.g. Martinoli, et al., 2006; Maiorano, et al., 2007; Carroll, et al., 2004), and that eventually each is destined to function as an isolated ecosystem (Bennett, 2003). Thus, conventional efforts to safeguard biodiversity in single-site protection areas are being challenged, in order to secure ecological efficiencies as well as socio-economic goals (Crofts, 2007).

In this context, various operational models have emerged in conservation planning. These include the Biosphere Reserves launched by UNESCO in 1974, the Ecological Network programme developed in several European countries, the Reserve Networks in Northern America, Bioregional Planning in America, and Biological Corridors and Eco-regional based conservation. Although these terminologies differ in scope and emphasis, they share the common vision of reconciling biodiversity conservation and sustainable development through a spatial allocation of specific functions based on their ecological value (Bennett, 2004). The EN concept has received increasing attention in recent decades which has moved it beyond single–site PAs by establishing linkages to the wider surrounding landscape, especially in Europe (Jongman, 1995; Jongman, 2004; von Haaren and Reich, 2006; Opdam, 2002). This approach is based on three substantive theories of landscape ecology (Turner, 1989); metapopulation dynamics (Levins, 1969) and island biogeography (MacArthur and Wilson, 1967) in the conservation biology discipline. Further, Opdam, Steingröver, and Rooij (2006, p. 324) define EN as «*a set of ecosystems of one type, linked into a spatially coherent system through flows of organisms, and interacting with the landscape matrix in which it is embedded*».

The key term for this concept is landscape connectivity, which is a critical feature of landscape configuration as it allows organisms to move, migrate, and disperse between habitat patches. This facilitates gene flow and helps maintain physically separated populations (Bennett, 2003; Soulé, et al., 2004). Furthermore, Leitão, et al. (2006) posit that connectivity is an important property in and of itself, resulting as it does from the interaction between landscape structure and function. This in turn keeps ecosystems functioning, and is relevant in conservation planning and management (Naveh and Lieberman, 1994; Forman, 1995; Bennett, 2003).

One question that needs to be asked however is whether integrating biodiversity conservation and other land uses through the establishment of ENs (figure 1) will deliver multiple ecosystem services in conflicting and competing land uses. Implementing this concept into the wider landscape requires other considerations around what the potential ecosystem services as it provides for society (Jongman, 2008). Early thinking in planning ENs focussed narrowly on the conservation and management of specific habitats and green spaces for focal or umbrella species as a proxy for overall ecosystem structure. Inevitably, planners ignored the wider ecological and social patterns and processes that surround the heterogeneous landscape (Hostetler, Allen and Meurk, 2011). A new way of thinking is required in order to manage the complex problematic situations «*that lie at the intersection of social and place-based systems*» (Hostetler, Allen and Meurk, 2011, p. 370). This new perspective on the sustainable use of biodiversity through the EN concept requires an integration of socio-economic and environmental information (Jongman, 2007). Moreover, the use of biophysical and socio-cultural information to suggest opportunities and constraints for decision-making about the use of landscapes needs to be incorporated into the ecological planning process (Steiner, 2000).

Rientjes as cited in Jongman (2007) suggests that information about the importance of ecosystem services at local, regional and national scales is crucial in enabling decision-makers to mobilize public support for its implementation. Innovative methods need to be initiated through a multifunctional spatial conservation concept to provide ecosystem services in an increasingly urban world. Ahern (2011) suggests this can be achieved through intertwining and combining functions (such as

Figure 1
An ecological corridor within a new urban development in Manukau, Auckland, New Zealand (Source: M. van Roon, personal communication 2013)

re-vegetated corridor functioning for animal movement and recreational trail), stacking or time-shifting, that will consequently prove to be spatially and economically efficient. This paper presents a critical review on the viability of the multiple services provided in the EN planning and implementation process. It focuses on the social-cultural dimension, which, it contends, remains unrealized in the decision-making process.

EN development has typically targeted and prioritised biodiversity conservation for ecological coherence. Green infrastructure as now popularly defined by landscape professionals in interdisciplinary fields (see for example Benedict and McMahon, 2006; Selman, 2008; Srinivasan, O'Fallon and Dearry, 2003) could logically encompass terrestrial ecological networks and associated waterways. Ecological Networks focussed on ecological coherence contribute a backbone for a green infrastructure framework that combines with other forms of land use in delivering multiple ecosystem services. The application of ecological principles as an imprint for a successful green infrastructure movement presents a significant and strategic way of achieving ecological and social sustainability simultaneously.

Method

The review is based on literature reported in the root disciplines of landscape ecology, conservation biology and applied disciplines, in landscape and urban planning, nature conservation and ecosystem services. A set of keyword combinations – ecological network, greenways, ecosystem services, socio-cultural process, socio-ecological systems – were used to direct the literature search. A computerized searching technique was applied to online database navigation from Science Direct, Springer, Taylor and Francis and Scopus. Papers were extracted primarily from those published between 1995 and 2012 to illustrate the chronological development of the concept from conservation-focused into integration in development planning perspective. Papers reviewed include theoretical, review, and empirical articles, both quantitative and qualitative. Literature was chosen to illustrate an in-depth understanding of the theoretical side of the EN concept and its role in enhancing both ecological functioning and the social system. A greater emphasis was placed on literature that addresses the impact on the socio-cultural process, along with issues in implementing the concept in the wider landscape and the implications thereof. The aspects taken into consideration in this review include an analytical approach in modeling EN, and the issue that has influenced its efficacy in ecological functioning, including spatial scales in its implementation.

Ecological Networks in a Sustainable Landscape

Spatial Concept and Components

The definition of the EN concept traverses disciplines, and its application extends from a rural to an urban context (Ignatieva, Stewart and Meurk, 2011). This concept is encapsulated in the conservation biology domain by the substantive theories (figure 2) of landscape ecology, metapopulation and island biogeography (Jongman, 2003). The EN model is composed of a core area, a buffer zone and a corridor or stepping stone (Bennett and Mulongoy, 2006; Jongman, 2003, 2004). The core areas have traditionally been existing PAs (such as national parks and forest reserves), with corridors or stepping stones to maintain physical linkages between core areas, buffer zones that protect the core areas from incompatible land uses, and sustainable-use areas for the exploitation of natural resources in the landscape mosaic. The concept embeds the principle of landscape cohesiveness through the connectivity of species that move between landscapes patches (Jongman, 2004; Bennett and Mulongoy, 2006). The development of an EN can facilitate ecosystem functioning at a variety of scales. The model can operate on a supra-continental scale, and on the ecological region, such as a watershed or mountain range. (Bennett and Wit, 2001). The review examines the applicability of an EN as an innovative spatial form integrated into a development pattern in nested hierarchical scales, i.e., a local-scale township, neighbourhood (urban or village) and urban-rural interface that connect to the larger ecological context.

Ecological Networks and Greenways – Spatial Integration

On the other hand, the concept of EN has expanded significantly to include the anthropogenic dimension of ENs in establishing a physical and functional connection to the visual and aesthetic, recreational and cultural resources in the landscape and in the urban planning domain (Beatley, 2000). The greenway concept (Ahern, 2002) developed from this perspective. It was originally intended to provide a linear passage connecting people in urban and rural areas in Northern America. The operational role of this approach evolved to form a spatial coherence which included significant cultural, visual and recreational dimensions (Fábos and Ryan, 2006). Greenways, or green corridors, often cross-link interchangeably but this can vary according to purpose and scale; wildlife corridor, scenic or historic route, or recreational trail (Little, 1995). The concepts of EN and greenway now overlap (figure 2) because of the similarity in its functional interpretation and structural similarities (Jongman and Pungetti, 2004). This progression has, for example, been illustrated in studies published in the special issue of the *Landscape & Urban Planning* journal that was dedicated to greenways (Volume 33, 1995) as an umbrella concept that captured the ecological and anthropogenic dimension of spatial integration (e.g., Burel and Baudry, 1995; Ndubisi, Demeo and Ditto, 1995; Yahner, et al., 1995; Zube, 1995). Therefore in this paper, the terms 'EN' and 'greenways' are both used as a matter of convenience to facilitate the data searching and communication.

Ignatieva, Stewart and Meurk (2010) posit that new models of urban ENs, as a subset of a broader network, should respect, conserve and enhance natural processes that will consequently improve biodiversity, aesthetics, and cultural identity and become an important framework for creating sustainable cities. However, there are questions as to how far the concept of an EN can be implemented (figure 2). Opdam, Steingröver and Rooij (2006) argue that ENs are an effective spatial structure to integrate the ecological, social and economic sustainability of the landscape, but the current body of knowledge is insufficient to support this proposition. This integrative spatial model provides an opportunity for more exploration into the relation of ecological functionality to social and economic values that moves from a spatially-explicit to a spatially-implicit approach (Opdam, 2006). The sustainable development of landscapes demands that «*the landscape structure supports the ecological, social and economic processes required, so it can deliver its goods and services to present and future generations*» (Opdam, Steingröver and Rooij, 2006, p. 323). The future challenge and role of ENs integrated with land use planning, will be their ability to link ecological efficiency to other aspects of social and economic benefits in a multifunctional landscape.

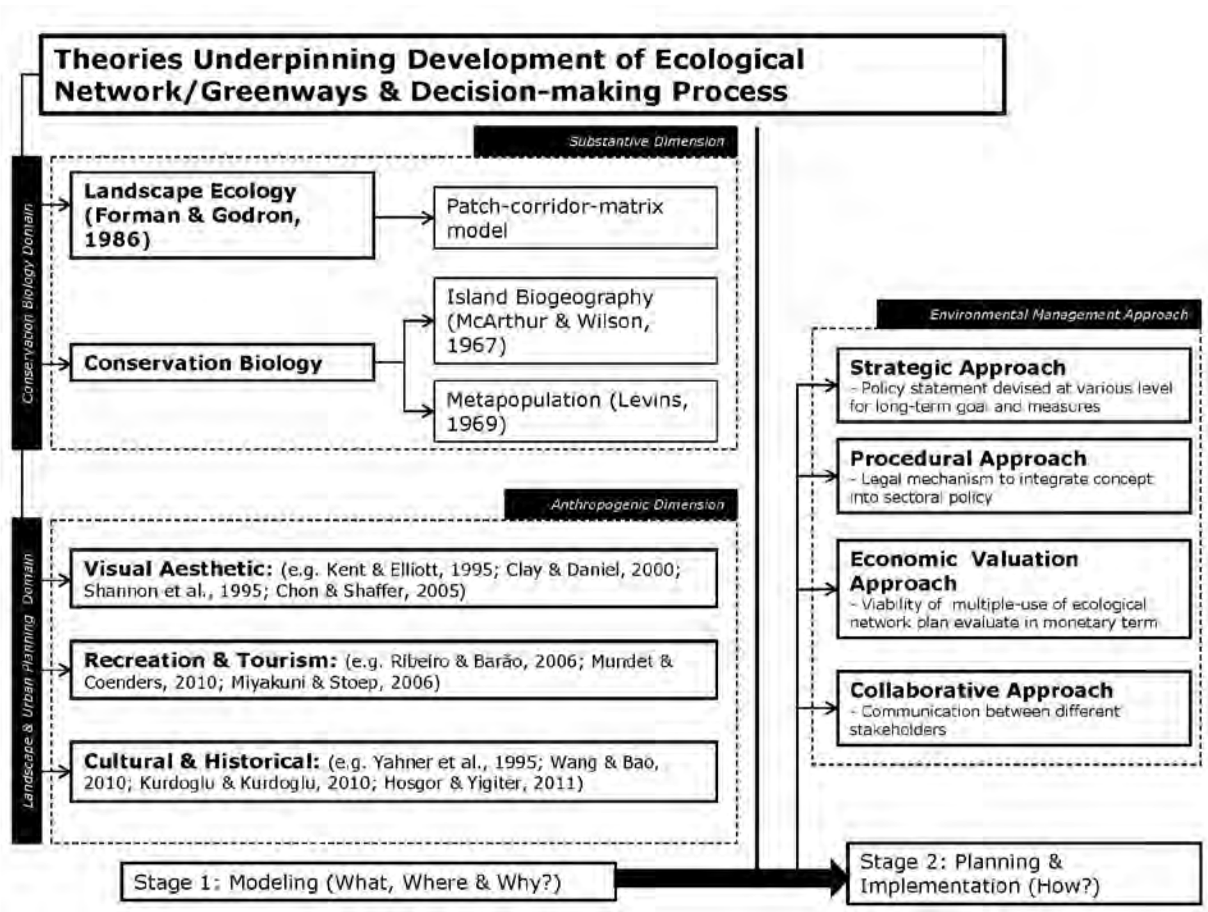

Figure 2
The theoretical underpinnings of the Ecological Network and Greenways concepts, including their implementation approaches in the decision-making process (Source: Author's own interpretation)

Findings and Discussion

Linking an Ecological Network and Socio-Cultural Values

While such planning of ENs is ecologically motivated, and highlights the connectivity characteristics of ecosystem processes through the linkage and connection of adjacent landscape patches *per se* (e.g. Gurrutxaga, Lozano and Del Barrio, 2010; Fleury and Brown, 1997; Fitzsimons and Wescott, 2008), it rarely incorporates data on any social or cultural aspects. Planning therefore relies on general ecological principles and assumptions, and on the success of particular connections, which also contribute to any social-economic sustainability. According to Forman (1991), creating landscape linkages addresses six public policy issues, namely; biological diversity, water resources, agriculture and wood production, recreation, community and cultural cohesion, and climate change. In other words, its roles and functions in the wider landscape should be looked at beyond their conservatorial role in order to realize such potential benefits.

Visual Aesthetic Quality

Besides a raft of attention about EN implications on biodiversity conservation, as discussed earlier, some efforts have been made to investigate the socio-cultural impact. In recent years, an increasing amount of literature has attempted to manifest perspectives on visual and aesthetic quality, and recreation, among others. Franco, et al. (2003) investigated the impact of agroforestry networks on scenic quality and found that the networks have a profound influence on the value of scenic beauty as perceived by respondents. Similarly, further researchers (Kent and Elliott, 1995; Burel and Baudry, 1995; Clay and Daniel, 2000; Zanon and Geneletti, 2011) indicated the integrated values of nature conservation and visual quality that need to be protected. Natori, Fukui and Hikasa (2005) argue that integrating biological and visual qualities at a human dimension into the environment provides a shared venue that addresses biotic and societal needs in nature conservation.

Recreation and Social Interaction

In the urban context, some research has been carried out to investigate the impact of creating a connected open space system on human recreational uses and experiences. For example, Coutts (2012) in his exploratory study found that not only did the community realize the ecological importance of connecting their park into the wider region, but they also increased their recreational activity as a result of having more available space through the interconnectedness. Several attempts have been made to identify and examine people's perceptions of urban greenways and their recreational use i.e.: Gobster and Westphal, 2004; Shafer, Lee and Turner, 2000: Tzoulas and James, 2010; Luymes and Tamminga, 1995; Asakawa, 2004). Greenways as an innovative spatial form also have been integrated in developing planned residential areas. For example, Zakaria (2006) proposed natural, recreational and cultural component to be integral part of greenways that influence the structuring of communities.

In another study, Yabes, Shetter and Schneeman (1997) recorded the evolving social values of urban waterways that resulted from the change in land use from farming into residential and commercial uses. The canal system plays an important role historically for older residents, as it used to support their agricultural activities, and presently it is an important venue for social interaction among community. Antonson, Gustafsson and Angelstam (2010, p. 3) provide a new perspective of connectivity that not only takes present needs into account but also the relationship to the «*historical connections that still remain*». Although the EN structure is more applicable at a local or regional level, but interestingly Lee, et al. (2008) found a positive correlation between neighbourhood satisfaction and certain landscape structures at site (neighbourhood) scale. The satisfaction increased when tree patches in the neighbourhood environments were less fragmented, less isolated, and better connected. In order to demonstrate the integration of EN as a principle in the green infrastructure framework, figure 3 illustrates an example that provides a multifunctional landscape structure that connects ecological coherence with social and cultural sustainability as argued in this article.

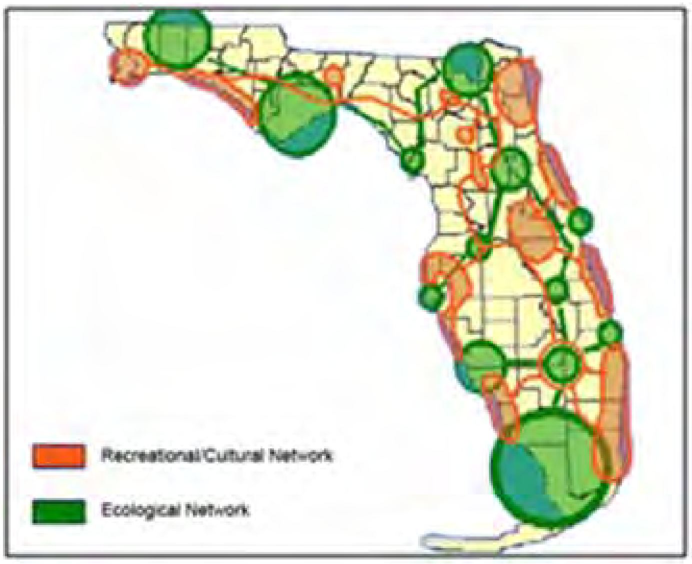

Figure 3
Florida state-level ecological network plan as part of the green infrastructure framework that addresses the vision to reconnect the fragmented protected areas system and urban green spaces based on community-defined typologies (Source: Benedict and McMahon, 2006)

Ecological Networks in Socio-Ecological Systems

The change of paradigm from the traditional ecological roles of ENs into an approach of sustainable development that integrates conservation and other goals is gathering momentum. In practice however, it is rare that information about ecological, social and cultural values is recorded and integrated into the decision-making process (Brunetta and Voghera, 2008). This is mostly due to the lack of research that has been done to understand and link those different dimensions (Antonson, 2009). Existing research has concentrated on assessing and describing individual values (Mander and Uuemaa, 2010). According to the European Landscape Convention (ELC), landscape is defined as an area, perceived by people, evolving through time due to both natural forces and human factors (Council of Europe, 2000 cited in Mikusiński, et al., 2012), which indicates that landscape is an integrated spatial unit that cannot be separated into individual systems (Matthews and Selman, 2006). From this perspective, the presumed role of an EN in protecting nature should also be extended to reconnecting people, and to a greater or lesser extent, should also be framed from the socio-economic lens (Bennett, 1997; James, Ashley and Evans, 2000).

One way to achieve this requires a holistic approach that integrates knowledge of both environmental and social sciences. One approach that takes this into account is conceptualizing the role of EN in a system thinking that is socio-ecological system (SES) which embodies the concept that humans are not placed as external to ecosystems, as in life science, but are an integral part of the ecological system that dynamically interacts in the whole (Berkes and Folke, 1998). A similar working definition has been defined as follows:

> *A system consists of a bio-geo-physical unit and its associated social actors and institutions. Social-ecological systems are complex and adaptive and delimited by spatial or functional boundaries surrounding particular ecosystems and their problem context* (Glaser, et al., 2010, p. 2).

Although ENs as one aspect of spatial resilience have attracted much attention in ecological research (Cumming, 2011), attempts to include the perceived landscape values that relate to ecological processes have received little consideration in informing decision making in resource management and planning. The inclusion of the socio-cultural aspects of human values is important, as it is one of a community's resilient characteristics which responds and adapts to dynamic landscape changes (Walker, et al., 2004, cited in Alessa, Kliskey and Brown, 2008). Recently, little literature has emerged highlighting the need to integrate ecological and social system assessments which could inform nature conservation and urban planning (e.g. Alessa, Kliskey and Brown, 2008; Bryan, et al., 2010; Donovan, et al., 2009; Kangas and Store and Kangas, 2005; Mikusiński, et al., 2012). As a consequence this research nucleus presents a significant platform for further exploration in the understanding of convergence between ecological and social systems and their implication in the planning process.

The similarities between a social and an ecological system lies in the fact that complex components are linked by dynamic processes open to exchange across their boundaries through connectivity (Limburg, et al., 2002). Despite these similarities, the previous thinking on EN implementation has concentrated on biodiversity conservation independently, with less consideration of a social response. This development-versus-conservation perspective is contradictory under a socio-ecological system where social and ecological systems are interlinked (figure 4), and their separation is arbitrary when analyzing sustainable use and the enjoyment of ecosystem services (Berkes and Folke, 1998). Therefore, the concept of ecosystem services emerges as a pivotal element in linking the formation of an EN for nature conservation with the social benefits that could be derived from it.

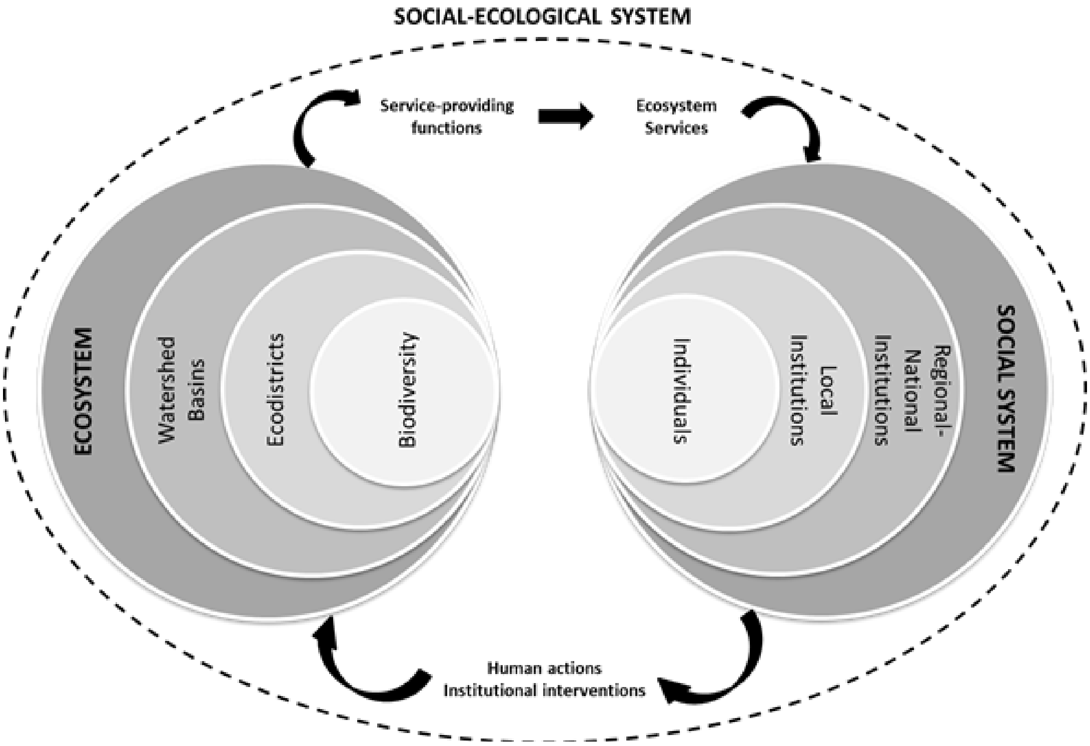

Figure 4
Components and dynamic interaction between ecological and social system at various scales (Source: Resilience Alliance, 2007 cited in Martin-Lopez, et al., 2009, p. 268)

Potential for Delivering Multiple Ecosystem Services

Poor understanding of the true value of nature often leads to poor judgement in environmental decision-making. This has caused severe ecosystem degradation and a lack of achievement in the potential values or services that it can deliver to the people. In a contested landscape, where conservation needs to be integrated beyond the normal protection areas, a wider understanding of potential values needs to be explored when establishing such linkages (Dudley and Rao, 2008). This would generate stakeholder support through a clear contemplation of what the potential benefits of EN implementation would be (Jongman, 2008). This runs in parallel with the sustainability of landscapes, whereby the EN not only facilitates the functioning of an ecosystem by conserving species and habitat, but also promotes the exploitation of natural resources in a sustainable manner (Bennett and Wit, 2001).

The scenario of EN development varies among countries and in the scope of their implementation. In developed countries, the development of ENs reconciles biodiversity conservation and economic development, while also emphasising recreational value in human-dominated landscapes. However, in developing countries, many of which are rich in natural capital, and human welfare is still largely dependent on a functioning ecosystem, the spatial concept provides an additional value that can be incorporated into planning and implementation (Bennett and Wit, 2001). Most of the cases outlined in this review are in developed countries, particularly in regions of Europe and in America, so that a deliberate examination of the progress of ENs in policy making and in their implementation can be made.

ENs are regarded as an innovative structural landscape form that can potentially deliver multiple ecosystem services in an integrated manner (Opdam, Steingröver and Rooij, 2006). However, a policy needs to be supported by evidence so society can gain an increase in value from the development of ENs. Goulder and Kennedy (2011) suggest that this requires an understanding of the various biophysical processes and services provided by ecosystems that contribute to human well-being. The concept of ecosystem services assessment from a socio-ecological point of view provides a framework that combines monetary and non-monetary values in an understanding of how human well-being depends on ecosystems. The Millennium Ecosystem Assessment (2005), defined ecosystem services as falling into four operational categories; provisioning, regulating, supporting and cultural services. Implementation of this concept facilitates biodiversity conservation that will support a functioning ecosystem in terms of the landscape, and in return it translates into ecosystem services, which contribute to human well-being.

A number of researchers have examined the ecosystem services of EN development, including marketable and non-marketable values, using an array of evaluation techniques. For example, Franco, et al. (2001) evaluated the willingness of farmers and citizens to pay to implement an agroforestry network. Using contingent evaluation, they weigh ten roles (variables) in an agroforestry network and a positive preference was observed in regard to the participant's acceptance of its implementation. Lindsey and Knaap (1999) evaluated the willingness of property owners, renters and country residents to pay for an urban greenway project. Although the results showed that most respondents believed that the implementation of the project would increase their quality of life in terms of recreational opportunities, sewage water improvement and property values, most of them (especially non-property owners) were not willing to donate to the trust fund.

In other studies, the implementation of the Dutch National Ecological Network as part of Natura 2000 has had a positive impact on the regional economy and has increased real estate prices (Berends and Vreke, 2002 as cited in Opdam, 2006). Similarly, the effect of greenways on surrounding property values have been evaluated using a hedonic pricing method (Nicholls and Crompton, 2005; Benhart and Davis, 2002). These studies revealed that the proximity of the greenway to residential areas is significant in terms of the value of houses. In tourism research, Cottrell and Raadik (2008) examined the impact of the Protected Area Network (PAN) on community and tourism development in Poland using qualitative and quantitative methods. Although their pilot study could not claim that the PAN program had a major impact on sustainable tourism development, stakeholders that were involved and familiar with PAN status valued them more highly. This was explained by the institutional benefits that allow a sustainable tourism network via a linking park policy and building up activities that associated local businesses and communities. Whilst some aspects of EN development (species diversity, ecological connectivity and visual aesthetics) as presented above hold ecological and social value, they don't always contain an economic value that can be considered equally in the cost-benefit analysis of such projects. The net benefit of EN establishment through ecological restoration depends on how people value the benefits created. Recent research by Newton, et al. (2012), suggests that the establishment of ENs in an intensively used landscape is unlikely to deliver positive economic outcomes unless the non-marketable values of ecosystem services are considered in the evaluation process. The effectiveness of stated preferences and a revealed preference method to capture certain goods and services that are not reflected in the market is crucial (Mazza, et al., 2011). Moreover, the non-market values which are mostly intangible must be considered in order for efficient resource allocation (Franco, et al., 2001).

Conclusion and Future Direction

Although much research has been done on EN efficiency from an ecological perspective, there are still impediments to be overcome to enable this spatial concept to meet socio-cultural and economic goals in a sustainable landscape. While the ecological and environmental implications of ecological networks are well observed, the intangible non-market societal values are often not able to be described in the decision-making process. This paper summarizes and presents the paucity of research findings that have been carried out to identify and understand the linkages between ENs and the socio-economic processes.

This lack of research may be underlines by the fact that it is integrative in nature, which requires a trans-disciplinary approach (Tress, Tress and Fry, 2006), including social and perceptual research linking to spatial features (Ryan, 2011), and the integration of the aims, perceptions and values of the stakeholders which will then contribute to a greater understanding of the intricate relationship between nature, society, ecology and economic development (Rosenzweig, 2003). In urban areas where land use policies and biodiversity conservation are often contradictory, the concept of ENs in ordinary landscapes is promising, especially where the functional ecological interdependency of an urban ecosystem and its bioregional context is widely recognized (Vimal, Mathevet and Thompson, 2012).

Conceptualizing the roles of ecological networks through the lens of the socio-ecological approach provides an insight into the holistic thinking required to understand this relationship. This parallels Opdam's (2006) suggestion, which stresses the role of an EN as a spatial integrative concept linking various ecological, social and economic goals in its development in sustainable landscapes. Above all, Mazza, et al. (2004, p. 199) argue that the planning and design of ENs in the conservation of biodiversity «*is often much more based on politics and human sciences than on bio-geographical and bio-historical considerations*». Because the concept is a societal construct, the conservation of biodiversity is a cultural manifestation in which the output form depends on the additional value that humans place on the landscape structure, which can then result in ecological gains.

In urban areas especially, where existing urban green spaces are encroached on and disconnected, the development of ENs presents an integrative approach for the delivery of ecological and social services. Although the urban matrix may be composed of mixed green space typologies, the incorporation of ecological principles in strengthening the coherence of these spaces provides optimistic outcomes from a societal perspective. This warrants a greater understanding of the multidisciplinary definition, and an interaction between those green space typologies with inhabitant, either from the point of view of professionals (scientist, planners, landscape architects and conservationist), or communities.

Finally, the full value of ENs (including intangible values), should be explored from a societal perspective to ensure clarity about how these values are to be incorporated into the decision-making process. The use of ecological theories to inform a spatial organization that enhances the ecological functioning of the landscape has been well explored in the hard science disciplines, but how these 'cultured landscape patterns' influence people's perceptions is a research area that needs further exploration. Consequently, future research should seek to identify the extent to which human society shapes ecological functioning through, for example, valuing residual post-development landscapes. This in turn will clarify how such landscapes evolve, and reinforce the apparent correctness of the initial valuations. A better understanding of this process will assist in efforts to restore functioning ecosystems and any associated ecosystem services.

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Biographical information

Muhammad Farid Azizul
Bachelor of Landscape Architecture (Hons), MSc. in Planning (Information Technology)
Place of work:
Department of Landscape Architecture at University Technology Malaysia (UTM)
Address:
School of Architecture & Planning, University of Auckland, Private Bag 92019, Auckland 1142, New Zealand
E-mail: mazi395@aucklanduni.ac.nz

Muhammad Farid Azizul is a tutor in the Department of Landscape Architecture at University Technology Malaysia (UTM). He holds Bachelor of Landscape Architecture (Hons) and MSc. in Planning (Information Technology) from the same university. His recent research interest area includes human dimension in ecosystem management. He currently is pursuing his PhD degree in Planning at The University of Auckland, New Zealand. His doctoral study investigates the impact of people-place relationships and attitudes towards planning and conservation decisions. He can be contacted at: School of Architecture & Planning, University of Auckland, Private Bag 92019, Auckland 1142, New Zealand, email- mazi395@aucklanduni.ac.nz.

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«MARGINAL» URBAN VEGETATION – THE CASE OF LISBON

S. MACHADO DOESBURG, P. FARINHA MARQUES

Abstract

The capacity of cities to respond to the physical, social, economic and environmental reality in order to guarantee sustainability, identity, bio-physical integration, social dynamics, mobility, diversity, security and comfort is being challenged. An ecological approach to urban planning and management is essential to maintain the long-term sustainability of ecosystem benefits, services and resources. The urban vegetation plays a key role in this process. While municipality plans identify and protect most green areas, a network of existing vegetation remains «marginal» in these plans and its contribution to the urban ecosystem remains unknown. In this study, by means of satellite images, the existing vegetation of the city of Lisbon is identified, quantified and compared to the Ecological Urban Structure Plan (EUS), as defined by the municipality. The amount of vegetation not considered by the EUS was defined as «marginal» Urban Vegetation. It consists of a considerable amount of areas, fragmented throughout the city and subjected to imminent pressures. This vegetation is investigated, evaluated and its evolution monitored with images of the past 7 years and finally, contextualized in the new urban plans for the city.

Key words:
Urban Vegetation, Remote Sensing, Urban Ecology, Urban Green Areas, Ecological Urban Structure, Lisbon

Introduction

In Portugal, urban development continues to reduce the amount of vegetation in the cities, resulting in the fact that most cities are perceived as lacking green areas and present levels of pollution and bio climatic discomfort that are deteriorating the quality of life of their inhabitants. Green infrastructure has been recognized as an important contributor in improving these urban conditions (Dale, et al., 2000), which affect surface temperature, hydrology, carbon storage and sequestration, biodiversity, while an inefficient urban planning, as well as insufficient green infrastructure, may result in raising environmental costs. Despite the efforts of Local Governments to implement green infrastructures in the cities, the presence of green areas, levels of pollution and bioclimatic comfort mostly remain inadequate.

Urban parks and gardens are considered green areas of the city, which – due to their identity – are part of people's everyday life. These spaces are classified in municipal plans as valuable ecological areas and are therefore protected from urbanization by the municipality, and especially, by the inhabitants. Another form of landscape value in the city is spontaneous vegetation, which covers slopes, vegetable gardens in empty plots and the vegetation in the inner-courtyards, which often have a negative image. These «marginal» spaces have their own dynamics, diversity, and often survive outside the municipal initiative, independently and without protection. They are the object of this study and are referred to as «marginal» vegetation, which is the vegetation that exists in the city that falls outside planning instruments.

Questioning the potential of existing resources of the city as a comprehensible structure, capable of generating better environmental conditions, require new dynamic tools. It also may provide understanding of existing processes and relationships at different scales. High resolution satellite imaging can provide accurate, economical and straightforward information to map, analyse and monitor urban vegetation because it offers a large and frequent temporal cover.

Through the analysis of data retrieved from Vegetation Indexes (such as the Normalized Difference Vegetation Index), information is gathered about how this vegetation works and aids in understanding (a) what this type of vegetation can contribute to the ecological matrix of the city and (b) how it relates to the formal Ecological Urban Structure. The spatial dimension of urban ecology can be a useful planning tool to facilitate the comparison of existing urban areas, which may help to predict the ecological impact of new urban developments (Botequilha Leitão and Ahern, 2002).

This paper will first present considerations about the process of developing the city as well as its ecological matrix in a Portuguese context, followed by defining what «marginal» Urban Vegetation is. Second, will be a description of the tools used in this study, namely «Very High Resolution Satellite Imagery», and an examination of the case-study of Lisbon. Finally, the «marginal» Urban Vegetation of Lisbon will be discussed and the conclusions of the study presented.

This study emphasizes the fact that, in Lisbon, there is a considerable amount of vegetation that falls outside of the city's planning instruments with no level of protection and that little is known about its potential and contribution to the urban ecosystem. It challenges the methods for implementing Green Infrastructures in the city by suggesting a broader approach to the urban ecological matrix.

Making City

Cities today are the engines of the world's economy, however, to be successful they have to be culturally resilient, socially robust, economically viable and ecologically sustainable.

In Portugal, the development of cities is defined by planning instruments, which determine how the city and its Green and Blue Infrastructure should progress. Urban plans, based on zoning with strict lines to regulate uses, dominate the current practise, and even though most Portuguese cities already have an Ecological Urban Structure Plan, these typically incorporate the green spaces of the city, such as parks, gardens, street trees and water surfaces. The method of planned green corridors, with ecological, cultural and symbolic systems (Magalhães, et al., 2007) is often used as can be seen in the example of the city of Loures. The city of Lisbon goes a step further with its new Municipal Urban Plan (2012), which provides active policies for the greening of the urban environment that go beyond the protection of more formal green areas. Furthermore, it defines dynamic strategies for storm and waste water management, energy savings, mobility, civic participation and land use. These strategies strive for a long-term sustainable development of the city, giving space for design innovations, cultural expression and ecological formation. However, the legacy from the modernist models of urban planning, based on rigid mechanisms of central planning, continue to lead planning practices in Portugal even to this day. The urban ecological matrix must be able to respond to the physical, social, economic and environmental changes in the city. A new sensibility about incorporating divergences between ecology and the urban development of the city has to guide the human role in its relationship to ecological needs. The underlying principle is that the process of urbanization is much more significant for emphasizing urban relationships than «particular» spatial forms of urbanism in and of themselves (Corner, 2006).

As Homi Bhabha said, timing and the significance of an event don't always go together and what we think we knew we don't know; what we think is new might or not might be so (Bhabha, 2010). The great question of urbanization is the capacity to consider the timing of interventions in the city. The timing of decision agents is very much related to governmental politics and bureaucracy, while the city develops with a temporary balance and interstitial possibilities. However, plans do not eliminate uncertainties, since they depend on opportunities and the price for not acting timely can result inthe loss of these opportunities (Portas, 2010).

The need for constant adaptation demands that urbanism does not take the form of fixed rules, but instead, promotes a series of flexible principles of ideas, systems and actions, which can be adapted to the given circumstances and opportunities. In the urban domain, the fragility of the ecosystem and the limits of resources should not be taken into account, but rather such conditions should be considered the essential basis for a new form of creative imagining (Bhabha, 2010).

The ecological matrix of the city

While in the past planners, municipalities, environmental organizations and ecologists were focused on conservation of wilderness areas, today, awareness of the importance of natural areas within cities where most of the human population resides, is increasing (Bryant, 2006). Natural systems are especially important in urban regions where they must serve many people by providing water supply, one-day recreation, flood control, farmland, wetland benefits, soil erosion/sedimentation protection, biodiversity, waste absorption/breakdown, and aesthetics or inspiration (Forman, 2010).

In the city, the urban landscape has the capacity to function as important cores or ecological arteries, and it has the ability to make scale transfers, placing urban areas into a regional scale and into a biotic context.Because the challenges of rapid urbanization and the limited global resources have become much more pressing, there is a need to find alternative design approaches that will enable us to consider the large scale differently than we have done in the past (Forman, 2010). The understanding of urban ecosystem processes in its territorial context will contribute to its survival and development. Furthermore, by providing ecosystem services within the city, it will not only improve the city's performance but also help protect the natural landscape around it.

To manage the dynamics of natural systems in the urban landscape, the ecological structure and processes need to be characterized and identified in order to understand the landscape system in terms of a) the structure, as the spatial pattern and the physical arrangement of ecological, physical, and social components, b) the functioning, as the way the components interact, such as the movement and flow patterns of animals, plants, water, wind materials and energy through the structure and c) change, as the dynamics or alterations of spatial patterns and their functioning over time. These organizations can be expressed at different scales and employed to interpret different functional spatial heterogeneity of urban landscapes (Zipperer, et al., 2000). The principles of landscape ecology apply to any land mosaic able to function equally in both, pristine natural areas and areas of intense human activity (Dramstad, Olson and Forman, 1996).

Defining a key of ecological principles, applicable to ecological research and land-use decisions in urban landscapes, is essential for maintaining the long-term sustainability of ecosystem benefits, services and resources. This framework includes principles such as a) content – the structural and functional attributes of a patch, b) context – the patch's location relative to the rest of the landscape, c) connectivity – how spatially or functionally continuous a patch, corridor, network or matrix of concern is, d) dynamic – how a patch or patch mosaic changes structurally and functionally over time, e) heterogeneity – the spatial and temporal distribution of patches across a landscape and finally, f) hierarchy – a system of functional units operating at different scales. These six principles, (content, context, connectivity, dynamics, heterogeneity and hierarchy) will help to simplify and understand the complexity of urban landscapes (Zipperer, et al., 2000).

The urban landscape should be seen as an ecosystem, with a functional and structural identity: a system with a series of elements and relationships, unitary in character, where changes to one part of the system affect the entire system. By evaluating the various components of identity of the city, it is then possible to understand the role of seemingly insignificant sites as actually being part of an important and valuable expression (McHarg, 1992).

Therefore, the ecological matrix is not limited to the formal components of the urban landscape, such as parks, gardens, green corridors etc., and much less to the citizen's perception of the city, but instead, consists of all the elements that are part of the ecosystem.

«Marginal» Urban Vegetation

In recent years, the potential of the existing resources of the city – understood as a structure that can generate a better environment – is being brought into focus through emerging fields such as Tactical Urbanism, DIY (*Do-It-Yourself*) urbanism, Guerrilla movements, temporary projects, and politics of space that were initiated by the Arab spring and other occupy movements.

While political agendas frequently plan large-scale transformative changes for the cities, small-scale improvements are increasingly seen as a way to enrich the liveability of cities. The city's existing resources are the base for these «marginal» interventions, which are its population, private initiatives, built structures and infrastructures, public and private open spaces and the biophysical conditions as well as themorphology of the city. This type of bottom up urbanism, developing «marginal» interventions in the conventional legal and regulatory frameworks, often produces novel and ingenious solutions for the city.

One very important resource of the city is its vegetation and the many benefits for the cities have been extensively studied. Areas covered with vegetation mostly indicate the existence of topsoil, and pervious surfaces, which have a negative correlation with the urban heat island effect, storm water floods, and other undesirable effects on environmental quality. Nevertheless, the cost of implementing new green infrastructure, and the time that it takes for its development to yield benefits of its functions, is too great.

The Ecological Urban Structure Plans are generally responsible for the establishment of ecological arteries that contribute to the connectivity between different systems of the landscape, contradicting the natural tendency for fragmentation in urban development. It also promotes the qualification, protection, conservation and implementation of green areas, mainly for public use, by restricting construction on these areas and specifying monitoring and execution strategies. In many cities there is a considerable amount of existing vegetation that falls outside of the domain of the Ecological Urban Structure Plan, which are under no or reduced protection policies, often resulting in being replaced by built or impervious areas.

These networks of «marginal» vegetation are based on areas that represent habitat fragments and open spaces. These areas may be important features for biodiversity (Mcintyre, Knowles-Yánez and Hope, 2000), and may also be valuable to function as corridors and stepping stones for species dispersal (Kirby, 1995). Therefore, they should be considered a key component of current ecological planning (Angold, et al., 2006).

In this study, the «marginal» urban vegetation is considered to be the vegetation that has established outside the Ecological Urban Structure Plan, and is, therefore, marginal to municipal policies. These spaces are not considered green spaces, nor does the municipality prioritize their preservation. This vegetation appears mostly spontaneously through natural succession, or through the care and maintenance of the local population. Yet, it functions as part of the ecosystem. These spaces are abandoned plots, wastelands, private gardens and inner courtyards among others (figure 1). For the purpose of identification of the areas in question, all types of vegetation identified in the satellite imagery are considered equally.

Figure 1
Representative photos of «marginal» urban vegetation in the city of Lisbon.

Since the ecological development of the city is not to be fully regulated by the municipality in all its complexity, or if so, the cost estimates would be too high, the ecological matrix of the city often relies, at least in part, on these «marginal» spaces. However, little information is available about the ecological structure and processes of these crucial spaces.

Like many other urban green areas, «marginal» vegetation appears in the city as patches of varying origins, different distribution, sizes and shapes. Their physical characteristics have a direct influence on their function and relationship with the Ecological Structure.

The interaction between patches and the matrix are numerous and often highly significant, creating fluxes that link ecosystems. Within the highly dense urban environment, the urban mesh can have a strong isolating effect, which could be compared to an island in the sea. By such comparison, a parallel could be drawn between the urban green areas and the Theory of Insular Bio-geography (Forman, 1995a). The edges of these patches mostly work as filters that determine the diversity of the patch, while the fact of being connected to the ecological network increases its diversity and dynamic potential. The disappearance of a patch can cause the loss of habitat, and reduces the number of meta-population (Dramstad, Olson and Forman, 1996).

The urban landscape structure and composition can change dramatically over time. The «marginal» vegetation, not being regulated by planning instruments, is very vulnerable to these changes. Understanding the process of landscape change, through change models at different times and scales, allows for defining the interaction of natural processes and evaluating the landscape.

There emerges a big challenge about learning how «marginal» vegetation influences the ecological matrix of the city. The following section will describe a methodology employed to tackle this challenge. This methodology makes it possible to identify, map and quantify the «marginal» spaces in a city, and thereby, can help to better understand the structure and the processes present in these spaces and their potential in relation to the Ecological Urban Structure. Following this section, the outcome of the case study of the city of Lisbon will be briefly addressed.

High resolution remote sensing and urban ecology

To understand the existing urban processes and their relations at different scales to the vegetation in the city requires new dynamic tools. The high frequency of urban spatial changes demands expedited ways of producing and updating spatial information. For this reason, high resolution satellite imaging can provide economical and straight forward information for mapping, analysing and monitoring urban vegetation, since it offers a large and frequent temporal cover.

While remote sensing is not able to replace field work and other procedures to gather information about the city, and also cannot identify single species, rarity and composition in the analysis of vegetation, it can, however, provide useful results in the form of such images and information, making the investment of image purchase and analysis a highly cost-effective solution (Langley, Cheshire and Humes, 2001).

In Portugal, one of the main instruments of urban planning and management, the PDM-Master Plan, is updated every 10 years. In highly urbanized and expanding cities, such periodicity is not suitable. Alternatively, high resolution satellite imagery, if weather conditions permit, can capture spatial data on a daily basis.

Even though high resolution satellite images present limitations in the urban context, such as the difficulty of classifying each pixel due to the high level and complexity of information (van der Sande, de Jong and de Roo, 2003), or the existence of shadows, these images contribute to a more general level of information that should be able to detect, more regularly, significant changes in urban environments.

Vegetation mapping through remote sensing

A satellite image is the registration by a sensor of the values of electromagnetic radiation reflected in the different frequencies of the electromagnetic spectrum. Vegetation has a very specific spectral behaviour. Chlorophyll strongly absorbs radiation in red and blue wavelengths but reflects green wavelengths, which is the reason why they appear «green». When the chlorophyll content is at its maximum, leaves appear the «greenest», and when there is less chlorophyll in the leaves, like in the autumn, there is less absorption and proportionately more reflection of red wavelengths, making the leaves appear red or yellow.

The photosynthetic potential is strongly related to a variety of ecosystem services, ranging from freshwater availability, biomass production to biodiversity (Field, Randerson and Malmstöm, 1995).

A vegetation index assesses the spatial texture of ecological quality and categorizes the image into non-vegetative and vegetative pixels with different values. Satellite-derived vegetation indices are excellent estimates of productivity and can also quantify spatial heterogeneity of vegetation; two important factors shaping biodiversity patterns (Mittelbach, et al., 2001; Tucker and Sellers, 1986).

The Normalized Difference Vegetation Index (NDVI) is an index calculated from reflectance measured in the visible and near infrared channels. It is related to the fraction of photosynthetically active radiation (Eidenshink and Faundeen, 1994).

$$NDVI = \frac{(NIR - NR)}{(NIR + NR)}$$

The NDVI value varies with absorption of red light by plant chlorophyll and the reflection of NIR (*Near InfraRed)* radiation by water-filled leaf cells. The outcome is a visual representation of the ecologically meaningful spatial structure, related to the production of chlorophyll and able to predict and assess vegetative characteristics, such as plant leaf area, total biomass, and chlorophyll content, the percentage of ground covered by vegetation and general plant stress and vigour.

Analyzing the vegetation mapping of the NDVI involves comparing different pixels based on visual elements, like tone (brightness, colour etc.), size, pattern (spatial arrangement), texture, shadow and association (relationship to other recognizable objects or features).

Case Study

The city of Lisbon is used as a case study in this research in order to understand and demonstrate «marginal» vegetation.

Study Area

The city of Lisbon, located near the coast on the North bank of the river Tagus, is the largest city in Portugal in terms of area (84 km^2) and population (547.631 habitants). Lisbon is characterized by its hills and valleys, which bring a dynamic and complex landscape to the city. It is dominated by two fundamental elements, which characterize the functioning of its urban ecosystem: in the west, the Monsanto Forest has a unique geological formation, and in the east and south are the Tagus River and Estuary.

The urban evolution of the city characterizes the urban morphology and the existing green infrastructure. The medieval period, up until the Discoveries (XV century), relates to the city's transformations, the organic distribution inside the city walls. This was followed by the «Maneirista» period (XVI to XVII century), that brought expansion of the urban fabric towards the west. In the XVII century, the city faced a major reconstruction after the great earthquake of 1755, in an orthogonal morphology. It was in the XIX Century, during the romantic period, that Lisbon occupied the central plateau with great avenues, gardens and squares. The planning approach of the «Municipal Master Plans» to design major accessibilities and land use patterns, was created in 1938. Two revisions (1958 and 1967) were approved over the following 25 years.

In 1993, a new revision of the Municipal Master Plan was approved, which introduced for the first time the Ecological Urban Structure Plan. Even though national regulation determines a 10 yearly revision of the Master Plan, it took almost 20 years to review this plan and finally, in 2012, the current Municipal Plan was approved.

This study analyzes the city of Lisbon within its administrative boundaries, taking into accountits regional and metropolitan ecological structure.

Data

Several spectral, altimetric, and planimetric spatial data sets were used for this study, specifically, Very High Resolution Satellite Images (VHR), topographic surveys and PDM – Masterplan maps (Plano Director Municipal) (PDM 1993 and PDM 2012). Strategic field visits and photographic surveys were also carried out.

Different data sets were used for the vegetation analysis; originating from different satellites, namely, Quickbird and Worldview from DigitalGlobe. The data sets used were pansharped to the resolution of the panchromatic band in PCI Geomatica, orthorrectified in order to reduce geometric distortions using the Rational Polynomial Coefficients (RPCs) and attributed to a national projected coordinate system (ETRS89-PT-TM06). The NDVI was derived from the bands of these images, and threshold changes were applied under the supervised classification method providing discrimination of vegetated/non-vegetated pixels.

Year	Day	Satelite	Panchromatic Sensor Resolution	Multispectral Sensor Resolution
2005	13th April	QUICKBIRD	0.6 m	2.4 m
2010	24th June	WORLDVIEW	0.5 m	2 m

Figure 2
Table with data specification of the imagery used for this article.

Methodology

Through the use of VHR, it is possible to analyse the vegetation at a specific moment in time and determine the relation between the total existing vegetation and Planning Instruments.

The produced data sets of NDVI from the available satellite images are overlaid with the vectorial data set of the PDM-Master Plans. Based on the NDVI imagery ofthe existing vegetation of the city, the NDVI imagery, which corresponds to the Ecological Structure of the PDM-Master Plans, is identified resulting in a) the existing vegetation incorporated in the Ecological Structure, and b) the subtraction of both images, consequently being the vegetation that is not included in the planning instruments: the «marginal» vegetation (figure 3). This vegetation represents urban spaces that have developed outside the established planning processes, and survive outside the municipal initiative.

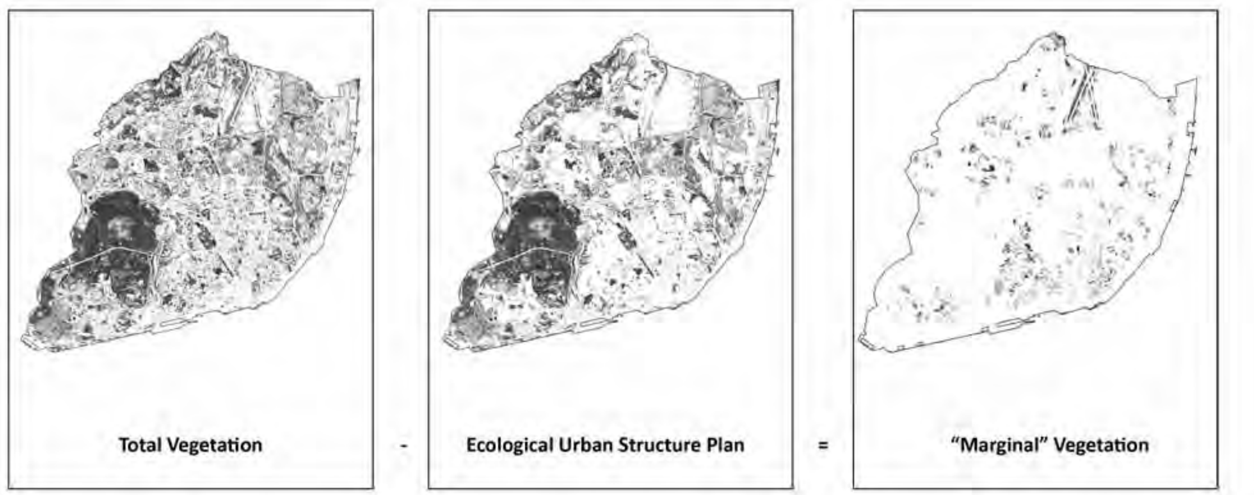


Figure 3
Definition of «marginal» vegetation for the city of Lisbon. The «Total Vegetation» image corresponds to the NDVI imagery of the existing vegetation of the city, the «Ecological Structure Plan» image corresponds to the existing vegetation incorporated in the Ecological Structure, and «Marginal Vegetation» image is the subtraction of the above plans, displaying the vegetation that is not included in the planning instruments.

Results and Discussion

The city of Lisbon presents a significant lack of different types of Green Areas for the wellbeing of its inhabitants, as well as unsatisfactory levels of air quality and noise (CML, 2002). In France, the «Protection et aménagement des espacesverts» (Protection and Development of Green Areas) recommends 35 m² of Green Area per capita as the minimum standard, while in England the «National Playing Fields Association» stipulates 52 m² per capita. In Portugal, the value was set to 40 m² per capita (Magalhães, 1992), which is based on the capacity of vegetation to produce oxygen. In 1994, the PDM-Master Plan reduced the Green

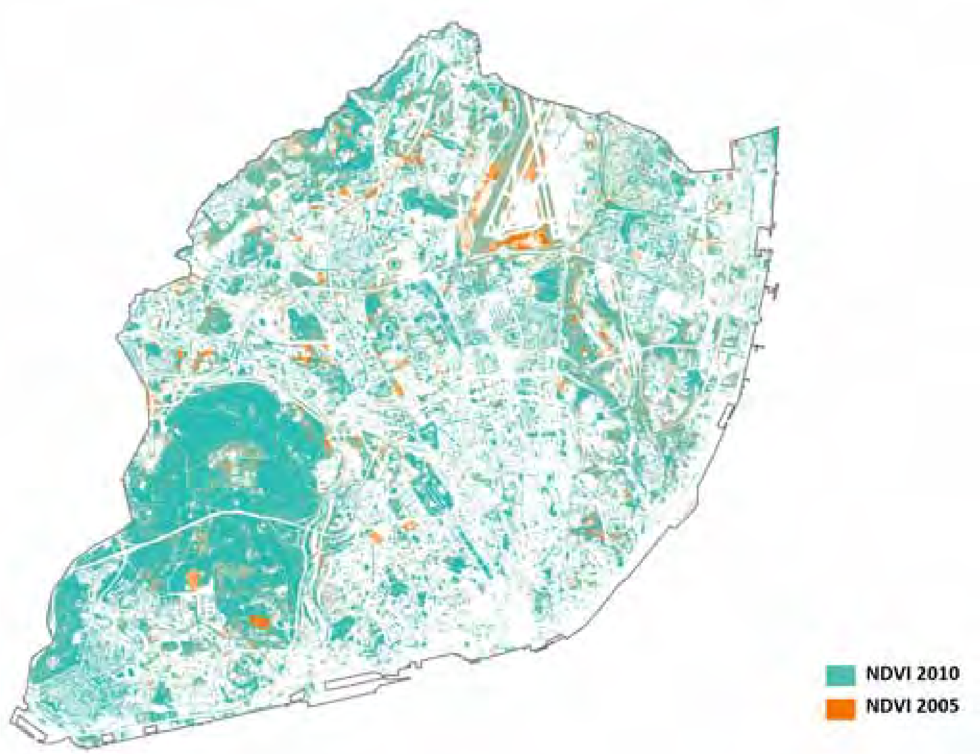
Area per capita to 19.4 m², and finally in 2007, it was raised again to 24 m² (CML, 2012). This increase, however, is also accompanied by the decrease of population in the city.

Study results of the NDVI image of 2005 and the former PDM-Masterplan of 1993, show that: a) of the total of 2. 370 ha of vegetation in the city of Lisbon, 740 ha corresponded to the Monsanto Forest and 860 ha corresponded to other parks and green corridors planned in the city; b) 770 ha of vegetation was left out and was spread throughout the city – «marginal» vegetation – which makes up 33 % of the total vegetation.

The City of Lisbon acknowledges having a lack of Green Spaces in the city, and yet only considers a part of the existing vegetation for its ecological structure. The interpretation and evaluation of the existing conditions, in terms of urban vegetation and its relation with the Ecological Urban Structure defined by the Local Government, can constitute the ecological, social and urban support for the city's development.

Looking at the evolution of these spaces, a lot has changed in the city of Lisbon over the past 5 years. Analysing the NDVI «marginal» vegetation image of 2010 and comparing it with a «marginal» vegetation image of 2005, we can see a reduction of vegetation values. Areas in orange highlight where some vegetation cover has disappeared and has been replaced with built areas. Furthermore, some areas have become more degraded and now present less vital vegetation (figure 4). From an

Figure 4
Overlay of the NDVI map of 2005 and 2010.



urban planning perspective, there are currently a lot of changes. For example the municipality is finally approving the new PDM-Master Plan in conjunction with its new Ecological Urban Structure.

Analysing the NDVI vegetation image of 2010 overlaid with the currently ruling PDM-Master Plan (1993), results in a considerable amount of vegetation that is not contained within the formally defined ecological structure – «marginal» vegetation (figure 5).

The future Ecological Urban Structure Plan is in general a big step forward towards the preservation of natural resources and the construction of green corridors. Analysing the NDVI image of 2010 overlaid with the Ecological Urban Structure of 2012, we can see that the «marginal» vegetation has become less (figure 6). This Plan goes beyond the protection of parks and gardens, but also introduces the protection of some inner-courtyards and empty plots. Further, it introduces new concepts such as the humid and the dry system (Magalhães, et al., 2007), which differentiate the functioning and the distribution of natural resources of the city. The humid system represents the areas of the watersheds: watercourses, floodplains, stilling basins, areas subjected to flooding and the transition system between these elements as well as the river flow and tide (CML, 2012). The dry system is defined by the areas of maximum infiltration, areas with erosion risks, soils with high ecological value and the protection of the ridge related to the watercourses (Magalhães, et al., 2007). This concept is carried out in the PDM Masterplan 2012 through the structure corridor system (CML, 2012), which integrates public and

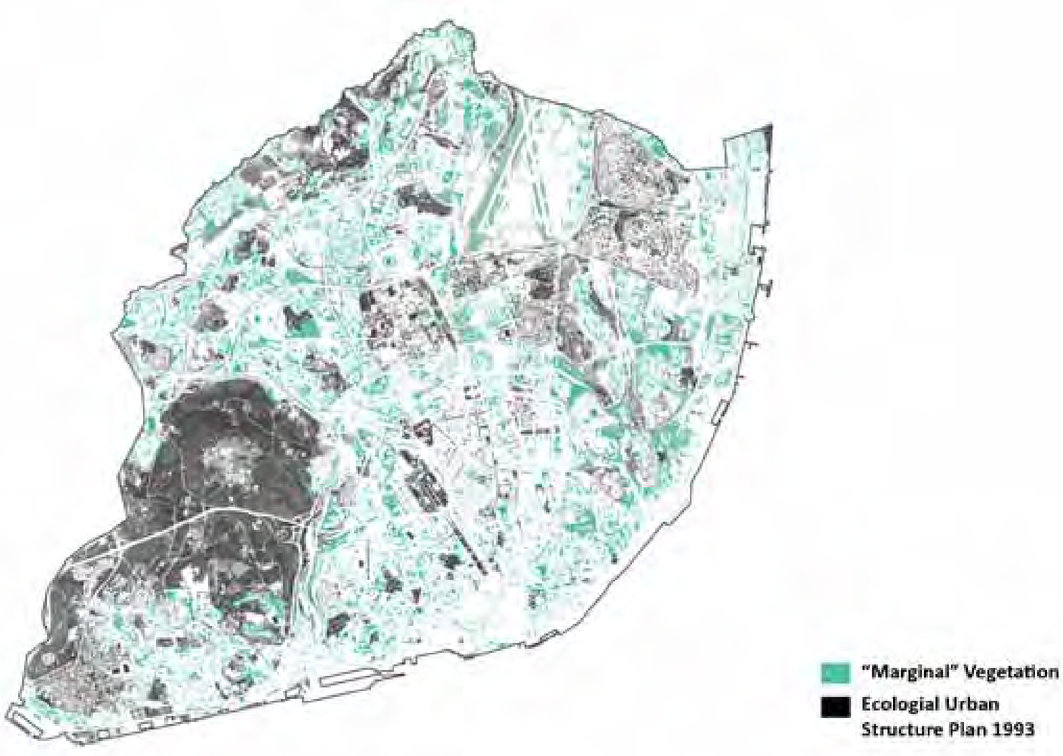


Figure 5
NDVI map of the Ecological Urban Structure of 1993 and the «marginal» vegetation.

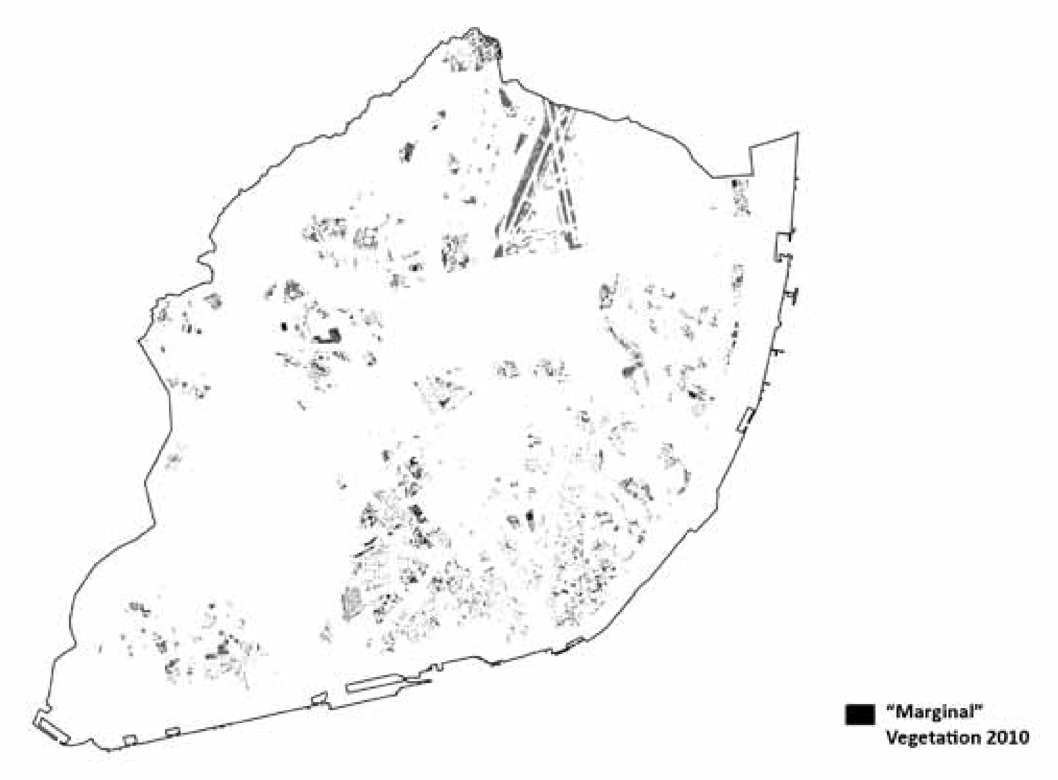


Figure 6
«Marginal» vegetation as a result of the 2010 NDVI map compared to the Ecological Urban Structure Plan of 2012.

private areas that establish connections or define reserves that promote an ecological structure. Most of the «marginal» vegetation of the PDM-Master Plan of 1993 included in this plan is integrated into the typologies of the structure corridors system and the humid system.

The image identifies vegetation that will survive outside this plan and shows a strong representation at the neighbourhood scale (figure 7). These spaces are mainly inner courtyards, gardens associated with public and private facilities and vacant plots.

Figure 7
«Marginal» vegetation as a result of the Ecological Urban Structure Plan of 2012 with the NDVI plan of 2005 and 2010.

Conclusions

Considering the environmental conditions that today's cities are facing, and the urban pressure on its ecological structure, green structures have been recognized as an important contribution to improve these urban conditions. However, the green structures implemented by the municipalities are mostly insufficient in responding to the challenges cities are dealing with, and more consideration is given to the existing resources of the city and bottom-up initiatives.

On the other hand, a network of vegetation within the cities has been identified, which shows an important expression and is distributed and dispersed with a more or less homogeneous form throughout the city and is found marginal to the planning instruments of the municipality – «marginal» urban vegetation.

These Green Areas are mostly not protected and ignored by Local Governments, suffering the changes and pressures from increasing urbanization. Since they are inserted into the urban tissue and have a greater contact and relationship with their surroundings, they have a great potential to reinforce the urban green structures.

Nevertheless, there is little or no information about this vegetation; not only in terms of location, quantity, content, structure or function, but also about its role and contribution to the ecological balance of the city.

This study identifies and quantifies the «marginal» urban vegetation of the city of Lisbon and concludes that there is a strong representation on the neighborhood scale, reaching 33 % of total vegetation in 2005. It also shows that the evolution of this vegetation overthe past 7 years has been a negative progression, resulting in many vegetation areas being replaced with built areas.

The knowledge provided by this study contributes to preserving and enhancing the existing vegetation, which is partly responsible for the quality of the city. Attention is drawn to the multifunctional capacity of spontaneous acts and processes, and to the fact that traditional planning instruments are unable to respond to the needs and dynamics of the city and its agents. It also opens a new way of looking at urban ecosystems and urban planning that is not only based on the ecological structure and planning instruments, but also considers the existence of a dynamic network of vegetation that establishes independently to these processes.

By acknowledging the existing «marginal vegetation» in the city of Lisbon and its dynamics and characteristics proposed in this study, alternative ways can be explored to articulate the existing urban vegetation with the ecological structure of the city. The potential of the existing resources of the city is questioned as a structure capable to generate better environmental conditions. This aim contributes to a framework that, by conjoining urban ecology, urban planning and remote sensing, can provide knowledge, methods, and clues as to what the urban city can become in future years.

More studies should follow, which evaluate the «marginal» vegetation of Lisbon with ecological principles, in order to understand its contribution to the ecological matrix of the city, and explore ways to enhance these existing spaces and promote the appearance of new ones.

The generalisation of the approach presented in this study, or its application in other case-studies, would be beneficial from multiple perspectives. It can serve as an instrument for policy makers to assess the impact of the «marginal vegetation» in their cities and create new policy making strategies. With the dynamic forces in today's urbanisation processes, the approach can also be used to study the unwanted consequences of interventions and existing monitoring instruments. Although the results of a general application of this approach to other cities are dependent on the methodology used in urban planning, different information at various levels can be extracted and used with the same methodology. This study shows that this approach provides a rapid and accurate ecological database to further inform the planning of ecological urban structures.

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Biographical information

Sara Machado Doesburg
Department of Geosciences,
Environment and Landscape
Planning, Faculty of Sciences,
University of Porto
Address: Rua do Campo Alegre
687, 4169-007 Porto, Portugal
E-mail: sara.machado@stroop.pt

Sara Machado Doesburg graduated from the Technical University of Lisbon in «Urban and Land Planning and Architecture», and holds a Master Degree from the Polytechnic University of Catalonia, in «Landscape Architecture».

Currently, she is a PhD student, of the «LINK Program – Landscape Architecture and Urban Ecology», at the Technical University of Lisbon, Porto University and Coimbra University, hosted in Investigation Center CIBIO – Porto. She is also collaborating with the Research Project «Neighbourhoods in Lisbon 2012» together with UAL, E-Geo and IHRU.

She is the founder of atelier stroop | landscape urbanism (2007), where her work covered Urban Design and Landscape Architecture projects. She also worked in several landscape architecture and urban design offices in Rotterdam, New York, Barcelona and Lisbon.

Biographical information

Paulo Farinha-Marques
Department of Geosciences, Environment and Landscape Planning, Faculty of Sciences, University of Porto
Address: Rua do Campo Alegre 687, 4169-007 Porto, Portugal
E-mail: pfmarque@fc.up.pt

Paulo Farinha-Marques is an Associate Professor of Landscape Architecture in the Faculty of Science at the University of Porto – Portugal. He graduated in Landscape Architecture from the Technical University of Lisbon (1988) and obtained a PhD in the Faculty of Architecture at the University of Sheffield – UK (1999). Since starting his professional activity in 1988, he has combined teaching with design practice of private and public spaces in a historic and contemporary context. His main area of interest is the design of parks and gardens as well as landscape visual quality assessment.

Currently, he is researching the planning and design of the green structures in metropolitan landscapes, articulating ecological approaches with social and aesthetic evaluation.

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THE ROLE OF NON-URBANIZED AREAS FOR DESIGNING AN URBAN GREEN INFRASTRUCTURE

RICCARDO PRIVITERA, FRANCESCO MARTINICO, DANIELE LA ROSA AND VIVIANA PAPPALARDO

Abstract

This paper presents an Urban Green Infrastructure (UGI) design approach aimed at re-defining the role of green area network as part of the Land Use Masterplan of the city of Catania (Italy), a southern Mediterranean city. It is a particularly relevant and challenging case considering the substantial lack of green spaces, which characterizes the urban environment of this city. The proposed approach is intended as a tool for implementing planning actions that aim to include existing Non Urbanized Areas (NUAs) into the construction of a Green Infrastructure. Actions are proposed to define and build different design scenarios including longitudinal, radial and urban core connections through specific Design Elements (Green Lines, Green Wedges and Green Hooks). As a result, UGI would provide an increase of green spaces up to 2250 % compared to the current amount of public green areas. Integrating rural landscapes into leisure areas, through protection and promotion of urban and peri-urban agriculture, would substantially increase the total amount of usable and accessible green space within the municipal boundary.

Key words:
Non Urbanized Areas, urban green infrastructure, peri-urban agriculture integration, sub-urban and urban green spaces

Introduction

The concept of Green Infrastructure (GI) has been introduced to upgrade urban green space systems, thus forming a coherent planning structure (Sandström, 2002). GI includes different kinds of green spaces, connected as networks of multifunctional ecological systems within, around and between urban areas, and at different spatial scales. GI should be designed and managed as a multi-functional resource, able to provide landscape, ecological services and quality of life required by affected communities. The concept of GI emphasizes quality as well as quantity of urban and peri-urban green spaces (Turner, 1996; Rudlin and Falk, 1999); their multifunctional role (Sandström, 2002) and the importance of interconnections between habitats (van der Ryn and Cowan, 1996). Its design and management should also enhance the character and distinctiveness of an area with regard to existing habitats and landscape types. GI comprises inter-connected natural areas instead of separate parks and recreation sites. It requires responsible intervention to safeguard critical land and actively practice conservation, regeneration and/or stewardship (van der Ryn and Cowan, 1996).

Numerous reasons exist for considering GI as an implementation tool for planning actions. From an ecological perspective, GI maintains the integrity of habitat systems and provides the physical basis for ecological networks, which has been advocated as a way for alleviating the ecological impacts of habitat fragmentation, even in urban context (Bierwagen, 2007). This makes biodiversity conservation an integral part of sustainable landscapes (Opdam, Steingrover and van Rooij, 2006). GI also plays a key role in climate change adaptation and mitigation by improving the city's capacity to cope with rising temperatures and extreme weather events associated with climate change (Gill, et al., 2008). Furthermore, the connection of urban green spaces increases the overall accessibility of these areas through the creation of cycling and walking paths.

The term «infrastructure» implies a system that is vital to the functioning of a city, whereas «green space» may be regarded something merely nice to have. Like other infrastructure typologies, such as transport, food/-energy supplies and water/waste management systems, GI can contribute significantly to the delivery of other forms of services to communities (MEA, 2005). For all these reasons, GI should be seen as a primary consideration in planning, developing and maintaining an eco-town. If GI is proactively planned, developed and maintained, it has the potential to guide the urban development by providing a framework for economic growth and nature conservation (Walmsley, 2006; Schrijnen, 2000; van der Ryn and Cowan, 1996). Such a planned approach would offer many opportunities for integrating urban development, nature conservation and public health promotion (Tzoulas, et al., 2007).

The present paper explores the possibilities of efficiently connecting the various open spaces in order to create a green infrastructure. It presents a design approach for the Urban Green Infrastructure (UGI), aimed at redefining the role of a green area network within the land-use Masterplan of the city of Catania, in Italy. The creation of an UGI is particularly relevant and challenging considering the substantial lack of green spaces that characterizes the urban environment of this city.

The various types of green space are extremely different and complex; therefore, specific strategies are required for dealing with each subgroup. The implementation of UGI will be based on the following strategies, which address: (1) environmental protection and integration of peri-urban agriculture, (2) development of sub-urban green areas, and (3) enhancement of current urban green spaces (see section Action Strategies).

Materials

As one of the main cities in southern Italy, Catania ranks second in economic and political importance in Sicily and has the tenth highest population in Italy overall. The city's municipal area is 180 km^2 with a population count of 295,591 in December 2010. The city's favorable location along the coast; its well-connected motorway and railway systems, and the presence of a commercial port and busy airport afford the city a strategic role in the region. Today, Catania is the most important commercial, industrial, administrative, cultural and educational centre of eastern Sicily, extending its influence well beyond the municipal borders of its province. The existing settlement has developed around the historical center and has grown beyond the city's administrative borders, incorporating existing agricultural and fishing villages into a large metropolitan area. The result is a rather heterogeneous aggregate of settlements, where rich and vital urban fragments are intertwined with poor and marginal ones, the latter often corresponding to social housing schemes or illegal settlements.

Catania is the centre of a large conurbation that represents the largest metropolitan area in Sicily (figure 1), a settlement system characterized by extensive urban sprawl. In the course of forty years (1961–2001), the total population of 27 municipalities included in the metropolitan area grew more than 27 % (La Greca, et al., 2011a). In 2008, approx. 60 % of its total population lived outside the main city, indicating progressive population expansion beyond the city center.

The amount of current public green space is less than the minimum amount stated by national legislation (D.M. 1444/68) that imposes to Local land use master plans to stipulate a minimum of 9 m^2 of public green space per inhabitant. To date Catania encompasses a total amount of

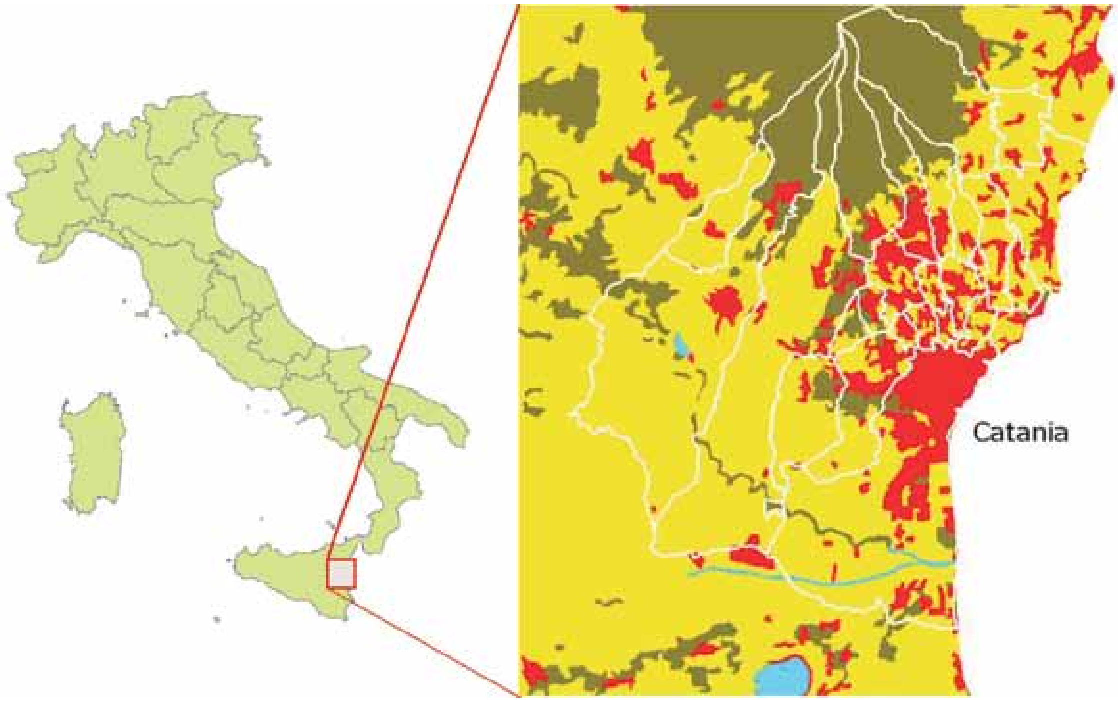


Figure 1
Catania municipal study area (Italy).

856,000 m² of public green space, which is far below the required total area (1,670,000 m²) according to population size. Public green spaces account for 3 m²/inhabitant; consequently approx. 814,000 m² are lacking in order to comply with the minimum amount required by law (Catania Master Plan, 2012).

Approx. 702,000 m² of the existing green spaces can be categorized into three groups: (a) 'Public green spaces', including few historical gardens and other small public parks, (b) 'Public open spaces', including squares planted with trees and flower beds and furnished with benches, and other small open spaces beside roads and public facilities, (c) 'Street trees' mostly composed of tree-rows, abandoned grass and roadside planting. These categories are mapped in figure 2 and summarized in table 1.

A natural reserve along the main river (*Riserva Naturale Orientata Oasi del Simeto*) is also included into the city's municipal boundaries, located along the south-eastern border (figure 2). This protected area covers 1,859 ha and includes the river mouth area, wetlands, sand dunes and river banks.

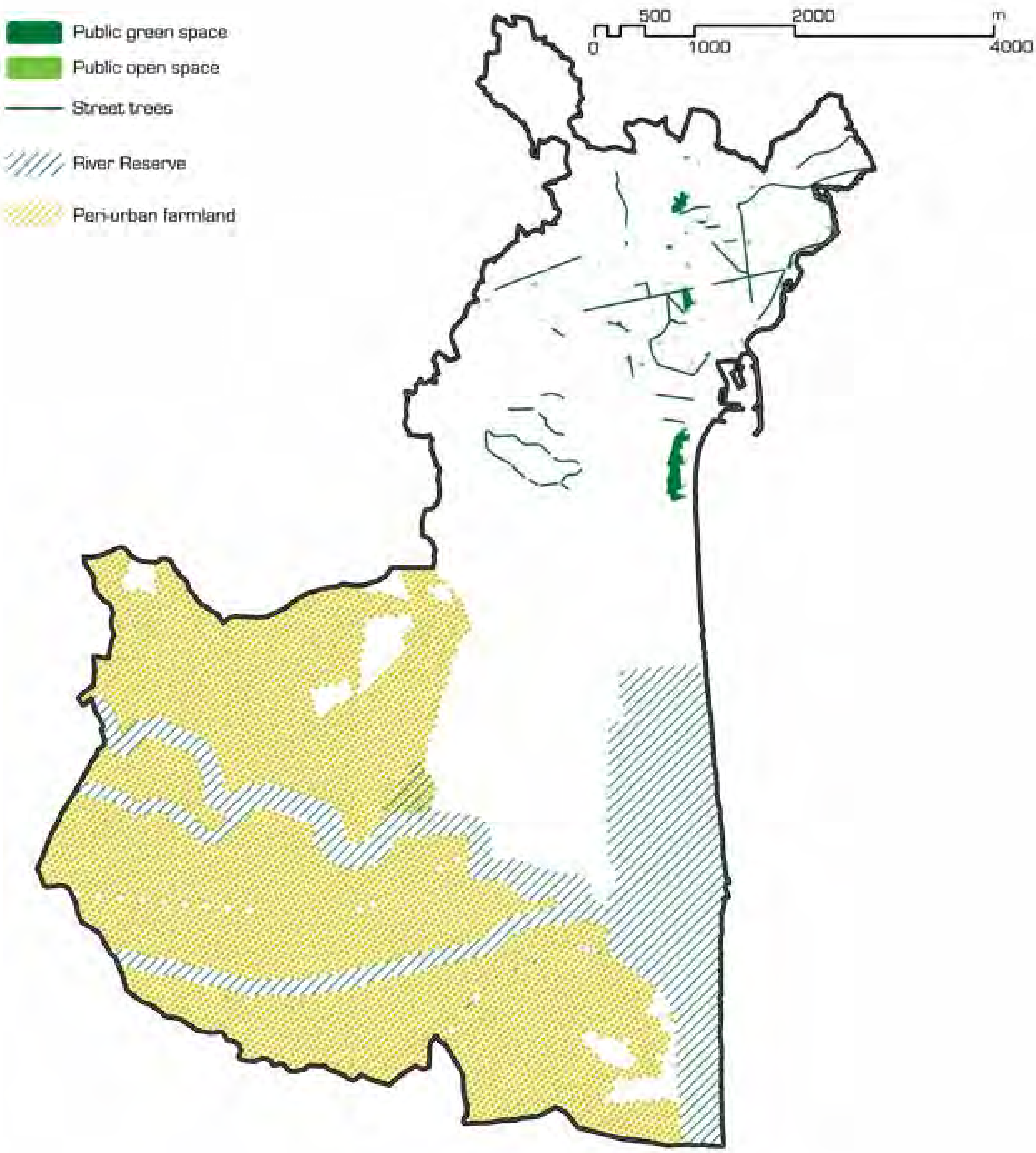


Figure 2
Map of current greenspaces in Catania municipal area.

Table 1
Categories of current green spaces.

Non-Urbanized Areas

Apart from public green spaces introduced in the previous paragraph, a significant number of other open spaces, currently unmanaged, are present in Catania. These Non-Urbanized Areas (NUAs) are outdoor places with significant amounts of vegetation, mainly semi-natural areas that represent the last remnants of nature within the built up area, able to produce ecosystem services (La Greca, et al., 2011a). These areas are quite heterogeneous in shape, size, land-use type, function, bio-physical features, and ecological and landscape value.

NUAs play a multi-various role in urban ecosystems, including preservation and enhancement of biodiversity (McHale, McPherson and Burke, 2007; Romano, 2005), production of oxygen (Jo, 2002), reduction of air pollution (Yang, et al., 2005), noise (Fang and Ling, 2003) and the heat island effect (Shin and Lee, 2005), regulation of microclimates, as well as the achievement of crucial health, well-being and social safety objectives (Groenewegen, et al., 2006).

To date, NUAs in the Catania area, in spite of their strategic role, have not been studied systematically. This lack of rigorous data collection and analysis may be directly attributed to an existing weakness of the region's planning policy. Nevertheless, NUAs are the elements suitable for use in an urban GI, considering that they can be converted into a multifunctional green network. Uncontrolled urban sprawl over the past thirty years has undermined the grid of natural ecosystems, which good planning policy attempts to restore by applying an UGI approach.

NUAs Land-Use Analysis

The initial step in designing the UGI was the construction of a land-use map for the Catania municipal area. The map was based on vector cartography (at scale of 1:10,000), municipal vector cartography (at a scale of 1:2000), field surveys and 2008 high resolution (0.25 m) ortho photos.

NUAs have been classified into two categories of land-use types: 'Farmlands' and 'Woods/Shrubs', both located in the northern part of the municipal area (figure 3). Peri-urban farmlands and the River Reserve, located in the southern part of Catania, have not been included in the proposal of the UGI, since these areas already have an important role in productive agriculture and environmental protection and thus are not suitable to be converted into different land uses.

The 'Farmlands' category includes: orchards, arable lands and vegetable groves. The 'Woods/Shrubs' category includes: woods, shrubs and lava fields (figure 4).

Figure 3
Map of Non-Urbanized Areas Land-use types.

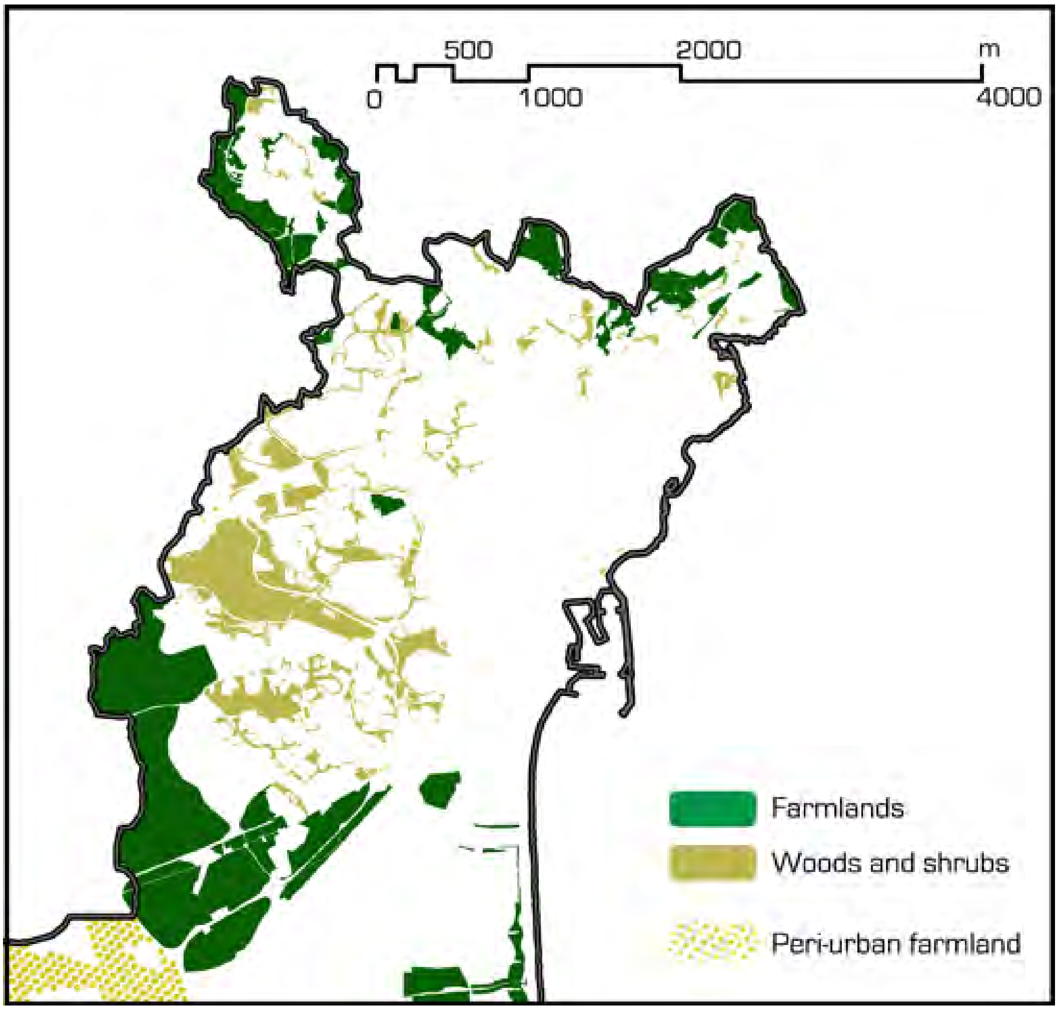


Figure 4
Non-Urbanized Areas land-use categories.

Orchards include vineyards, orange groves, lemon groves, olive groves and other orchards (figure 5) and they are mostly located in the southern part of the municipality, next to *Simeto* River. In the northern part, most of the farmlands are abandoned as a result of urban sprawl and fragmentation, resulting in the loss of biodiversity and ecological integrity (Franklin, Noon and Luke George, 2002; Romano, 2005).

Arable lands, located in the southern part of the municipality include grasslands and pasture lands, which represent an important habitat for many bird species. Vegetable groves are scattered throughout the municipal area and represent the most economically relevant farmlands. Shrubs are usually located beside the urban fringe, which are characterized by annual and perennial vegetation typical of the *maquis* (Mediterranean flora). Lava fields represent the most peculiar habitat and are characterized by lava flows, colonized by pioneer vegetation beginning a chain of ecological succession (Doelle, et al., 2008). Woods are mainly characterized by fragments of the *maquis* located beside the coast of Ionian Sea and fragments of the so called *bosco etneo* in the northern part of the municipality. They represent the last remnants of wider natural systems, once present in the area of the *Mt. Etna* slopes, typically populated by oak woods (*Quercus virgiliana*, *Quercus dalechampii*, *Quercus congesta*). In the last decades some plots of woodlands have been reforested for preserving dunes and orange groves.

Examples of orchards, arable lands, vegetable groves, shrubs, lava fields and woods are shown in figure 5.

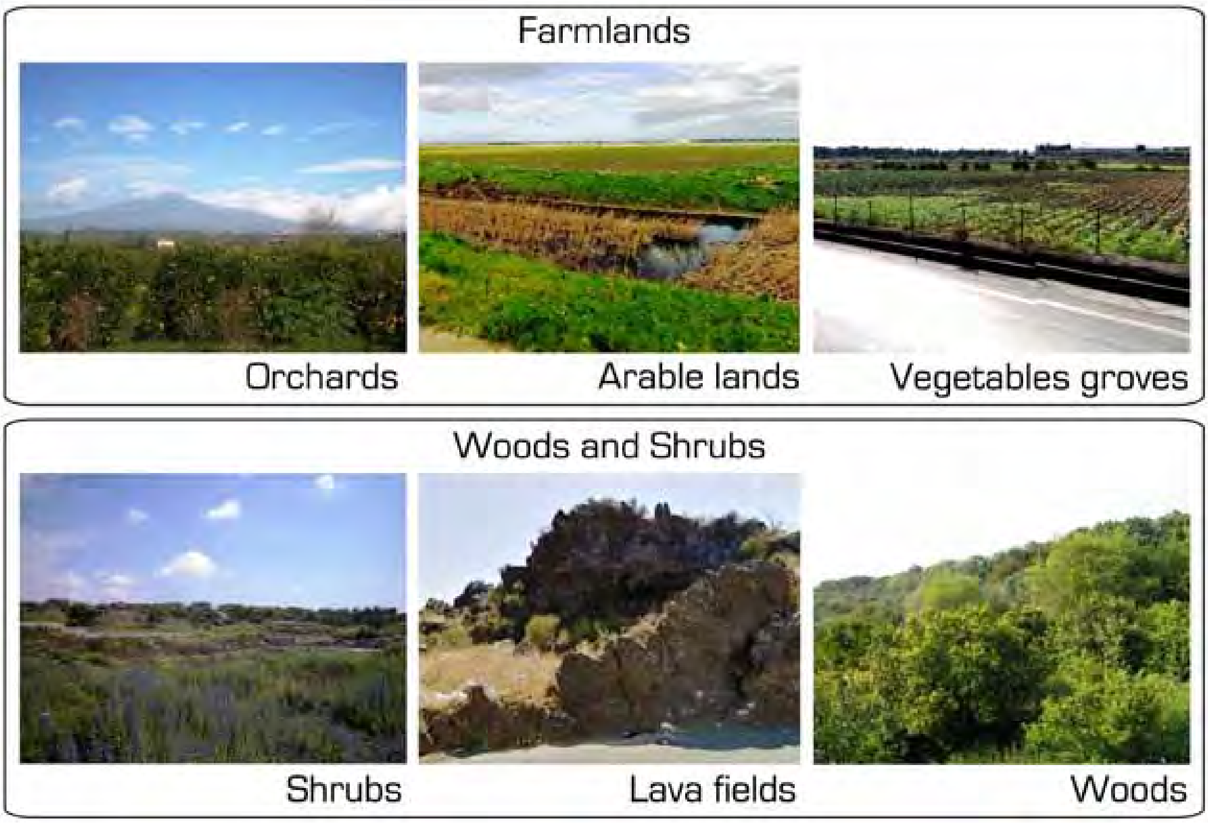


Figure 5
Non-Urbanized Areas land-use detailed categories.

Design Approach

The design of an UGI for Catania is based on the main concept of creating a network of green areas (OCS, 2007), involving both, existing urban green spaces and currently unmanaged NUAs. Ecological connections need a robust and defensible green network, especially when they are embodied within cities (Beier and Noss, 1998). Within urban context the ecological functions of the GI are generally weak (OCS, 2007) and in need of improvement. In the municipality of Catania the natural character of some peripheral NUAs can contribute to improve the ecological functions of an UGI. The design proposal presented here follows a multifunctional approach of GI in urban contexts (Benedict and McMahon, 2002; Hostetler, Allen and Meurk, 2011; Walmsley, 2006). It not only takes into account the ecological functions, but also highlights the importance of agriculture in an urban context (Thornton, 2008) and the issues of accessibility and equitable distribution of urban parks, garden and playgrounds (Smoyer-Tomic, Hewko and Hodgson, 2004) as well as stating the need for an alternative mode of transport next to car traffic (La Greca, et al., 2011b). These issues are particularly relevant within the given context, in which heavy traffic and lack of public transportation are common.

Thus, the proposed UGI aims at following action strategies:

a. environmental protection and integration of peri-urban agriculture into urban context, providing specific new urban agricultural land-use types such as agricultural parks, community supported agriculture and allotment gardens (La Rosa and Privitera, 2013). These land uses can provide various improvements, such as increasing local food production in the city (Granvik, 2012), becoming areas for leisure and supporting the integration of socially deprived population groups (Rubino, 2007);
b. development of sub-urban green areas in order to provide a new distribution of public parks and gardens;
c. enhancement of current urban green spaces by improving quality, usability and accessibility.

Moreover, the UGI provides the basis for establishing *connections for leisure,* a network of green spaces consisting of pedestrian and bicycle pathways among NUAs, which are characterized by different functions and land-use types (Jongman and Pungetti, 2004).

Land-use Analysis, described in section Land-Use Analysis, identifies NUAs that can be used as elements in the UGI. Figure 6 shows the conceptual model of the Design Approach proposed for the UGI implementation. It is based on Connecting Scenarios, Action Strategies and Design Elements, as introduced in the next sections.

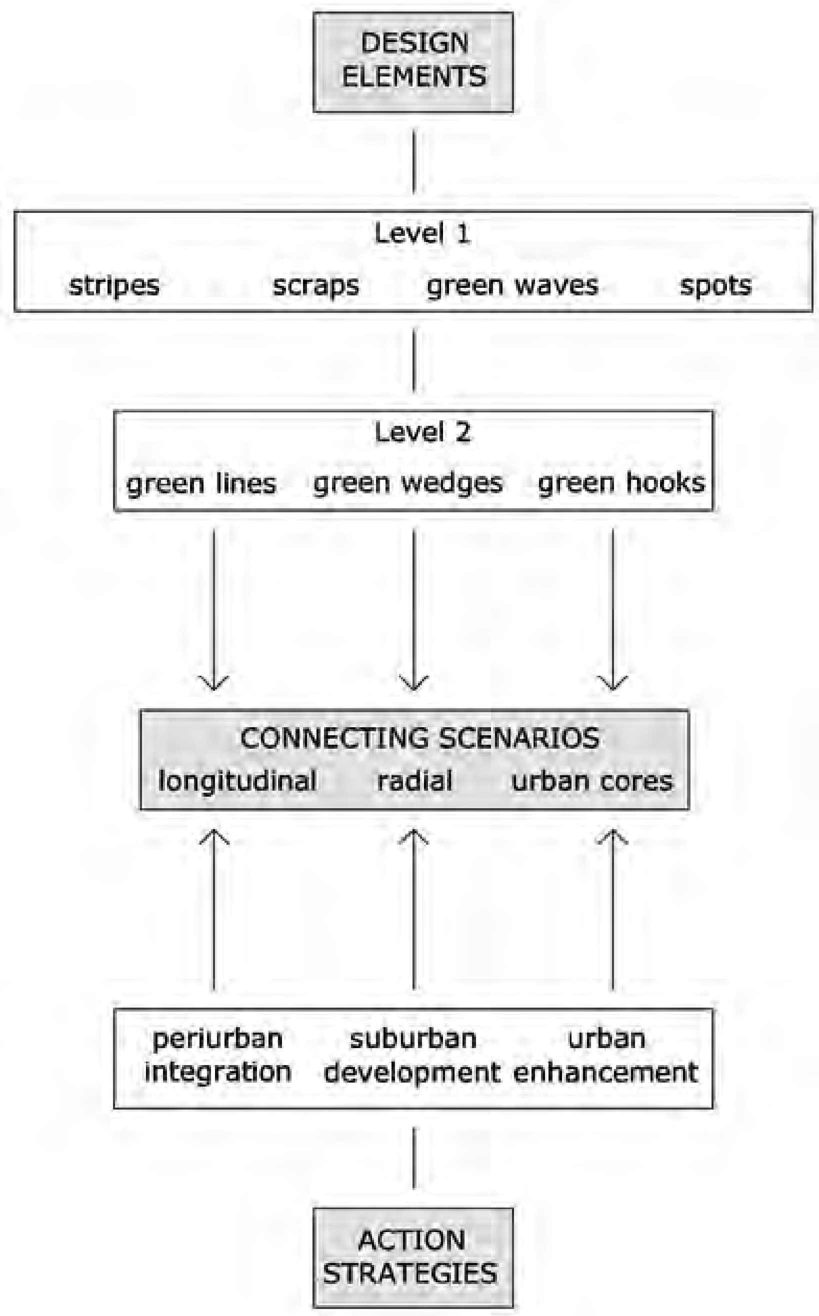


Figure 6
Conceptual Model of Design Approach.

Connecting Scenarios

Connecting Scenarios represent different new spatial configurations that can be assumed by the UGI and are defined according to different connection purposes and types of connected NUAs. Position, land-use, land cover features, shapes and sizes are also taken into account when defining the proposed scenarios. Three categories of NUAs have been identified to specify the relationship between *Connecting Scenarios* and NUAs, which are: (a) '*NUAs at the city edge', (b) 'NUAs in the city periphery', and (c) 'NUAs in the city core',* as shown on map in figure 7.

'*NUAs at the city edge' (*991.4 ha) are larger areas with high ecological value. They include farmlands and represent the most important green hubs of the municipality. '*NUAs in the city periphery'* (570.8 ha) are smaller non-urbanized areas scattered between the city's surroundings. '*NUAs in the city core'* (85.5 ha) are very small green areas including Public green spaces, Public open spaces, and other unmanaged areas within the urban fabric (see section Materials).

Figure 7
Map of types of Non-Urbanized Areas.

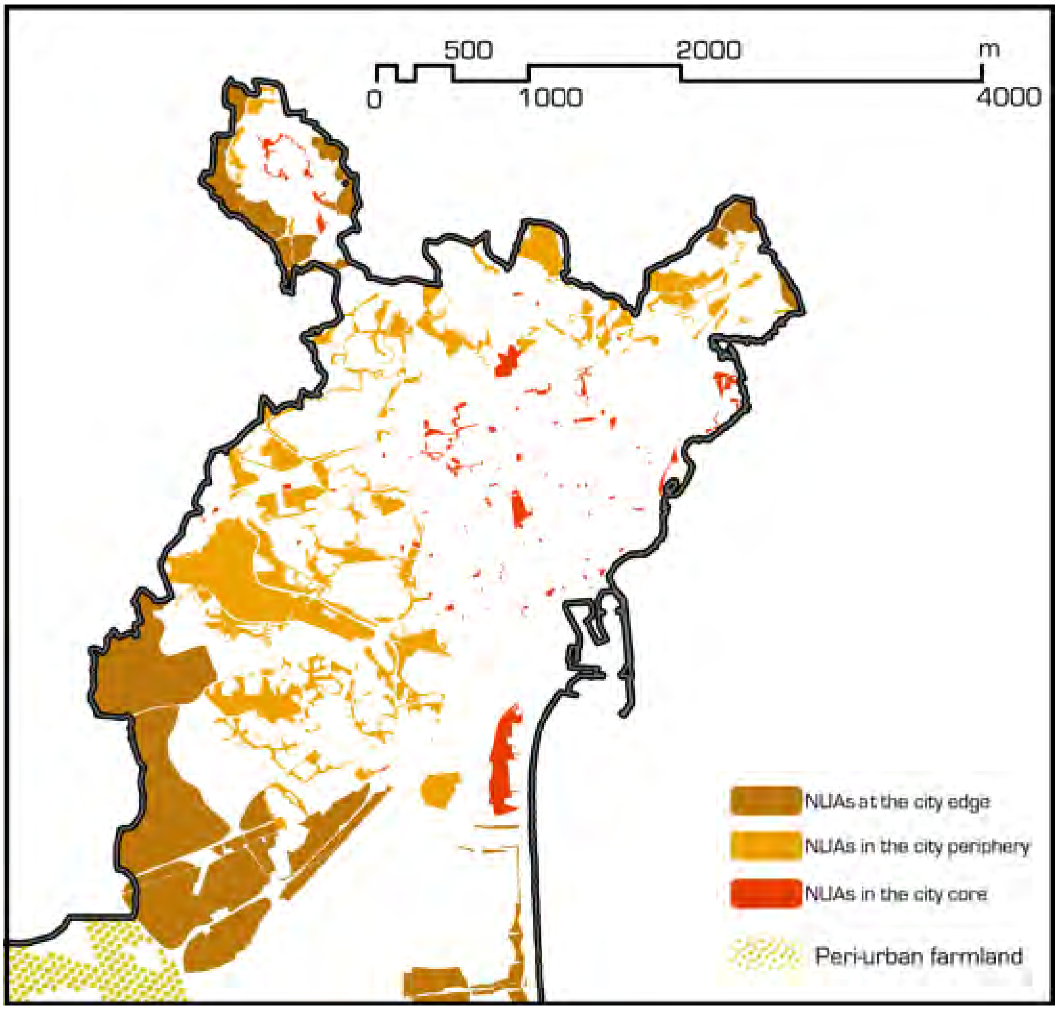
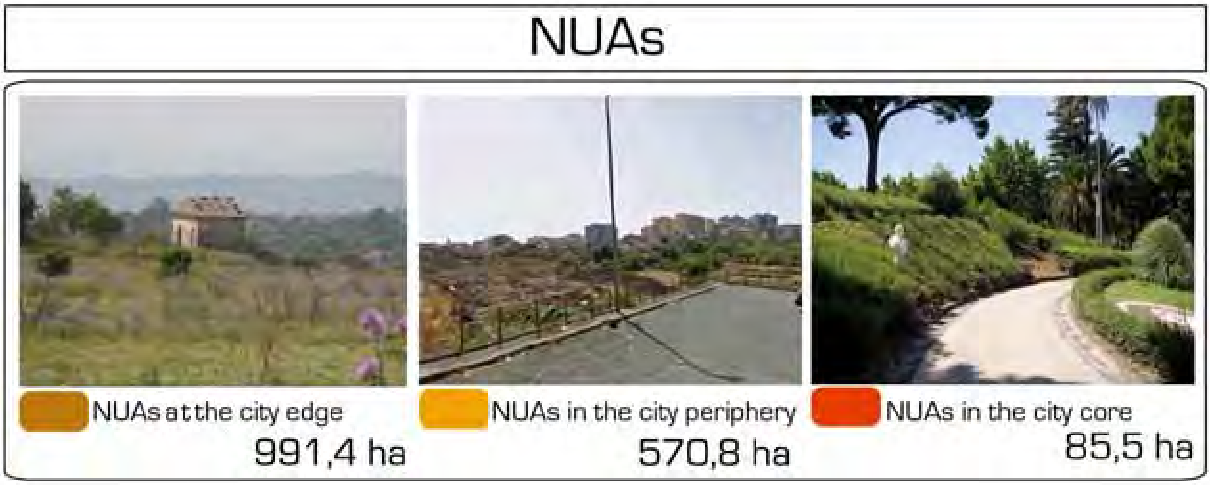


Table 2
Categories of Non-Urbanized Areas.



Taking into account these different NUAs categories, *Connecting Scenarios* have been divided into: *(a) Longitudinal Connecting Scenario* that links *'NUAs at the city edge'; (b) Radial Connecting Scenario* that links '*NUAs at the city edge'* to the widest *'NUAs in the city core', and (c) Urban-cores Connecting Scenario* linking *NUAs in the city periphery* and *NUAs in the city core*.

Action Strategies

Action Strategies are a set of actions created for achieving the aims listed in section Design Approach. From this perspective, strategies include objectives, design scenarios and actions relating to different types of NUAs, indicating functions and new land uses for each NUA. *Action Strategies* have been divided into three categories: *Peri-urban Integration Strategy, Sub-urban Development Strategy* and *Urban Enhancement Strategy*.

Peri-urban Integration Strategy is aimed at integrating agricultural land uses and leisure by promoting urban and peri-urban agriculture and the conservation of traditional rural landscapes (Valentini, 2007; Fanfani, 2009). Actions include the conservation and improvement of NUAs, which account for larger patches of the following two land-use categories: 'Woods/Shrubs' and 'Abandoned Farmlands'. Land pertaining to the category 'Woods/Shrubs' could be converted into *countryside parks* (Donadieu and Mininni, 2006), thereby offering different opportunities, such as the formation of a boundary for anticipated urban growth and an opportunity for enjoying the rural landscape. The second category, 'Abandoned Farmlands' could be zoned as *agricultural parks*. Setting aside these large patches of farmland for agriculture (preferably based on organic farming) would give them stringent rural landscape protection according to law (La Rosa and Privitera, 2013). This strategy leads to the *Longitudinal Connecting Scenario* for the *NUAs at the city edge*, which was introduced as the first scenario in the previous section.

Sub-urban Development Strategy is aimed at converting current NUAs into new public parks and gardens for leisure. Actions include the design of urban parks, urban gardens, allotment gardens, re-forestation and a network of pedestrian and bicycle pathways connecting these individual areas. This strategy leads to the second scenario: *Radial Connecting Scenario* for the *NUAs in the city periphery.*

Urban Enhancement Strategy is aimed at improving the quality, usability and accessibility of urban green spaces. Actions include the conservation, improvement and promotion of green features, such as tree-planting, recreational equipment and facilities for playing informal games and for encouraging social encounters. Finally, this strategy leads to the third scenario, which is *Urban-cores Connecting Scenario* for the *NUAs in the city core*.

Design Elements

Design Elements are the components of the UGI network that are used to implement *Action Strategies* and *Connecting Scenarios*. They represent the design configurations of NUAs and are divided into *First* and *Second Level Elements*.

First Level Elements are the basic components of the network, such as nodes and linkages, and include the following categories: (a) *Stripes*, *(b) Green Waves*, (c) *Scraps* and *Spots*.

Stripes are mostly characterized by a linear shape and a width ranging from 10 m to 20 m. They include 'Woods/Shrubs' and 'Abandoned Farmlands', into which pedestrian and bicycle pathways are designed. The two main purposes are to preserve existing green areas and to increase the permeability of paths.

Green Waves are located along existing or planned urban roads. They include existing and new 'Street Trees', new cycle paths and enlarged sidewalks, which together provide an overall improvement of road quality. The improvement of soil permeability is achieved by using specific surface materials. The shape of *Green Waves* strictly depends on the size of the adjacent road.

Scraps are elements of the network that include urban parks, local parks, countryside parks, agricultural parks, areas for Community Supported Agriculture (van En, 1995), allotment gardens and sport facilities. They mostly correspond to '*NUAs in the city periphery*' and are characterized by a significant amount of vegetation.

Spots are small areas including existing '*Public green spaces', 'Public open spaces' (figure 2)* as well as '*NUAs in the city core' (figure 7)*, which are suitable for new resting areas for pedestrians. The design features here may include tree-planting and minimal facilities for playing informal games and social encounters.

In the UGI network *Stripes* and *Green Waves* represent linking elements, while *Scraps* and *Spots* represent node elements. Particularly, *Stripes* are designed to link *Scraps,* while *Green Waves* are designed to connect *Spots (figure 8)*.

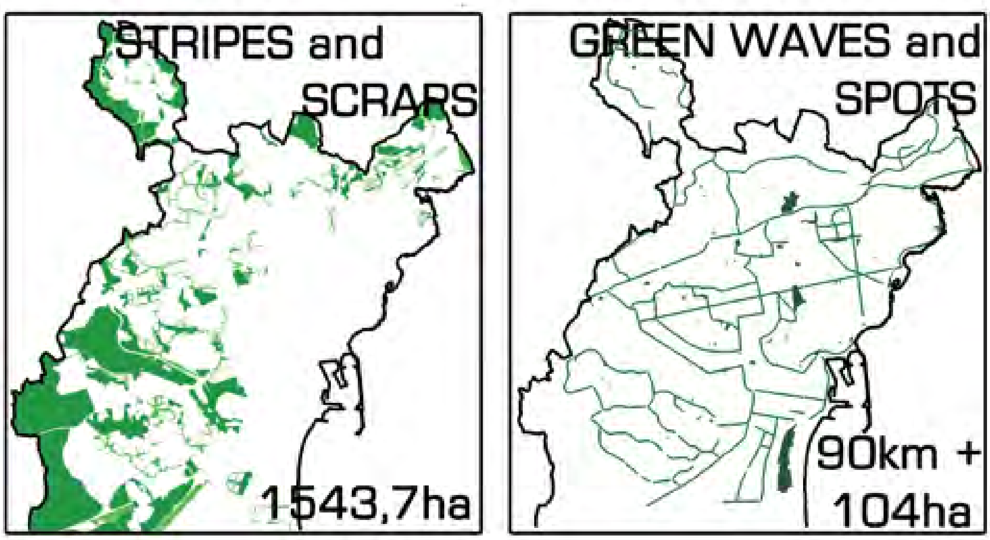


Figure 8
Map of First Level Design Elements (Stripes, Scraps, Green Waves and Spots).

Second Level Elements are elements, which connect areal (Scraps and Spots) with linear ones (Stripes and Green Waves). They represent the design configuration of the three proposed *Connecting Scenarios* and are divided into: *Green Lines*, *Green Wedges* and *Green Hooks*.

Green Lines connect northern rural landscapes of 'Abandoned Farmlands' with southern productive 'Farmlands' (figure 9, left). They are located in the western part of the municipality and along the seaside in the East and represent the design configurations of the *Longitudinal Connecting Scenario*. Particularly, Green Lines new land-uses, such as countryside parks, agricultural parks and allotment gardens are prospected for Scraps.

Green Wedges are aggregations of the largest natural or semi-natural areas, mainly in *'NUAs at the city edge'*. They are targeted toward environmental protection, leisure and new forms of agriculture. Particularly, Scraps within *Green Wedges* are intended for urban parks mixed with Community Supported Agriculture and allotment gardens. The three proposed Green Wedges (figure 9, middle) are the design configurations of the *Radial Connecting Scenario*.

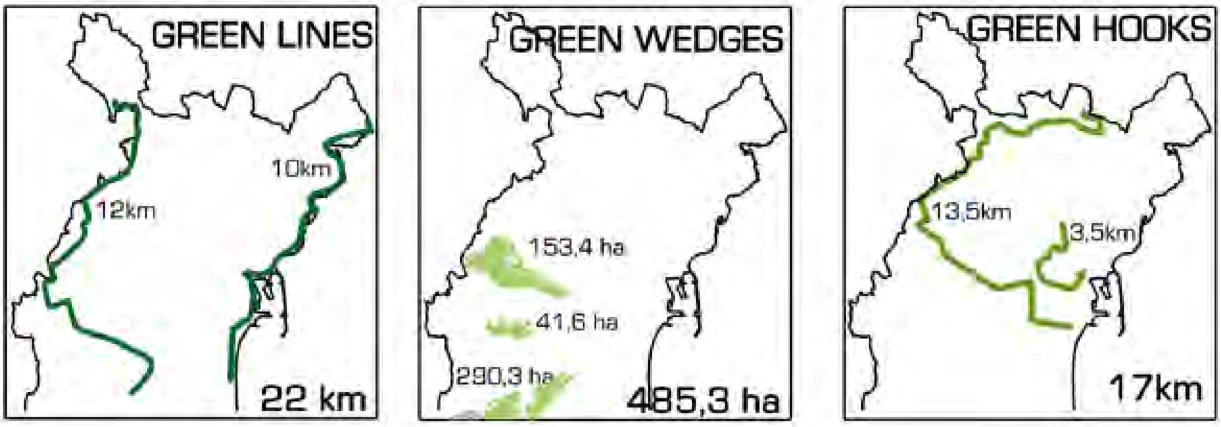


Figure 9
Maps of Second Level Design Elements (Green Lines, Green Wedges and Green Hooks).

Green Hooks are connections of *Green Waves* and *Spots*. They are intended to create green links inside the urban fabric allowing connections between 'NUAs in the city periphery' and in the 'NUAs in the city core'. Green Hooks are designed on the existing main urban ring roads. The two proposed Green Hooks (figure 9, right) represent the design configurations of the *Urban-cores Connecting Scenario*.

Results

Figure 10 shows the final configuration of Catania's UGI as a network of Scraps and Spots connected through Stripes and Green Waves. Stripes and Scraps amount to 1543.7 ha, Spots cover 104 ha and Green Waves have a total length of 90 km (figure 8). Within the category of Second Level Design Elements (figure 9), Green Lines and Green Hooks have a total length of 22 km and 17 km respectively, while the Green Wedges cover an area of 485.3 ha.

The comparison between existing public green spaces (table 1) and the proposed UGI of new public open spaces (figure 8) shows a remarkable increase in surface area of about 2250 % and an increase of 246 % in terms of length of roads planted with 'Street trees' (table 3).

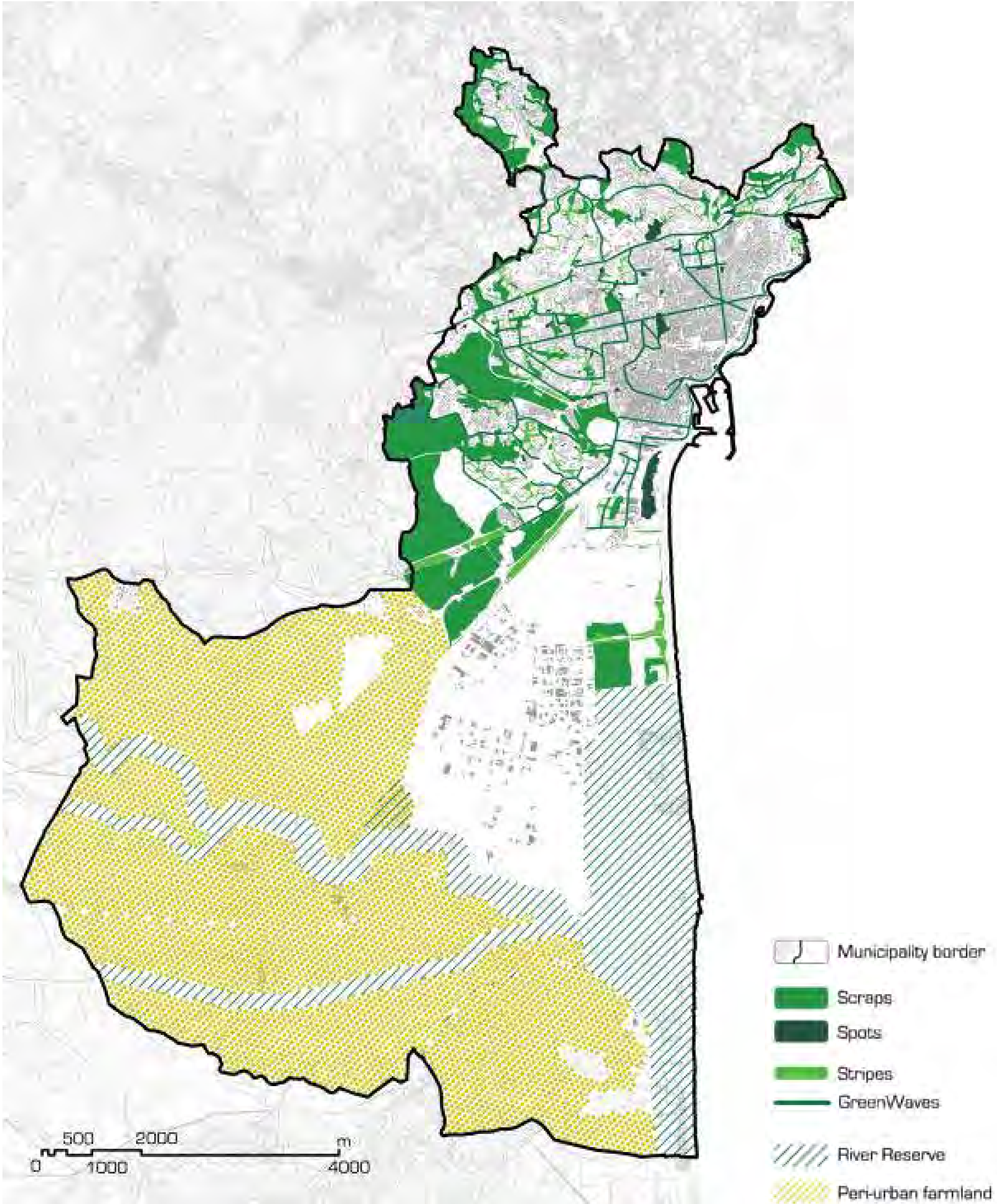


Figure 10
Map of Catania Urban Green Infrastructure.

Table 3
Percentage of green areas and street trees increases.

	Green areas (Ha)	Street trees (Km)
Existing	70.2	26
Urban Green Infrastructure scenario	1647.7	90
% of increase	+2247	+246

Interestingly, the Peri-urban Integration Strategy, involving 100 % of 'NUAs in the city edge', provides the most important contribution to new green areas (more than 60 %) (see table 4). Sub-urban Development Strategy, deals with 35.6 % of UGI green areas and involves 100 % of 'NUAs in the city periphery' and 17.9 % of 'NUAs in the city core'. Finally, Urban Enhancement Strategy concerns 4.2 % of UGI green areas and involves more than 82 % of the 'NUAs in the city core', representing the categories of *Public greenspaces, Public open spaces* and *Street trees (section Materials).*

Table 4
Contribution (%) of the three Strategies for implementing Urban Green Infrastructure.

Strategies	Green areas (Ha)	involved NUAs %	UGI %
Peri-urban Intergration	991.4	100 'NUAs at the city edge'	60.2
Sub-urban Development	586.1	100 'NUAs in the city pheriphery'	
		17.9 'NUAs in the city core'	35.6
Urban Enhancement	70.2	82.1 'NUAs in the city core'	4.2

Sub-urban and peri-urban green areas, even if non-urbanized, are mostly not accessible to people. Thus, the relevance of developing an UGI is mainly related to increasing the total amount of public green spaces and improving their connectedness and accessibility. Some of the proposed solutions for the Design Elements of the Catania UGI (Stripes and Green Waves as First Level Elements and Green Wedges as Second Level Elements) are presented here in order to highlight their specific contribution in providing new green areas. Figure 11 and figure 12 show two types of proposed Stripes. Type A is beside an existing or new urban road, while Type B is within a NUA. Their widths vary from 14 m to 20 m, with a total percentage of green cover varying from 70 % to 75 % and permeable surface of 92 % and 100 % cover respectively. They are composed of a bed of arboreal species with a width between 6.8 m and 7.8 m. The trees' maximum height ranges between 5 m and 12 m and their canopy spread between 3 m and 6 m. Following species are proposed for the Stripes: *Ligustrum japonicum, Phillyrea agustifolia, Magnolia grandiflora, Celtis australis*. These exotic species are widely used in the Catania municipal area. Experience, so far, has shown these species not to be aggressive or negatively affect local urban biodiversity.

One-way cycle paths (1.5 m wide) are included in the Stripes and can be paved with a bituminous layer. Pedestrian paths have a width varying from 2.1 m to 2.5 m. Pedestrian and bicycle pathways are always paved with natural permeable materials. *Zoysia japonica* species can be used for lawns, as it is a very robust species suitable for the Mediterranean climate. The result is a configuration of public green spaces where usability, thermal comfort and safe mobility are the main objectives.

Figure 13 and figure 14 show two types of Green Waves (Type A and Type B). The first represents a Green Wave situated between different built-up areas, which include a total road section of 12 m. The second is a Green Wave beside an Urban Park with a total road section of 32 m. These examples show that the green component (green area) can vary from a mini-

Figure 11
Stripe Type A (First Level Design Element).

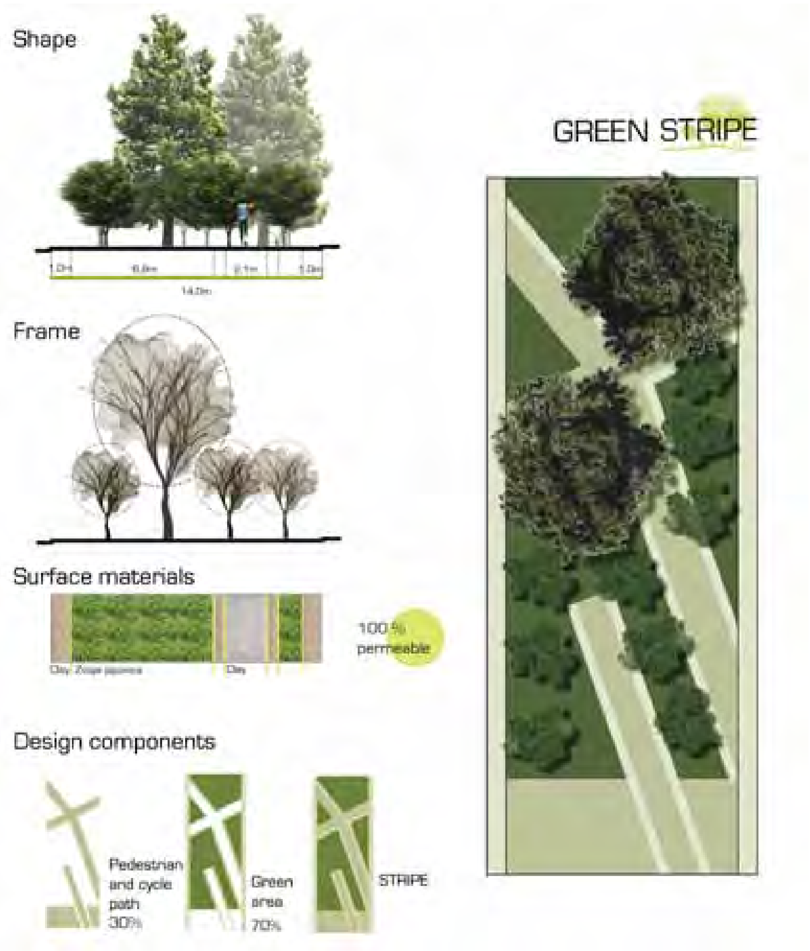


Figure 12
Stripe Type B (First Level Design Element).

mum value of 1.5 m width (Type A) to a maximum width of 10 m (Type B) in road sections with bicycle paths, pedestrian paths and bus lanes. These values represent approx. 12.5 % and 31 % of the total width of the road section.

The Green Wedge (figure 15) covers an area of approx. 153.4 ha and represents a Second Level Design Element. It is to be allocated to major parks providing leisure and sport facilities, or for urban agricultural purposes. This Wedge is mainly composed of two different types of Scraps. The first one is a large urban park aimed at protecting current woods and shrubs as well as providing spaces for sporting and recreational activities. The second Scrap is a smaller area, containing abandoned farmlands, where community supported agriculture and allotment gardens have been proposed. Next to the northern part of the Green Wedge boundary, a Stripe is designed along a stream to restore its vegetation. In the southern part, a Green Wave (Type B) has been proposed to sit next to a newly designed urban road.

Figure 13
Green Wave Type A (First Level Design Element).

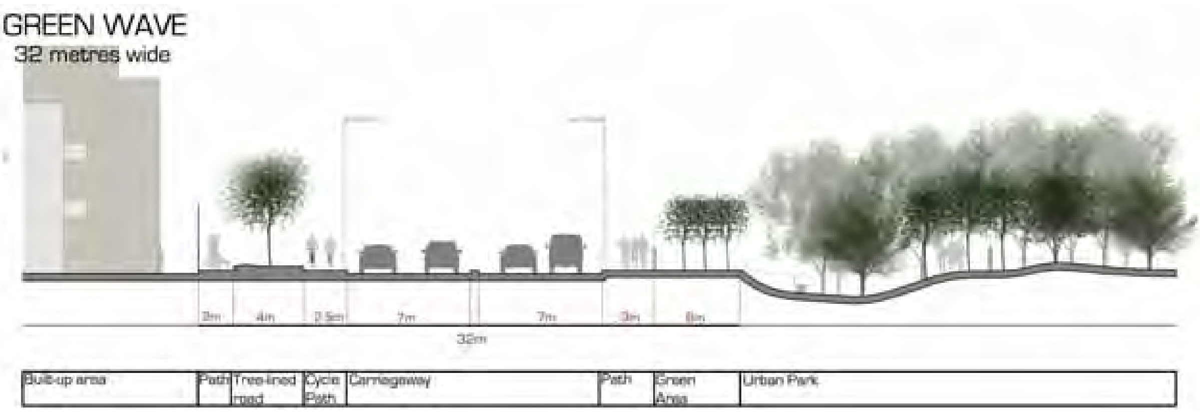


Figure 14
Green Wave Type B (First Level Design Element).

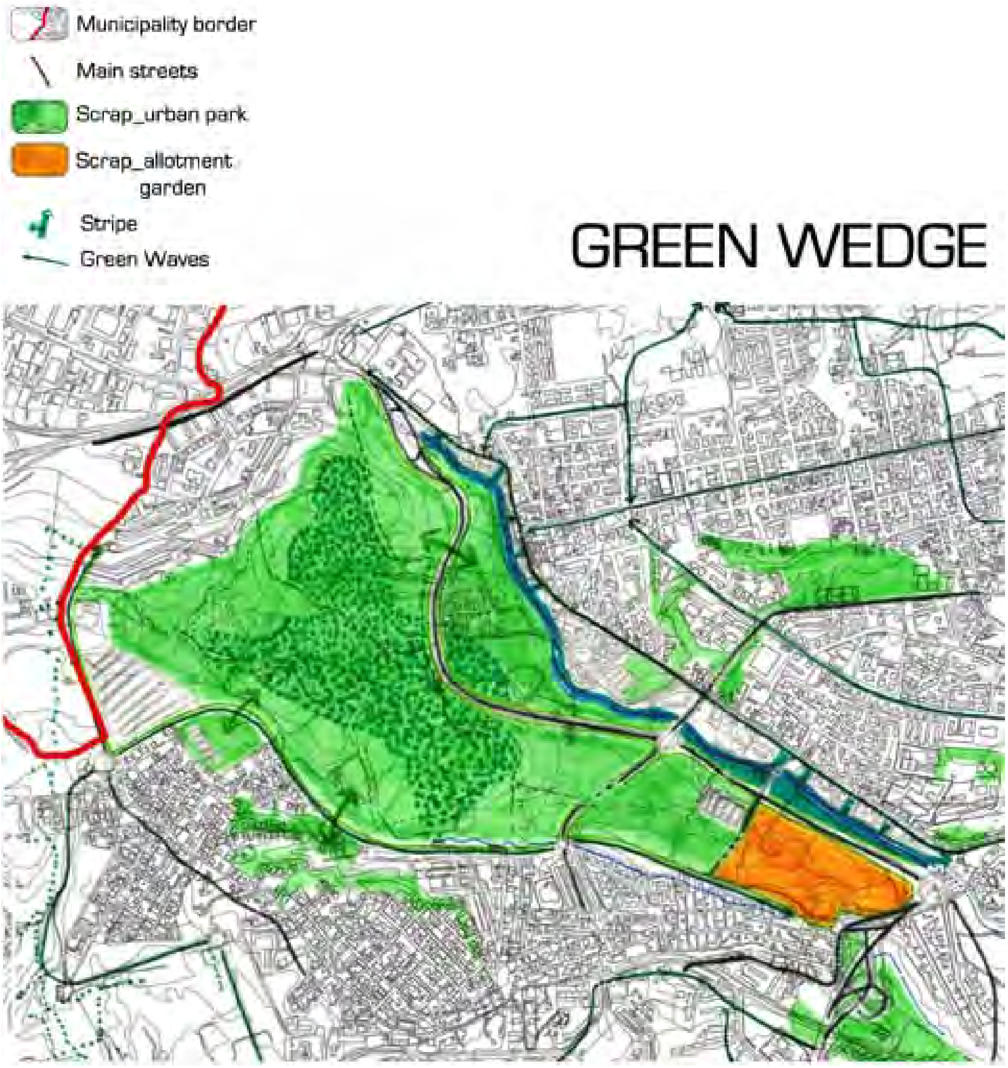


Figure 15
Green Wedge (Second Level Design Element).

Discussion and conclusion

In the Catania municipal area, urban land-use plans have always considered NUAs as generic farmlands or undefined green spaces without any particular importance or role (La Rosa and Privitera, 2013). Despite their appearance of being abandoned and neglected areas, NUAs could play a strategic role in the construction of UGI, especially within urban contexts where the lack of green spaces is particularly relevant. Environmental, social, economic and cultural benefits can be derived from integrating NUAs into the urban fabric; therefore, they need to be given careful consideration.

The importance of this paper is that it represents a design approach aimed at enhancing the current land-uses of NUAs through the implementation of an UGI. Classification of NUAs into three main categories ('NUAs at the city edge, in the city periphery and in the city core) has been a fundamental step for re-thinking and expanding NUAs' value in terms of UGI components. *Action Strategies (Peri-urban Strategy, Development Areas Strategy* and *Urban-core Strategy)* are proposed in order to define and build different Connecting Scenarios (longitudinal, radial and urban core) through specific Design Elements (Green Lines, Green Wedges and Green Hooks). As results show, Peri-urban Integration Strategy would provide the largest amount of total green area for the implementation of UGI. Thus, integrating rural landscapes and leisure, through the protection and promotion of urban and peri-urban agriculture, would allow for a major increase in the total amount of usable and accessible green spaces within municipal context.

Moreover, the results show that UGI would provide an increase of green spaces up to 2250 % compared to the current scope of public green areas. This significant gain of new green spaces triggers issues of economic feasibility for local government and resistance from private landowners. These issues could be addressed through incentive-based approaches for managing urban growth and protecting open spaces (Stoms, McDonald and Davis, 2002). From this perspective, Transfer of Development Rights programs can be used to design NUAs in order to promote the economic benefits of UGI components for different stakeholders, incluing landowners of land parcels to be included into UGI, developers of land parcels to be developed and local administrators, who may implement land-use allocation decisions with non-financial efforts (Brabec and Smith, 2002; Kaplowitz, Machemer and Pruetz, 2008). In particular, *Urban-core Strategies* related to NUAs in the city core could provide a stage for testing the approach of Transfer of Development Rights programs.
Finally, UGI can provide municipalities or other public decision making agencies with a strategic tool for the implementation of planning policy relating to NUAs aimed at the construction of a Green Infrastructure. Such a tool would be extremely relevant in the context of Catania, where the presented UGI has been developed within the on-going Catania Master Plan process. It represents a proposal for creating a Green Infrastructure in an urban area where previous master plans have always neglected NUAs.

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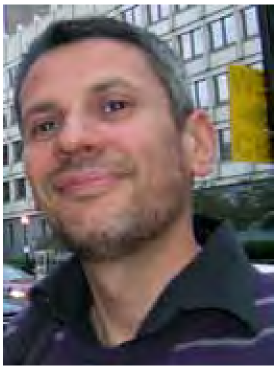

Biographical information

Riccardo Privitera
Address: Università di Catania Dipartimento di Architettura, Viale Andrea Doria 6, 95125 Catania (Italia)
Phone: +39 095 738 2528
E-mail:
riccardo.privitera@virgilio.it

Riccardo Privitera got a master degree in Civil Engineering and a PhD in Urban and Regional Planning at the University of Catania (Italy). He has been working on different urban master plans for public bodies, including Municipal Authorities and University. His scientific interests are: urban-planning, non-urbanised areas planning, ecosystem services, land cover analysis, land suitability analysis, urban and peri-urban agriculture studies. He is recently working with energy-related issues and their relations to urban and spatial planning.

Biographical information

Francesco Martinico
Associate Professor
Address: Università di Catania Dipartimento di Architettura, Viale Andrea Doria 6, 95125 Catania (Italia)
Phone: +39 095 738 2528
E-mail: fmartinico@dau.unict.it

Francesco Martinico is Associate Professor in Town and Regional Planning at the University of Catania (Italy) and Deputy President of the School of Architecture. His main fields of interests are: regional and landscape planning, management issues related to land use, and the use of GIS in planning. He is author of books and papers and member of local and national research groups on regional planning themes. He has been consultant for several land use and landscape protection plans, including the master plan for Catania. He is a member of The International Society of City and Regional Planners (ISoCaRP).

Biographical information

Daniele La Rosa
Address: Università di Catania Dipartimento di Architettura, Viale Andrea Doria 6, 95125 Catania (Italia)
Phone: +39 095 738 2528
E-mail:
dlarosa@darc.unict.it

After a master degree in Environmental Engineering, Daniele La Rosa got a Master in Soil and Water Engineering and a PhD in Urban and Regional Planning at University of Catania (Italy). He has been previously working as research assistant in landscape and regional planning projects. Among his scientific interests are: GIS applications for urban and landscape planning, environmental indicators, Environmental Strategic Assessment, landscape studies, landscape ecology, spatial analysis.

Biographical information

Viviana Pappalardo
Address:Università di Catania Dipartimento di Architettura, Viale Andrea Doria 6, 95125 Catania (Italia)
Phone: +39 095 738 2528
E-mail:
pappalardo.viviana@gmail.com

Viviana Pappalardo is a graduated construction engineer and PhD student in Evaluation and Mitigation of Urban and Land Risks at the Department of Architecture of University of Catania. Her graduation thesis focuses on themes such as ecosystem services, green infrastructure and peri-urban settlements. She is starting to do research for her doctoral thesis concerning topics of smart green cities, green infrastructure and the implications of resilience theory in urban contexts for urban planning.

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GREEN INFRASTRUCTURE IN THE CONTEXT OF RURAL SPACE RESTORATION AND DESIGN

ATTILA TÓTH AND L'UBICA FERIANCOVÁ

Abstract

This paper focuses on green infrastructure (GI) for restoration and design of rural settlements in Slovakia. We explain our planning and design approaches with a case study developed for the rural settlement *Tvrdošovce,* situated in the south-western region of Slovakia, in the *Danube Lowland*. Our case study is a complex landscape architectural project conducted at three planning levels and scales based on administrative and territorial units of different areas. At the first level, there is a GI concept for the micro-region *Cergát-Váh* (area: 195.70 km^2, 15,545 inhabitants), the second planning level consists of a more detailed concept concerning the cadastral area of the village *Tvrdošovce* (area: 55.56 km^2, 5,301 inhabitants) with the intention to create a visual and functional linkage between settlement and landscape. At the third planning level, we deal with public space design at a fine scale relating to the central part of the village *Tvrdošovce* (0.09 km^2 within the overall urban area of the village that covers around 3 km^2). The area in focus is the present village centre and the linear historic open space situated in the central part of the village. Our design follows the surrounding landscape and uses principles and rules of rural space design. It is a qualitative contribution to the rural community and its micro-region.

Key words:
Green ways, green infrastructure, linear historic open space, micro-region, planning levels, rural settlement

Introduction

The development of the Slovak countryside during the 20th century brought a lot of noticeable changes, which left behind a modified village and visible footprints on its urban structure, aesthetic values, social life and local identity. These changes negatively impacted the image of contemporary rural settlements and are related to the previous political and social structure of the socialistic planning economy model, e.g. introducing an urban architecture, which was foreign to this rural context, see figure 1.

Figure 1
The photos show the typology of urban architecture introduced to Slovak rural settlements during the socialistic regime. This architectural morphology was applied not only to public buildings (on the left) but also to private family houses (on the right).

However, these interventions are not only an attribute of the last century but are also part of ongoing development. In order to improve the image of Slovak villages, it is necessary to define the current deficiencies and find sustainable development solutions. From the urbanism and architecture point of view, the most common obstacles are oversized transport structures or 'Routine-catalogue' architecture, which did not, and still does not, have much to do with the rural character and local identity of the settlement. This phenomenon is related to the core concept of socialistic urbanism and architecture as tools for the realisation of a centralised planning system. One of the goals was to match life quality of the countryside with urban living standards. To fulfil this goal, a modernistic 'catalogue' for housing units and uniform public buildings (e.g. schools, service and community centers) was developed. In the second half of the 20th century, there was a boom in construction of new transportation structures as well as a focus on improving such existing structures by sealing new asphalt and concrete surfaces. However, according to contemporary norms for traffic, this design is significantly oversized, meaning that more open spaces are covered by impermeable surfaces than is really needed. Today's traffic engineers pay more consideration to cars than people and, therefore, streets are dominated by cars rather than pedestrians (Šarafín, 2006).

The rural character of the Slovak countryside has been significantly disrupted and still awaits renewal. The image of the street as a common and convenient public space for village inhabitants has noticeable changed. As Štěpánková and Kristiánová (2012, p. 180) state, *«In most cases the use of streetscapes is reduced only to the transportation function and there is an absence of public spaces represented by accompanying greenery or parking possibilities».* Every house has its own front garden sheltered by a high fence, which caused the extinction of authentic Slovak village characteristics, such as the doorway with a shaded bench under a spreading tree. Thereby, the street has lost a very important semi-public space function, which represented a soft transition from public streetscape to private courtyards. Similarly, the rural architecture today faces a significant pressure from the individualistic approach, which is typical for the era of globalisation and market economy. It does not comply with logic and sustainable aesthetics of urban planning principles such as the building and street line or the general architectural characteristics of the specific region, e.g. materials, roof inclination or facade.

In order to find adequate planning solutions for rural spaces, it is crucial to identify deficiencies of rural space from a landscape architecture and planning point of view. In the open agricultural land, the most common problem is connected to consequences of the agricultural collectivisation, which aims at receiving greater profits from collectively owned land. The process of collectivisation in agriculture was typical for Eastern European socialistic systems. It consisted of uniting small pieces of land into larger blocks that allowed for more intensive industrialised farming. This was a profitable solution in terms of economy, but at the same time, it brought with it a range of negative environmental impacts such as intensive drainage of landscapes, deforestation, removing vegetation along roads, watercourses, shelter belts or field baulks. The agricultural landscape lost its inherent diversity and natural permeability. All these interventions caused an ecological destabilisation of the landscape, which now needs to undergo rehabilitation. Sacral elements, which have been a traditional and integral part of the open land and field roads of Slovak villages, have been neglected and long forgotten. Many of them have even disappeared. The villagers gradually lost their attachment to the landscape – they do not know the field roads, the meadow vegetation and the local fauna anymore. They do not go for walks along the brook, to the meadows or into the woods. The contact and the linkage between settlement and landscape, as well as between man and nature, have considerably faded. Disruptive elements were introduced to the built up areas of the villages, often with good intentions. One example of this is the introduction of coniferous woody plants to rural settlements situated in southern regions of Slovakia surrounded by bottomland vegetation and agricultural landscape (eg. *Thuja occidentalis, Platycladus orientalis, Picea abies, Picea pungens, Pinus nigra, Pinus sylvestris* and other species). The front gardens and public spaces in these villages have been, and still are, 'decorated' with introduced woody plants like thuja, as well as by autochthonous (native, domestic), however, for concrete regions, nonspecific woody plants like juniper, spruce, fir or pine. This trend is in line with the current tendency of using a global pool of plants from international nurseries (Ignatieva, 2011).

Historic village centres were the most significant public open spaces from a cultural, historical and social point of view. In the 20th century, these spaces often turned into overcrowded parks with a lot of conifers or uniform and strict alleys, which have taken away the cultural and historical value and identity, and the main function of these spaces has been lost – to be a spacious and clear green village square.

The open space of the village centre did represent, in the context of historical development, a particularly central space where the economic, social and cultural village life was concentrated. Around this space the village gradually grew and, therefore, represents the most valuable historical legacy concerning the organic development of urban structures. It is the main attribute of village identity.

In different cultural settings (eg. in German-speaking countries), rural settlements are interlinked with a common infrastructure including transport, ecological, urban, landscape, social and economic layers. In Austria, a great importance is given to solving village reconstruction in a micro-regional context (Retzer Land, 2013). A further example of such a concept is the fellowship of six rural towns that decided to join into one administrative unit – Nettetal in Germany (Optendrenk, 2013). Within cadastral areas of the member municipalities of the micro-region Retzer Land (Austria) or the town fellowship Nettetal (Germany), there are concepts dedicated to interlinking settlements and landscapes and creating a functionally and visually coherent and harmonious whole, including both, open land and built-up areas. To fulfil all these requirements, there is a landscape planning strategy – *green infrastructure (GI)* – that is being implemented in several countries in Europe and around the world. It is also included in the Europe 2020 strategy (European Commission, 2013) and in terms of the services and benefits provided by GI, it can be regarded as a valuable and constructive approach, which may also be applied to the restoration of the Slovak countryside.

This paper is dedicated to explaining the importance of the GI concept for village restoration and rural development in Slovakia. We present our results from a case study conducted in the rural settlement *Tvrdošovce* situated in the *Danube Lowland*. For this settlement, a GI concept was developed at micro-regional and cadastral level. At the local level, a complex landscape architectural design has been developed for the central part of the village dealing with a linear open space of the historic streetscape. This urban structure represents a significant cultural heritage with important historical legacy. In our design, we deal with these issues in order to create a valuable contemporary open space for the inhabitants.

Our research question is how contemporary GI planning principles can be adapted in order to constructively contribute to restoration and design of rural spaces with specific urban and landscape structures.

Description of the case study

The main focus of this case study is the landscape architectural development of the rural settlement *Tvrdošovce* and its GI at three planning levels, see figure 2.

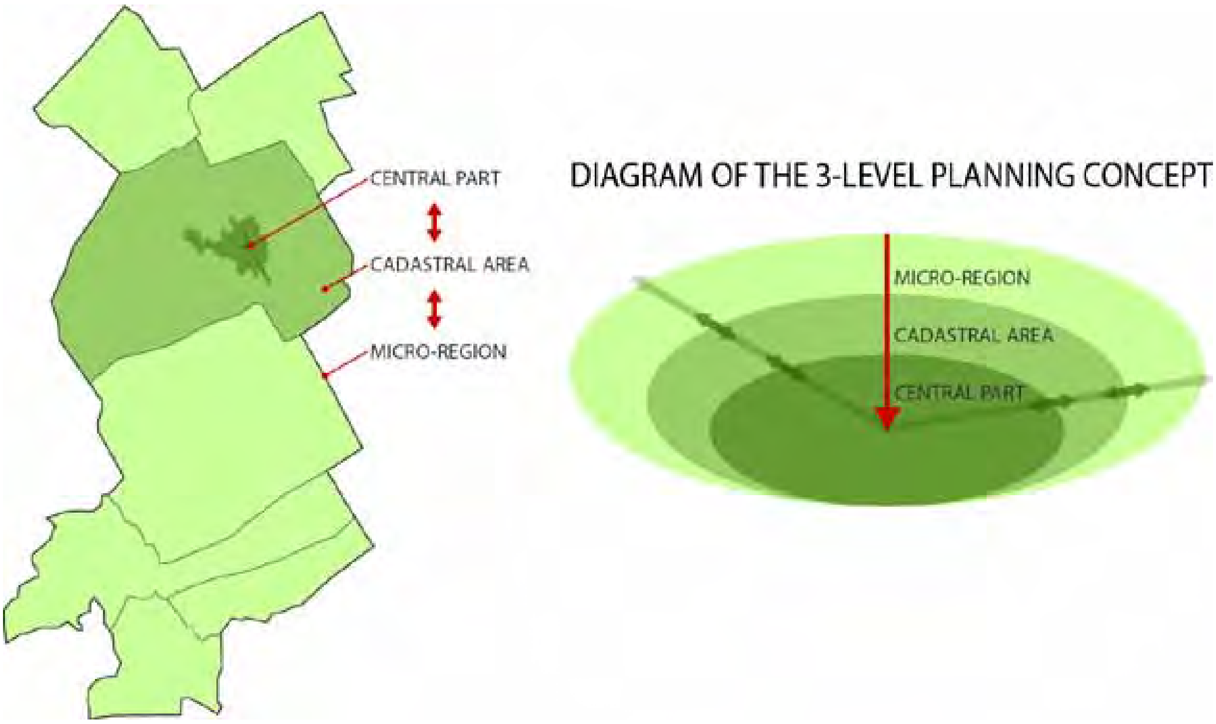

Figure 2
The diagram shows the idea of a coherent and integrated planning approach at three planning levels and scales.

At the micro-regional level, we developed a GI concept for the micro-region *Cergát-Váh* (a geographically delimited area with common natural, demographic, historic, cultural and other features; an interest association of 7 rural settlements, including the village *Tvrdošovce*). Its aims are a) to support sustainable development of the micro-region as a coherent whole, b) to stimulate local economy, c) to develop agri tourism and to strengthen ecological stability of the area. Thereby, a complex micro-regional GI can be built and public awareness of the landscape can be raised.

The second intermediate planning level is represented by the cadastral area of the village *Tvrdošovce* (the administrative territory of the municipality, including the built-up urban area and the open agricultural land). For this settlement, a more detailed GI concept has been developed. The principal goals of this concept are a) to create a visual and functional linkage between settlement and landscape and convert it into a continuous and harmonious whole, b) to raise the visual and perceived value of the settlement and landscape image; to make the open land accessible for the inhabitants and visitors, c) to improve the local green infrastructure and to increase the ecological stability of the area.

The main goal of the third planning level, which concerns the village centre (the urban core of the village consisting of the historic streetscape – the common, and the present village centre defined by public facilities), is to develop a unified landscape architectural arrangement of the village center including the historic streetscape, which arose in the Middle Ages. The linear open space in the village center is unified by landscape architectural tools in order to convert it into an attractive public space. Our concept emphasises the identity and the rural character of the target area.

Methodology

One of the first steps in this study process was a detailed analysis of the historic landscape, settlement structures and the spatial development of the village *Tvrdošovce*. The method used for this analysis was a visual interpretation of historic maps of the cadastral area from the 18th and 19th century (the 1st and 2nd military mapping) as well as visual interpretation of historic photographs from the end of the 19th and the beginning of the 20th century, see figure 3.

Figure 3
Historic landscape and settlement structures of the village *Tvrdošovce in* the 18th and the 19th century (Tóth, 2012, pp. 45–46).

Compared to figure 4, a significantly higher portion of grasslands in relation to arable land is visible and a considerably denser communication network in the landscape exists. Therefore, it can be stated that the open landscape structures were more balanced, permeable and accessible in historical periods compared to the present.

To develop the landscape architectural design of the central open space of the village, it was necessary to analyse the geographic and natural conditions of the area including spatial, climate, temperature, precipitation, wind, geological, soil, hydrological and potential-natural-vegetation characteristics.

To develop a new landscape architectural arrangement for the rural settlement *Tvrdošovce,* we decided to apply planning at three levels. The first level is represented by the micro-region *Cergát-Váh* (this micro-region consists of seven rural settlements including the village *Tvrdošovce, authors' note*), the second level is the cadastral area of the village and the third level, the central part of the village consisting of the linear historic core and the present village center.

At the micro-regional and cadastral level, we developed a greenways concept. Greenways stand for natural or designed linear open spaces along anthropogenic or natural corridors for pedestrians, cyclists and other users. They connect the landscape with the urban area and provide society with social, economic and environmental services. For developing this greenways concept, GIS processing and visual interpretation of map data was applied.

The primary structure of this concept is composed of linear elements linking rural settlements of the micro-region and forming a coherent GI. At cadastral level, we used GIS to create landscape planning schemes depicting the landscape in different layers such as water, transport, landscape, urban and green space structure. These schemes were used as a basis to develop a detailed GI concept at cadastral level.

In order to create the public space design of the village center, we applied principles from Slovak, Czech and Austrian authors, who have been continually engaged with long term research into rural space design (Mareček, 2006; Pleßl, 2003; Šarafín and Tóth, 2011).

To improve the design, we went on research trips to *Burgenland* and *Lower Austria* (two Austrian regions located in the eastern part of the country). We drew inspiration from public space arrangements of villages located in these regions because their urban structure proved to be very similar to Slovak settlements.

Within the design concept, we worked out a zonation of the designed area, which was divided into four main zones: 1) sport and recreational spaces of the historic streetscape, 2) public spaces of the present village centre, 3) main promenade of the historic streetscape and 4) public spaces of the living street situated in the contact zone between settlement and landscape (Tóth, 2012).

As a starting point for public space design of the village center, we used the inventory of woody plants in the central part of the village *Tvrdošovce,* developed by Tóth (2010). *«Urban greenery and woody plants represent a very important component of public space design as they have historical, social, aesthetic, recreational and perceptual values»* (Supuka, 1998, p. 115). The complex knowledge of woody plants, acquired during the research from an inventory and assessment of woody plants (Tóth, 2010), made it possible to work out a more ecological public space design concept, which utilizes the spatial potential of the village center.

Results

The results are presented below using the same structure as the 3-level planning concept.

Green infrastructure (GI) at the micro-regional planning level

The GI of the micro-region aims at creating a coherent and integrated green system with ecological, spatial, social and economic dimensions, see figure 4. The figure shows the green infrastructure concept at micro-regional level containing primary and secondary greenways structures and areal elements of the green infrastructure. The developed concept contains proposals of how to enhance ecological stability of the area. It supports a sustainable development of rural settlements; improves visual and perceptual values of the countryside; creates a functional and visual linkage between built-up area and open land; provides recreational, educational and cultural functions of green structures and promotes sustainable tourism and non-motorised transport.

Figure 4
Greenways concept for the micro-region *Cergát-Váh* (Tóth, 2012, p. 44).

Enhancing ecological stability is mainly achieved by increasing the portion of non-forest woody vegetation in the landscape. A higher portion of non-forest woody vegetation would improve the existing landscape structures impacted by agricultural collectivisation. We propose to enhance the portion of woody vegetation in the landscape, mainly by establishing new linear vegetation structures along field routes and watercourses. This approach would not only provide aesthetic benefits (unifying the common image of the rural settlement and landscape) but also environmental benefits, such as increasing biodiversity and structuring the landscape through bio-corridors for wildlife in a currently impermeable landscape. These migration corridors are missing in the present agricultural landscape of Slovakia. Besides the mentioned ecological benefits, an increase in non-forest woody vegetation would also eliminate one of the largest problems of Slovak agricultural landscapes, soil erosion. Vegetation structures next to watercourses would lower the eutrophication of these water resources. There is also a NATURA 2000 area *Panské lúky* (SKUEV0095; area: 77.79 ha) within the cadastral area, which functions as a protective landscape tool at policy level and aims at protecting the GI and increasing ecological stability of the area. Our greenways concept is based on results from long term research done by Ahern (2004) into greenways planning and implementation. He determines greenways as an efficient planning tool for the protection of maximal amounts of natural resources through minimal land consumption (hypothesis of coexistence). Greenways support biological and physical functions of the landscape and, therefore, they are important for the sustainable development of a spatial unit.

The main dimensions and functions of the green infrastructure at micro-regional, cadastral area and built-up area level are summarized in table 1.

Table 1
Overview of principles and functions of greenways, green networks and green infrastructures (Feriancová and Tóth, 2012, p. 46).

Ecological Dimension	Urban and Spatial Dimension	Social Dimension	Economic Dimension
Bio-corridors, bio-centres, interactive elements and natural systems	Aesthetic, design and cognitive function; visual-landscape-forming, compositional and spatial significance; urban-space-forming element	Recreational function	Agriculture and forestry function
Importance for nature conservation, environmental and landscape protection			
Promotion of sustainable land use, development and way of life; linking of greater natural areas, existing and planned green spaces	Connection and transport function	Educational function	Positive impact on local economy
	Linking inner-urban areas, connecting the urban area with the surrounding landscape	Cultural function	Positive impact on sustainable tourism
Strengthening of ecological stability of the area	Inclusion of major source and destination points and public facilities	Participation in design and maintenance of the green network	Positive impact on mobility
Urban ecology and urban climate function	Multifunctional ways for non-motorized users	Safe and attractive routes to school	

The main elements of the primary greenways structure are the river *Váh,* as the longest river in Slovakia, it is of supra regional importance and impacts several regions, and the canal *Cergát* (regional importance). Within the cadastral area of *Tvrdošovce,* the village brook is the main linking element between settlement and landscape. The secondary structure of the micro-regional GI consists of field roads connecting settlements with each other and with recreational spaces in the open land. They make the agricultural landscape accessible and represent a cultural and historical legacy in the form of physical and social linkages between settlements. This historical heritage has to be protected, improved and appropriately used. The vision for *Cergát-Váh* is to become a micro-region of countryside tourism and agri tourism by using the proposed GI system to offer recreational use of the agricultural landscape. The role of municipal self-governments is to find their position and tasks within the vision of the micro-region and to work out a common strategy for further sustainable development.

Green infrastructure (GI) at the cadastral area planning level

Landscape planning at the cadastral level resulted in a more detailed GI concept, which deepens the micro-regional concept and makes it more thorough. The principal function of this concept is to link the settlement and landscape visually and functionally and, thereby, create a coherent and visually unified whole, see figure 5.

The green infrastructure at cadastral area level (figure 5) depicts present landscape and settlement structures where structural changes are clearly visible compared to historical sources. The concept contains primary and secondary greenway structures as interlinking elements as well as more ecologically significant components such as protected areas, smaller woods, orchards, grasslands, etc.

The GI concept has been developed by adapting landscape planning schemes. Its main focus is the historic village center, which consists of a linear open space of the wide historic streetscape of significant cultural, historical and social value. It is one of the most important landmarks of the village and, therefore, became a space of particular interest for public space design. This linear open space in the historic village center, together with other public green spaces, creates the GI within the built-up

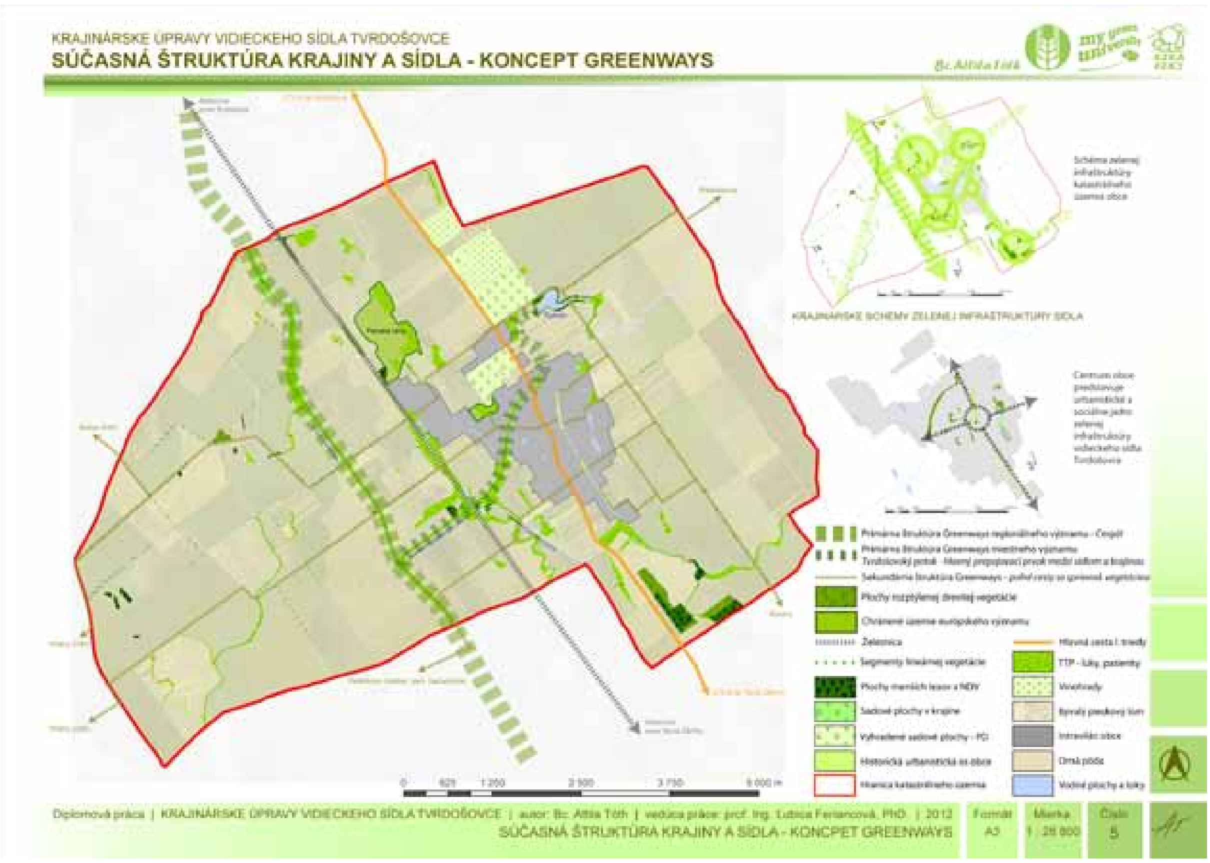

Figure 5
Current landscape and settlement structures – Greenways concept (Tóth, 2012, p. 48).

area. Linkages between spatial elements of the GI are provided by linear greenway elements, which are represented within the built-up area by streets and their accompanying green elements.

A considerable amount of small lakes within the built-up area represents a historical legacy of the settlements' hydrological system. These lakes have a great potential to improve microclimate and to provide attractive open spaces (lakesides) for sport and recreational use for inhabitants and visitors.

Elements of the village GI, which have great local significance, are the historic streetscape and the village brook, which also has regional significance. The village brook functions as the main linking element between settlement and landscape, as it flows through the built-up area and continues to the open land. Architectural improvements along the brook are proposed in order to convert it into a natural 'green promenade' for the village.

Green infrastructure (GI) and public space design at the central part planning level

The existing public space design of the historic streetscape suggests a visual and functional integration of the linear open space with the present village center. The open space improvements can then convert the central public space into a continuous, harmonious whole, see figure 6.

Within the landscape architectural concept we developed a unified public space design for the central streetscape and the present village center. The additional photos show the urban environment of the village center in order to understand the spatial and perceptual characteristics of the designed area.

The proposed changes have a clear compositional structure, typical and suitable for rural spaces. The predominant vegetation elements are represented by lawns with solitary and group plantings of high deciduous trees – limes (*Tilia cordata* Mill., *Tilia platyphyllos* Scop.), oaks (*Quercus robur* L.), maples (*Acer platanoides* L., *Acer campestre* L.) and ashes (*Fraxinus excelsior* L.) as fundamental trees supplemented by birches (*Betula pendula* Ehrh.), willows (*Salix alba* L.; *Salix alba ´Tristis´*), cherry trees (*Prunus avium* L.), apple trees (*Malus domestica* L. Borkh., *Malus sylvestris* L. Mill.) and pear trees (*Pyrus communis* L., *Pyrus pyraster* L.). A significant portion of the vegetation elements are woody plants and consist of existing healthy tree plantings, which have a higher landscape architectural value and are in accordance with the compositional aim of the design (particularly in the case of common ash, common birch, small-leaved lime and Norway maple, *based on the woody plants inventory* developed in 2010 by Tóth). Cherry trees are the most visually unifying elements of the historic village center. They make up a conceptual 'ribbon',

Figure 6
Landscape architectural concept for the central part of village Tvrdošovce (Tóth, 2012, p. 49).

meandering through the whole linear space. The idea of a stylised common orchard is based on the historic function of this space, which has always been a common 'property' of villagers. Continuous grass surfaces with solitary and group plantings of high trees provide a more efficient use of the spatial potential of linear green space. As Kuczman (2008, p. 34) states, *«vegetation elements can decrease the visual impact of negative elements of a streetscape and thereby they are able to improve the visual quality of a streetscape and the settlement as a whole»*. These spatial improvements return historic and social value to the space and raise its perceived quality.

According to the predominant function and use, we divided the designed area into four main zones. North of the church, there are wider areas of the historic streetscape aimed at sport and recreation. Here, the open space of the historic streetscape is at its widest, in some parts up to 40 meters. The provision of lawns in combination with the calm character of the living streetscape, determine its potential for becoming a sport and recreational public space right in the village center. It is designed to have continuous lawns in the middle of the streetscape, which are framed by tree groupings and solitary trees. This attractive and calm public space has potential to become a safe playground for children, a place to sit- or lie-down on the grass or in the shade of a spreading tree.

The historic streetscape will as well attract young and elderly residents to enjoy sitting-down on a bench, have a picnic on the grass or to engage in sport activities. In the southern part of this zone, there will be an open air gallery displaying carvings from local woodcarvers. These wood carvings will attract visitors to step onto the 'green carpet' of the streetscape and to look at the open air gallery surrounded by greenery.

The next zone is located in the southern part of the streetscape where the built-up area borders directly on the agricultural open land. Attractive views to the landscape exist here, and its compositional elements significantly impact on the perception of this space. The distance between this section and the village center provides a calm living streetscape. It also contains common spacious front gardens, which belong to the inhabitants and adorn the whole streetscape. The adjacent open land attracts walkers and provides the possibility to observe the natural expressions of beauty of the agricultural landscape, its variety and diversity. Future prospects to construct a thermal recreational complex at the thermal well on the south-eastern boundary of the built-up area, create a future image of this part of the central village streetscape. It would create an extension to the current village promenade, from the historic square up to the planned thermal recreational facility.

In terms of public space design, these two zones situated in the central part of the streetscape are of utmost importance.

The current center is defined by existing community facilities *(church, kindergartens, florist shops, chemist's, pizzeria, café, confectioner's, community guest house, community cultural centre with amphitheatre, municipal authority, firehouse, restaurant with bar, service centre, supermarket and bakery),* which are concentrated around the central part of the settlement, the midpoint of the village, which is marked by the main urban and architectural landmark – the church. Existing and proposed open spaces are the target for proposed public space design and consist of: 1) the historic square around the church with a gathering space at the oldest artesian well, 2) the surroundings of the community cultural center, 3) a new square in the courtyard of the municipal authority.

The main promenade in the historic center is formed by the streetscape leading from the church up to the primary school. It is used all year round as a gathering space in the central part of the village and also serves as a public space for inhabitants and visitors. During the school year, this area becomes the main route to school, therefore, the majority of users are children from the ages 6 to 15. The streetscape provides a true promenade-function during St. Stephan's days, at the end of August, when traffic is diverted and the whole street is used as a promenade, directing people from the historic square and the church along the market stands to the seasonally used car park in front of the thermal swimming pool. In this green space, in front of the primary school, there is an amusement park with merry-go-rounds and a market fair. Another unifying element of the promenade composition is situated besides cherry trees, a stylised brook that meanders through the entire promenade. Of particular value to the locals are the existing horse chestnuts (*Aesculus hippocastanum* L.) planted around a baroque sacral sculpture and the common birches (*Betula pendula* Ehrh.) in front of the primary school. The importance given to these elements has warranted their inclusion into the design concept (Tóth, 2012).

In summary, it can be said that the design focuses on the present village center and the main promenade of the historic streetscape. It solves issues of parking (static traffic) in the village center by providing three larger car parks at the service center, the supermarket and the cultural center, as well as several smaller car parks near public facilities. Main elements of the present village centre are the historic square, the new square with a market place and the surroundings of the community center, see figure 7.

Cross sections of the streetscape on the right show the spatial dimensions of the designed streetscape as well as the relation to their framing urban structures. Plans on the bottom of the figure show selected

Figure 7
Landscape architectural design of the village center of Tvrdošovce
(Tóth, 2012, pp. 50–62).

public spaces of the village center – the historic square with the church, the multifunctional market square and the open space improvements at the community center. Provided are some additional sketches and drawings, which underline the intention of the designed public space improvements.

The spatial flexibility of the new market square is provided by a lawn adjacent to the central paved surface. This solution enables, if needed, a spatial extension to the square. The landscaping of the new square creates an attractive and cosy space for users. Soft terrain modelling brings pleasant dynamics to the small park to the left of the community center and provides attractive surroundings for sitting-down around a fountain. By removing the car park in front of the community centre, a gathering space with green surfaces and benches adds adequate social function to this space. The historic village square is improved by removing the fence around the church garden and, thus, makes an attractive public garden accessible. A path with gathering spaces loops around the church and serves during religious holidays for processions. The landscaping of the church garden is designed in two vertical dimensions. The higher dimension is composed of deciduous trees framing the views to the church, while the lower dimension, of 'human scale', comprises an alley, which lines the path leading to the main entrance. The core of the restored historic village square is a gathering space arranged around the reconstructed artesian well. The historic monument at the gathering space will become an integral part of the public space by removing an existing fence, similar to opening the church garden.

A stylised meandering brook adorns the main promenade and 'returns' to the village center in the form of a gravel brook bed lined by grasses and perennials. The stylised brook contains dynamic water elements such as drinking fountains and water playing elements for children. Thus, water returns to the public space of the historic streetscape in a way that corresponds to current user requirements, enhancing the rural character of the public space. The green strip, which frames the two roads, will once again become an attractive public space, a living streetscape. The stylised brook will not end at the lawn, but will continue through the parking area in a meandering line of darker pavement. Thereby, the green and the hard surfaces will be linked visually and thematically, which will contribute considerably to the perception of the streetscape as being a unified and coherent linear space. The paved surface of the parking area will add a subtlety. The green space in front of the primary school will serve during the school year as a playground-meadow and will extend the functionality of the open space of the primary school and promote interaction between the users of public and semi-public spaces. Preference is given to solitary and point plantings over linear vegetation elements. These can create long narrow spaces with a dominant linearity more effectively compared to uniform linear vegetation elements. They make the composition of narrow spaces softer, cleaner and more transparent, as they enhance the visual linkage between the architectural objects along both sides of the linear open space. The sacral sculpture in front of the primary school deserves special attention. The architectural and spiritual value of this element is emphasised by old horse chestnuts, which are the oldest trees in the historic streetscape and certainly belong to the overall image of the sacral element. In the Slovak countryside, sacral elements (sculptures or crucifixes) were always accompanied by vegetation elements – mostly deciduous trees (lime trees, oaks, horse chestnuts, etc.). This cultural and historical heritage has to be maintained and protected and deserves to be restored in the future. To make this significant sacral element more attractive, the design proposes to remove the fence, thereby achieving a visual link to the public open space of the streetscape (Tóth, 2012).

Discussion

The result of our work is the proposed landscape architectural design of the rural settlement *Tvrdošovce* at a micro-regional, cadastral and central part (fine scale design) level. The application of greenways and GI planning strategies in the process of rural settlement restoration provides a better integration of *Tvrdošovce* with the micro-region *Cergát-Váh*. It also incorporates new progressive experiences informed by Western and Nordic countries. It works in accordance with the Europe 2020 strategy that promotes research into GI and its implementation (European Commission, 2013). The network of greenways has not only a positive impact on the countryside restoration process, but at the same time, it renews the faded relationship and linkage between *'settlement-landscape'* and *'man-nature'*. These issues are also discussed by Murphy and Mourek (2010) who state that greenways promote rural development, active tourism, local employment and improve relationships between inhabitants. This is one of the reasons for applying the greenways and GI strategy to re-design the rural settlement *Tvrdošovce*. These concepts can potentially intensify the cooperation between settlements of the micro-region, which currently is stagnating. Our design is a contribution at urban (e.g. re-connection of urban areas in the countryside), landscape (e.g. creation of a coherent rural landscape image integrating urban areas), ecological (e.g. enhancing the biodiversity and ecological stability of the landscape; creation of wildlife corridors), social (e.g. renewal of the linkage between man and landscape) and economic level (e.g. supporting local and micro-regional economics by agri tourism and other supplementary economic activities). A significant short-coming of current master plans of these settlements, is the fact that they do not plan the development of the village in micro-regional context. This fact prompted the development of a design at three planning levels. The developed greenways concept at cadastral level has to be understood as a thematic and content extension of the *Territorial System of Ecological Stability* developed within the master plan of the village *Tvrdošovce*. This statement is based on results of a long-term study done by Ahern (2004) who, among others, states that greenways represent an effective method to protect nature and landscape through occupying a relatively small area for multiple functions at the same time (ecological, urban, landscape creation, social, economic and other functions). Therefore, greenways are an effective and proven landscape planning tool, which should be applied to the process of Slovak village restoration, thus enhancing rural settlements and their micro-regional associations. The proposed planning approach has potential to solve issues of the Slovak countryside described by Štěpánková and Kristiánová (2012, p. 180) who state that, *«the most significant manifestation of suburbanisation in rural settlements is an extensive growing of built-up area into open land».* Most of the current projects and strategic rural development plans in Slovakia are developed only at local level. However, common trends of rural space design, e.g. in German speaking countries, prove that integrated planning approaches in rural space design, within the context of micro-regions, constitute a much higher improvement potential for the designed settlement. The results of a long-term cooperation between villages of micro-region *Retzer Land* in *Lower Austria* show that coordinated planning and design approaches of rural spaces within micro-regional context provide a significantly more dynamic development (Retzer Land, 2013). As Ahern (2004) explains, local plans have to always be solved in the context of greater territorial units in order to promote cooperation between individual settlements and their sustainable development in the fields of rural tourism, land use and local economy, which is in accordance with our 3-level planning approach. The importance of linkages in the landscape is also supported by research results from Jongman (2004) who focuses primarily on ecological corridors and networks. Thus, greenways and green networks can be regarded suitable for the Slovak countryside within a historic context. The interpretation of historic maps concludes that the amount of linkages between different settlements of the rural countryside of the 18th and 19th century was significantly higher and more complex than nowadays. A greenways concept provides a progressive strategy for renewal of rural communities and, thus, can also be considered an effective tool to build positive relationships between current villagers and their landscape. This is also proven by Hellmund and Smith (2006) who state that appropriately designed greenways can, besides obvious recreational use, create also social linkages between neighbourhoods and communities. These can increase civil interaction and, at the same time, extend and improve a sense of community. This attribute of greenways described by Hellmund and Smith validates the suitability of the GI planning strategy to solve present issues of the Slovak countryside. According to Mareček (2006), one of the greatest deficiencies of restoration projects for rural public spaces is that, only partial improvements are offered without an overall concept for public open spaces of a settlement and without attention to its historic context. Our integrated planning approach responds to this deficiency by offering a self-government approach of the village, a complex and unified design of the linear historic village core and creating the current village center to become a coherent whole. It responds to deficiencies of the project «*Revitalisation of the central zone of village Tvrdošovce (2010/2011)»,* which focused only on a transportation concept and neglected a more complex urban and landscape architectural solution and also failed to connect design with the cultural and historical heritage of the village center. The mentioned revitalisation project did not utilize the spatial potential of the central part of the village and furthermore, the landscaping included in this project did not respect the basic compositional principles and rules of rural space design.

The aim of the landscape architectural design described in this paper is to rectify the deficiencies of the mentioned revitalisation project. Thereby, it contributes to a qualitative improvement of the central part of the village by creating an attractive public space for inhabitants. The significance of the village center for community life is also emphasised by Šarafín and Tóth (2011, p. 17) who state that one of the priorities of rural development has to be seen in the improvement of the village appearance. This includes raising the attractiveness of public spaces for inhabitants and visitors because they represent the center of community life. Design tools are used that are in line with Mareček (2006) and other experts' findings on rural space design suitable for historic village centers, which, in summary, are the use of solitary trees and groups of high-stem deciduous trees and the maintenance of continuous central open spaces in the form of lawns.

Conclusions

This paper brings forward two points of discussion: a) the importance of interlinking settlements and landscapes into a coherent whole, and b) understanding rural villages as being part of the cultural landscape. The micro-regional greenways concept developed at the first planning level represents a complex green infrastructure with ecological, urban, landscaping, social and economic dimensions. The designed GI system consists of primary and secondary structures. The primary structures are represented by bio-corridors of supra-regional, regional or local importance within the *Territorial System of Ecological Stability (TSES)*. The secondary structures respond to historical legacy of how rural settlements were linked in the past. These linkages are renewed in a way, which corresponds to current cultural, social and demographical conditions of the Slovak countryside. Our greenways concept at micro-regional level contributes to a sustainable development of the micro-region to become a coherent whole. The micro-regional GI presents a tool with the potential to strengthen the ecological stability of the area and to contribute to the master plans of the villages by providing thematic and content improvement of *TSES* concepts.

The greenways system supports development of rural tourism within the micro-region, primarily in the form of agri tourism. The concept emphasises attractions and offers sport and recreation possibilities to visitors. This concept also describes the potential for further development of municipalities. Greenways make the agricultural landscape accessible for users by providing cycle trails, pedestrian recreational routes and routes, which enable an experience of the agricultural landscape, its vegetation, diversity, aesthetic value and wild life. Making the landscape accessible will attract inhabitants to visit valuable places outside the boundaries of the built-up area, in the open land. Inhabitants will become acquainted with the surrounding landscape and will begin to take ownership of it and finally, protect it.

The main purpose of primary and secondary greenway structures at cadastral level is to link settlement and landscape visually and functionally. The greenways concept at cadastral level creates a unified and harmonious image of the settlement and landscape. In our case study, the main linking element between the built-up area and the open land, is the village brook. This brook is the primary driver of a conceptual landscape architectural design, which aims at creating a natural 'green' promenade for the village. The secondary greenways structures connect the settlement with the surrounding landscape and neighbour municipalities. Thereby, the historical heritage of linkages in the landscape will be renewed and the landscape will become accessible. The developed concept significantly contributes to ecology, tourism, settlement and landscape image, local economy and recreation opportunities for inhabitants and visitors.

At the third planning level, we developed a landscape architectural design for the central part of the village, which comprises a complex and unified solution for the whole central space consisting of the linear historic streetscape and the current village center. The design solution uses principles and rules of rural space design and also responds to the historical development of this significant space. The goal is to maintain and enhance the identity as well as the cultural and historical heritage of the site. Landscape architectural and urban design tools are used to unify the historic streetscape and the central space of the village. This study focuses on converting the village center into an attractive contemporary public space for the municipality.

Our results can contribute to the sustainable development of the micro-region *Cergát-Váh* and the rural community *Tvrdošovce*.

The greenways concept can be used as a basis for developing a common sustainable development plan and strategy for the micro-region. At the cadastral level, it represents relevant thematic and content improvement of the master plan and thereby contributes to a sustainable development of the settlement.

The landscape architectural design presented here may be regarded an important methodical basis for the self-government of the municipality in order to develop a new compositional arrangement of the village center, which will respond to the cultural and historical legacy, while also responding to current needs of inhabitants.

We further propose to generate detailed greenways concepts for the other municipalities of the micro-region as well. These should be based on thorough analysis of settlement and landscape structures. After a detailed analysis of historic structures, we propose to develop urban design projects for the public spaces of these communities.

A good contribution to the cadastral area of the village *Tvrdošovce,* could be the development of partial landscape design projects for landscape areas that have recreational potential. The village GI could be improved through further design projects for other public green spaces.

The public space interventions proposed at the third planning level are being gradually implemented, mostly by self-initiative and voluntary work of the community and is also supported by the local government through participative planning and social inclusion. The concept has also functioned as a strong negotiation tool acting against development pressures of a major supermarket chain, which had plans to take charge of one of the open spaces in the village center. The local government will utilise the design developed at the third planning level, to apply for the *Green Village* grant announced by the national *Village Renewal Programme* (2014). At higher planning levels, some further negotiations are needed to advocate the implementation of the GI strategy and its integration into local and regional planning policy.

The planning approach presented in this case study points to possible ways of planning and designing rural areas in Slovakia and other European countries. The 3-level planning concept may be regarded an integrated way of designing rural communities and landscapes by focusing on linkages and interactions between settlements and landscapes at different scales. Linking rural communities within greater territorial or administrative units, like micro-regions, encourages better cooperation and networking, which is crucial for their economic, environmental and social viability and competitiveness in the regional context. Therefore, we propose that the presented approach should be further verified through more case studies in different contexts in order to confirm its relevance for GI planning in the context of rural space restoration and design.

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Biographical information

Attila Tóth
Master of Landscape Architecture
PhD Student, Dipl.-Ing. Landschaftsarchitekt
Department of Garden and Landscape Architecture
Slovak University of Agriculture in Nitra
Address: Faculty of Horticulture and Landscape Engineering, Department of Garden and Landscape Architecture, Tulipánová 7, 949 76 Nitra, Slovakia
Telephone: +421 908 135 972
E-mail address:
at.attilatoth@gmail.com

Attila Tóth is a graduated landscape architect and PhD student at the Department of Garden and Landscape Architecture at the Slovak University of Agriculture in Nitra. His research topic and doctoral thesis focuses on green infrastructure of urban and rural settlements. He is dealing with contemporary landscape architecture, planning and design of open spaces, greenways and green infrastructure in urban and rural contexts. Within his master thesis, he developed a complex landscape architectural design for the rural settlement Tvrdošovce introduced in the article.

Biographical information

L'ubica Feriancová
professor of landscape architecture and Head of the Department of Garden and Landscape Architecture at the Slovak University of Agriculture in Nitra
Address: Faculty of Horticulture and Landscape Engineering, Department of Garden and Landscape Architecture, Tulipánová 7, 949 76 Nitra, Slovakia
Telephone: +421 37 641 5426
E-mail address:
lubica.feriancova@uniag.sk

L'ubica Feriancová is professor of landscape architecture and Head of the Department of Garden and Landscape Architecture at the Slovak University of Agriculture in Nitra. She is currently doing research into the restoration of rural open spaces and greenery. Her area of professional interest includes current trends in urban and rural open space and vegetation structure design. As senior landscape architect, she leads the Open Space Design Studio.

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THE POTENTIAL OF TOPKAPI PALACE TO CONTRIBUTE TO URBAN GREEN INFRASTRUCTURE PLANNING

PINAR KOYLU

Abstract

Green infrastructure encompasses a variety of green spaces at all spatial scales. Historical gardens, when considered as a type of green space, are significant for today's cities and societies, not only for their cultural, historical and aesthetic value, but also for their natural features. Therefore, historical gardens can be thought of as part of a wider natural and/or constructed system. This paper focuses on Topkapi Palace, which dated from the Ottoman period, and originally consisted of an inner core and outer gardens. Whilst the inner core had four main sequentially-located courtyards and a harem section, the outer gardens covered a vast area of land in which various crops were grown, and where both wild and domestic animals were raised. Moreover, significant change has occurred in the outer gardens due to the ongoing processes of urbanisation and westernisation, resulting in the loss of various plant and animal species. Despite this, the remaining gardens and courtyards, with their existing endowment of monumental trees and plant species, could still support the formation of a structured network of urban green spaces in today's metropolitan city of Istanbul. Thus, this paper focuses on the potential of historical gardens, in this case those of Topkapi Palace, to contribute to urban green infrastructure planning.

Key words:
Green infrastructure, green space, historical gardens, Topkapi Palace

Introduction

Green infrastructure, which is a relatively new concept, has various definitions. Depending on the context, it means different things to different people (Benedict and McMahon, 2002; Sylwester, 2009). Benedict and McMahon (2002, p. 5) define green infrastructure as «*an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations.*» The definition of green infrastructure offered by the South Yorkshire Community Forest Partnership (2005) highlights that the term green infrastructure indicates «*the network of open space, woodlands, wildlife habitat, parks and other natural areas, which sustain clean air, water, and natural resources and enrich their citizens' quality of life*».

The concept of green infrastructure underlines both the quality and quantity of urban and peri-urban green spaces (Turner, 1996 and Rudlin and Falk, 1999, both cited in Tzoulas, et al., 2007, p. 169). In this sense, a description of the term presented by Natural England (2012) puts an emphasis on the quality of green spaces and defines green infrastructure as «*a strategically planned and delivered network of high quality green spaces and other environmental features.*»

Other definitions consider strategic planning and the management of networks of natural lands, working landscapes and other open spaces (The Conservation Fund, 2012), as well as strategic approaches to land conservation (Benedict and McMahon, 2002).

There are many social, environmental, economic and health benefits associated with green infrastructure. It provides places for recreation and physical activity, increases quality of life and interaction in the community, improves opportunities for environmental education and experiencing nature, preserves habitats for wildlife, enriches biodiversity, protects aquifer recharge, minimises inversion, absorbs air pollution, and raises property values. It decreases the cost of public infrastructure and public services, including the costs of storm water management and water treatment systems, supports local business and tourism, maintains opportunities for local food production, and reduces stress (Benedict and McMahon, 2002; Centre for Green Infrastructure Design, 2011; Natural England, 2012). Furthermore, green infrastructure improves the aesthetic quality of cities and creates a sense of place.

Green infrastructure planning takes place at a broad landscape scale (The Conservation Fund, 2012). However, elements of this network can be found on a wide variety of scales, from an individual parcel of land to local, regional, and state-wide scales. At the parcel level this could mean designing homes and businesses around green space while at the community level it might mean creating greenways to connect existing parks. In a more comprehensive context, at the state-wide level it could, for instance, entail the protection of broad wildlife movement corridors connecting state and national forests (Benedict and McMahon, 2002).

Green infrastructure comprises «*all natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales*» (Tzoulas, et al., 2007, p. 169). Thus, urban green infrastructure encompasses a variety of green spaces such as parks, urban forests, roof and vertical gardening, private gardens, green corridors, public green space and allotments, as well as green elements such as street trees (Cameron, et al., 2012). Green spaces can be regarded as multifunctional. A green space, for instance, may be a recreational area and a historical garden at the same time (Sandström, et al., 2007).

Historical gardens are an important part of our cultural heritage as they provide a setting for period buildings and are evidence of the past and of cultural and social change. They also provide an opportunity to understand the usage of plants and to recognise historical plant cultivation procedures (Looker and Patrick, 1987). Some of them may still encompass a wide variety of plant (and animal) species. In this context, historical gardens (i.e. palace gardens) can be deemed not only cultural assets, but also natural assets as well.

Palaces and their gardens, which were often built centuries or even many centuries ago, are thus of both significant environmental and cultural importance for today's cities and the societies that inhabit them. Among other features, some cities are often closely identified with their famous palaces inherited from the past, for example, Schönbrunn Palace in Vienna, the Palace of Versailles in Paris, and the Alhambra in Granada. Istanbul, together with its other natural and cultural features, is also intimately associated with its historical endowment of palaces.

Istanbul (figure 1), which is the most populated city in Turkey (General Directorate of Population and Citizenship Affairs, 2012), possesses a number of palaces, namely Topkapi, Dolmabahce, Ciragan, Yildiz, and Beylerbeyi, all legacies of the Ottoman Empire (figure 2). All these palaces had gardens which included a variety of plant and animal species. The oldest one among them is Topkapi Palace, located on the peninsula where the Bosporus, Golden Horn and Marmara Sea interconnect (see figure 2). Topkapi Palace was for centuries both the seat of government of the Ottoman Empire and the residence of the sultans.

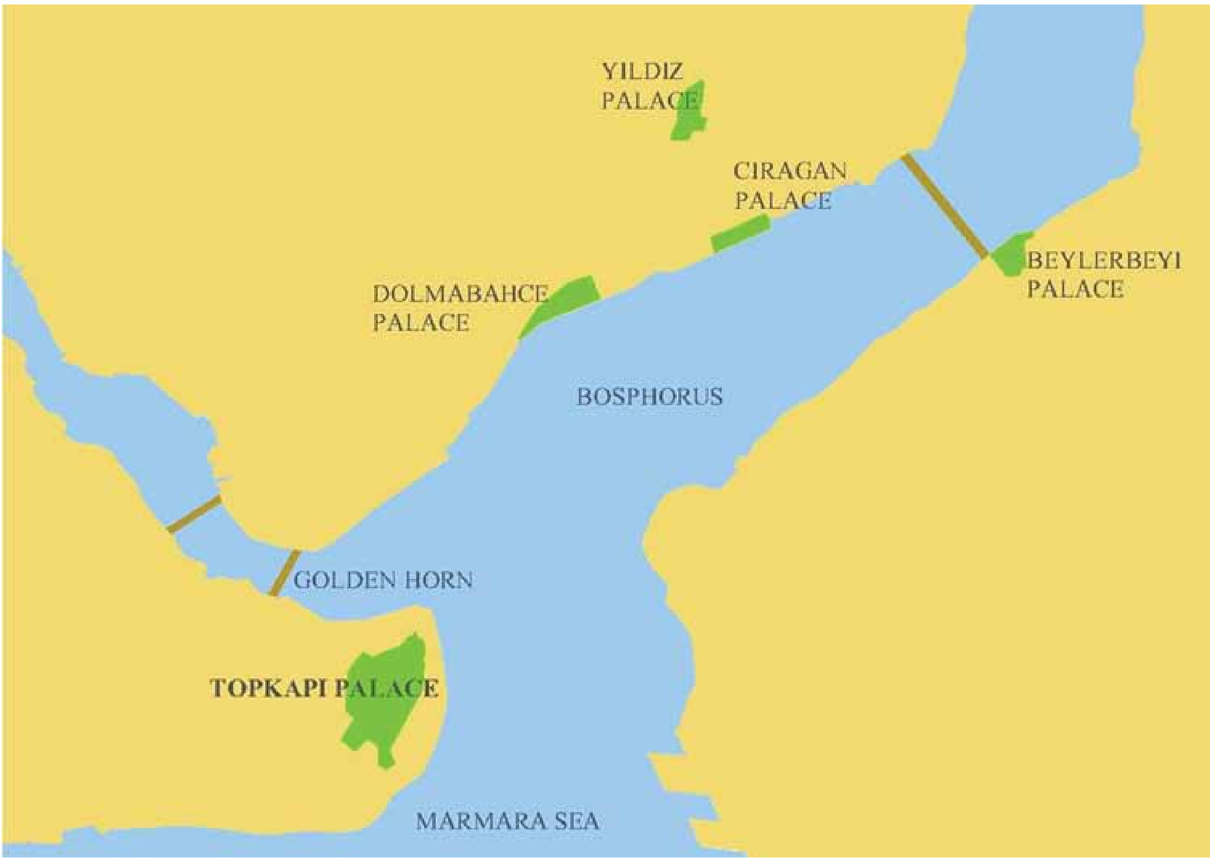

Figure 1 (top)
Location of Istanbul (after Google Earth, 2012).

Figure 2 (bottom)
Palaces in Istanbul.

This paper seeks to examine whether or not historical gardens can make a significant contribution to urban green infrastructure. By using Topkapi Palace as a specific example, this paper supports an affirmative response to this question. This positive conclusion has been developed through a review of the scientific literature and of a number of historical maps, in addition to site visits. Various definitions of green infrastructure have been explored in relation to the review of the literature. Thus, both scientific articles and NGO publications related to green infrastructure have been analysed. Data relating to Topkapi Palace was obtained through publications, plans, maps and site visits. In order to demonstrate the spatial distribution of green spaces in Istanbul, *Google Earth* images have been utilised. On following this line of research, the paper intends to explain how, historically, the gardens of Topkapi Palace contributed to the sustainability of the palace and to the biodiversity of the city, and how even today, they retain the potential to support the formation of an urban green infrastructure.

General Layout and Courtyards of Topkapi Palace

Long before the conquest of Istanbul, the Ottomans first came across Byzantine gardens when they set foot in Rumelia and became close neighbours of the Byzantine world. After the conquest of the city in 1453, they continued working on Byzantine land, gardens, farms and vineyards, not only protecting those green areas, but integrating them with their own cultural knowledge, tastes and experience (Atasoy, 2007).

When Mehmet the Conqueror sought out an area for his new palace, he conferred with his advisors and the leading engineers of the age. A land survey was made in order to determine the availability of water and the cost of building a new palace. Following these consultations, it was decided to construct the new palace of the Ottoman emperor on the ancient acropolis of Byzantium, which had formerly been an olive grove and a residential area. Consequently, Topkapi Palace was built up on top of a hill from where vineyards and gardens sloped down to the seashore (Necipoglu, 1991).

Although the construction of the palace was completed in the second half of the 15^{th} century, it was subsequently expanded over the course of centuries, with various structures being added and others rebuilt and enlarged as a result of fires, earthquakes and the increasing number of people living in the palace. Hence, the irregular and asymmetrical plan of the palace had acquired its present appearance by the end of the 16^{th} century (Necipoglu, 1991; Müller-Wiener, 2001).

As it was not considered appropriate for the sultan to live close to the public, Topkapi Palace was isolated from the city by high, irregular walls, some of which dated back to the Byzantine acropolis. Thus, when viewed from the outside, the palace presented a powerful image and resembled a fortified castle (Necipoglu, 1991; Müller-Wiener, 2001). In order to improve the safety measures within the palace, the area containing the main buildings was also surrounded by high walls (Uzuncarsili, 1984). Hence, Topkapi Palace consisted of an inner core and outer gardens (figure 3).

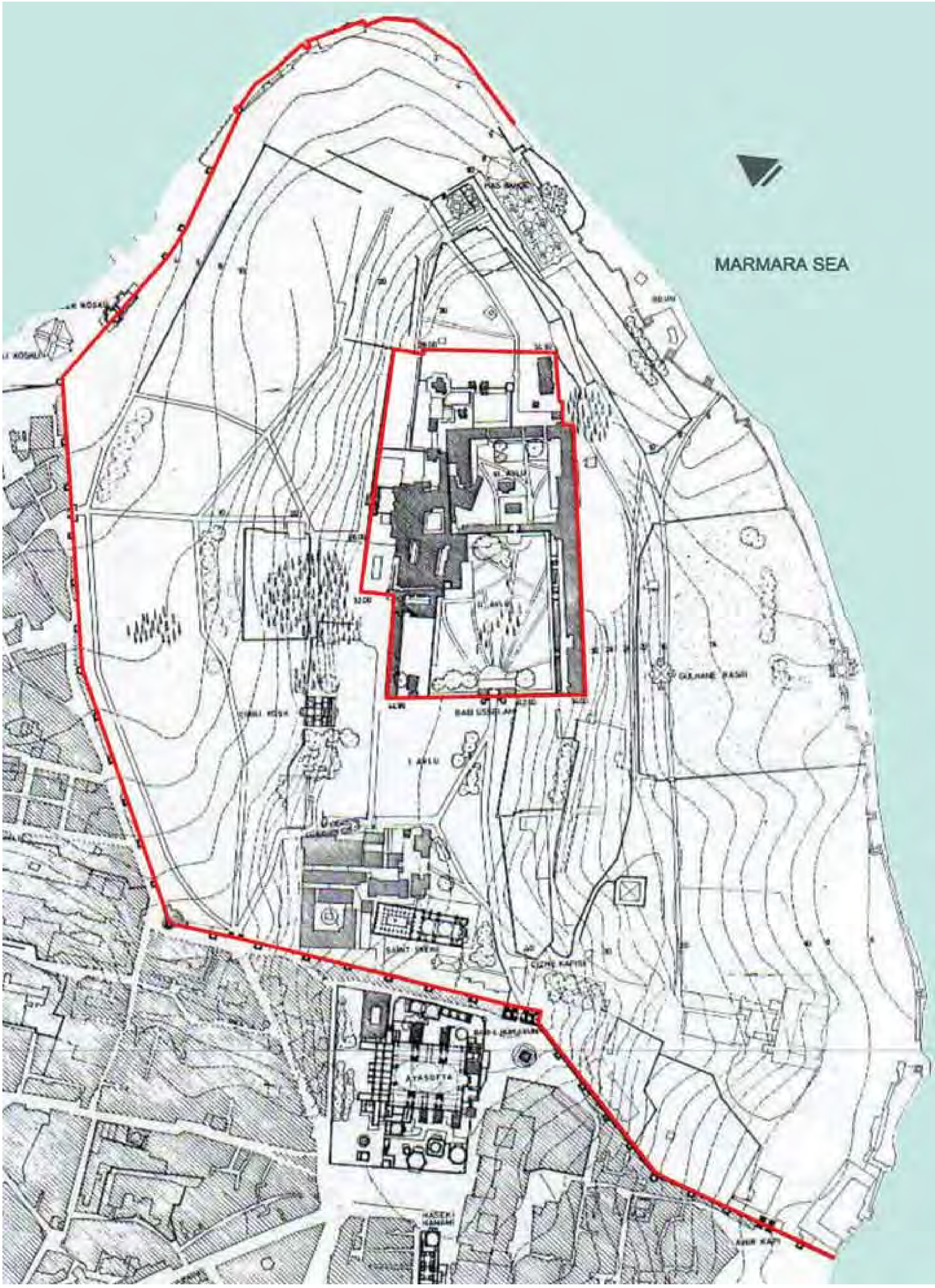

Figure 3
The inner core and outer gardens of Topkapi Palace (after Eldem and Akozan, 1982).

The inner core had four sequentially-located main courtyards and a harem section. These courtyards gradually proceeded from public zones to more private areas. Various buildings enclosed these courtyards, in which trees, fountains and some animals were to be found (Eldem and Akozan, 1982; Uzuncarsili, 1984; Necipoglu, 1991; Müller-Wiener, 2001). In addition to these main courtyards, there were also other mid-sized to small courtyards. The outer gardens, on the other hand, lay beyond this inner part, between the outer and inner walls, and covered a vast area.

The First Courtyard is the largest of all the courtyards of Topkapi Palace. It includes royal buildings, functional structures, and a number of fountains. During the Ottoman Period, various exotic animals were exhibited within this open space, which acted as a gathering place. With its tall trees planted in the centre, this place gave the impression of a village square (Kocu, 1960; Eldem and Akozan, 1982; Ministry of Culture and Tourism, 1983; Uzuncarsili, 1984; Necipoglu, 1991; Goodwin, 1999).

The Second Courtyard is surrounded by the Imperial Council (*Divan-i Humayun*) Building, the Tower of Justice, the kitchens, the Imperial Stables, the Dormitories of the Halberdiers with Tresses, and the Imperial Treasury Building. Foreign ambassadors and officials were permitted to enter this enclosed space which reflected the character of a garden. Various animals and birds such as gazelles (*Gazella dama*), peacocks (*Pavo cristatus*), ostriches (*Struthio camelus*) and nightingales (*Lusciniamagarhynchos*), and a number of trees, especially cypresses (*Cupressussempervirens*), were to be seen in this courtyard (Kocu, 1960; Eldem and Akozan, 1982; Ministry of Culture and Tourism, 1983; Uzuncarsili, 1984; Anhegger-Eyuboglu, 1986; Sozen, 1990; Necipoglu, 1991; Sehsuvaroglu, n.d.).

The Third Courtyard was a semi-private space. The sultan, his family and some of those who worked in the palace lived in the buildings located around this part. Important officials could enter this place only when they were granted the authorisation of the sultan. Similar to the First and Second Courtyards, the Third Courtyard is also enclosed by various buildings. These include the Audience Chamber (also known as the Chamber of Petitions), the Hall of the Privy Chamber (*Has Oda*), which was formerly the dwelling of the sultans and housed the offices of the sultan as well as the sacred trusts, the Conqueror's Pavilion, which housed the Imperial Treasury, dormitories of various officials, and a small mosque. In addition, there is another building, called the Library of Ahmed III, standing in the centre. The size of this courtyard is almost equivalent to that of the second one, and it also had the appearance of a lush garden. In one of the corners, birds were raised for the sultan's table (Kocu, 1960; Eldem and Akozan, 1982; Uzuncarsili, 1984; Sozen, 1990; Necipoglu, 1991).

The Fourth Courtyard acts as a transition zone between the successive courtyards and the outer gardens surrounding the palace. It has views towards the Golden Horn, the Bosporus and the Sea of Marmara, as well as the Asian and European shores. Both the Marble Terrace of Sultan Ibrahim and gardens at different levels make up the Fourth Courtyard. As stated by various writers, this part of the palace was allocated to the sultan to be used for recreation and other activities. The Marble Terrace, with its marble pool, was a place for musical and theatrical entertainments. The terraced gardens, as well as the numerous kiosks dispersed around in the Fourth Courtyard, were used by the sultans for relaxing, thinking, eating, reading, writing, listening to music, watching sports activities, and for surveying their vast surrounding land holdings. Various plant species were found in these gardens. An account book of 1564–1565 tells us that the private hanging garden of Suleiman the Magnificent had an orange grove, potted jasmines (*Jasminum* sp.), and carnation (*Dianthus* sp.) fields. Other account books of later years also pointed to the existence of jasmine and vine pergolas, as well as orange and lemon trees (*Citrus sinensis* and *Citrus limon* respectively) (Kocu, 1960; Eldem and Akozan, 1982; Necipoglu, 1991; Goodwin, 1999; Atasoy, 2002; Albek, 2006).

The Harem of the palace is located on a steep slope. High walls isolate this part of the palace from the Second and Third Courtyards and from the outer gardens. It consisted of the apartments of the queen mother, the favourites of the sultan, the consorts, the concubines and the rest of the family, including sisters, children, and their servants, as well as the harem eunuchs (black eunuchs). These apartments enclose courtyards of various sizes. Among them, the largest belonged to the queen mother while the smallest was for the sultan's consorts and concubines. The paved Courtyard of the Black Eunuchs, a long and narrow space, led to the main entrance of the Harem. Although no traces of plants can be found in the courtyards of the Harem, some of them have good vistas. For example, the Courtyard of the Favourites has a view over the Boxwood Garden. This courtyard was used by the women for playing ball, strolling about or sitting. Formerly, it featured a pool, 18.40 x 32.40 m in size and 1.10 m in depth, which had been the gathering place of the sultan's family. However, this pool was covered with soil and later used as a garden (Anhegger-Eyuboglu, 1986; Necipoglu, 1991; Evren and Girgin Can, 1997).

As well as the courtyards, the Harem also has small gardens enclosed by high walls. Until they reached adulthood, the crown princes, while training in the discipline of the Ottoman harem, were housed in apartments in the Boxwood Garden. Today, only the traces of these apartments can be seen in this garden. The other garden of the Harem, located at the basement level in front of the dormitories of the concubines, is called the Harem Garden. Neither the Boxwood Garden nor the Harem Garden has a panoramic view because of the high walls enclosing them (Eldem and Akozan, 1982; Anhegger-Eyuboglu, 1986).

Outer Gardens of Topkapi Palace

The inner core of Topkapi Palace was surrounded by outer gardens which lay along the triangular cape on which the palace had been built. The outer gardens covered the greatest amount of green space within the palace complex by including cultivated lands, vineyards, pastures, meadows, the Privy Gardens of the Sultans (*Hasbahce*), as well as stables, menageries and sports grounds. This vast area of land was used by the sultans for recreational activities. The sultans hunted and strolled in this area and watched the grandees at horseback javelin tournaments after Friday prayers. Wrestling games and the performances of lion trainers also took place in the two arenas, the Javelin Maidan and the Sand Maidan. The sultans also practiced horseback archery and javelin throwing there (Necipoglu, 1991; Goodwin, 1999).

The daily routine of Murad III was described by the Venetian Gianfrancesco Morosini in 1585:

> *When he remains outdoors, he retires to some part of his gardens to practice archery and to play with his mutes and buffoons. He frequently has noisy instruments played, and enjoys artificial fireworks very much [...] He also frequently has comedies acted [...].* (Necipoglu, 1991, pp. 94–95).

There were a number of summer palaces, pavilions and kiosks in the outer gardens. The sultans visited them to rest after hunting and practicing at archery and the javelin. From the kiosks, they could also watch the departure and arrival of the fleet, races among soldiers, wrestlers, parades of tradesmen, performances of the military band, acrobats and horses, or simply enjoy the view. They could also discuss political, philosophical and religious issues with important officials and religious men in the kiosks (Necipoglu, 1991).

The facilities of the outer gardens supported the sustainability of the facilities of the inner core of the palace. A fish market, boat houses, a windmill for grinding flour, storehouses for flour and wheat, a bakery, a rose-water distillery, baths, a kitchen, a hospital, a small mosque for the gardeners, sewing rooms for tailors and tent-makers, and dormitories for gardeners, millers and oarsmen were all located in the outer gardens. Cold water and ice were stored in numerous Byzantine cisterns and in the cellars which were built by the famous Ottoman architect Sinan (Necipoglu, 1991; Goodwin, 1999). Moreover, various crops were grown, and both wild and domestic animals were raised in this vast area.

Both visuality and functionality were considered in the arrangement of the outer gardens. The most elaborate formal gardens were located towards the Golden Horn. While cypresses (*Cupressus sempervirens*), which symbolised immortality, were the dominant trees of these gardens, roses (*Rosa* sp.) and hyacinths (*Hyacinthus* sp.) were the main flowers used in the Privy Gardens of the Sultan (*Hasbahce*). On the other hand, green areas which lay along the Sea of Marmara, directly below the kitchens, were mostly functional. This part of the palace gardens consisted mainly of vineyards, vegetable gardens and meadows. In addition, some tamed wild animals such as lions and elephants were kept in pens and stables, while birds were raised in aviaries (Necipoglu, 1991).

The outer gardens, filled with pavilions, fountains, and pools, and planted with cypresses (*Cupressus sempervirens*), pines (*Pinus* sp.), tulips (*Tulipa* sp.), narcissus (*Narcissus* sp.), jasmine (*Jasminum* sp.), as well as cultivated and wild roses and herbs, have been compared to the Garden of Eden by various writers, historians, and travellers. One, Kritovoulos, described many species of plants, an abundant supply of clear, cold water, and many sorts of wild and domestic animals. Another, Angiolello, also mentioned the existence of many species of plants such as fruit trees, grapevines (*Vitis vinifera*), roses (*Rosa* sp.), lilacs (*Syringa vulgaris*), saffron (*Crocus sativus*) and other species of flowers, and many kinds of animals including roe deer (*Capreolus capreolus*), foxes, hares, sheep (*Ovis aries*), goats (*Capra hircus)*, Indian cows (*Bos primigenius indicus)*, birds, wild geese (*Anser anser*) and ducks. We can understand from the words of Lorenzo Bernardo that there were also wild boars (*Sus scrofa*), bears, lions (*Pantheraleo)* and horses in these gardens (Necipoglu, 1991). Therefore, we can say that the outer gardens of Topkapi Palace were rich in terms of biodiversity.

The gardeners, who also acted as guards, were in charge of the maintenance of the outer gardens. Flowers, fruits, vegetables, animals and raw materials were ordered from all over the Ottoman Empire, and were gathered, grown or stored in this vast area. Various animal and plant species that provided food for the royal table and for visitors to the palace could be obtained from these gardens, and water could be supplied through the underground cisterns. The excess of vegetables and fruits which were harvested in the gardens of the palace, as well as those brought in from various places throughout the Empire, were sold by the chief gardener in the public square which was located in front of the Imperial Gate. The money gained from the sale of food produced in these gardens was used to pay for the expenses incurred in connection with the palace kitchens (Necipoglu, 1991). Thus, Topkapi Palace functioned like a city within a city, and it could sustain itself for days.

Deterioration of the Outer Gardens

Despite their beauty and functionality, the outer gardens of the palace began to deteriorate in the 19th century, due both to neglect and ongoing 'Westernization'. After the sultan's residence had moved from Topkapi to Dolmabahce Palace in 1856, the historical peninsula lost its significance. The very few guards who were left behind to care for Topkapi could not keep up the maintenance of the gardens. In addition, a destructive fire swept the coastal area of Topkapi in 1863, and a new railway was constructed there in 1871. The gardens were abandoned, factories were built in their place, and the traditional appearance of the city was transformed as a result of the chaotic industrial growth which took place from the mid-19th century onwards (Ministry of Culture and Tourism, 1983; Ergun, 2004).

The deterioration of the outer gardens of Topkapi Palace has been described in various sources. A detailed plan of Istanbul dating from 1875–1882 illustrates the loss of gardens and kiosks, and The Guide of Istanbul which dates back to the beginning of the 1900's draws attention to a park and an outdoor café located in the area between the railway and the seashore (Kayra, 1990).

The Privy Garden of the Sultan known as Gulhane Park (Rosehouse Park) was transformed into a public park (Aslanoglu Evyapan, 1972) in the 20th century. As noted by Müller-Wiener (2001), that part of the gardens was granted to the Municipality by Mehmed V in 1913. Before the most recent renovation, the park contained recreation areas, coffeehouses, playgrounds and a zoo (Yaltirik, Efe and Uzun, 1997). As stated by these authors, more than ninety species of exotic plants have, over a long period of time, been planted in Gulhane Park. These include, to name but a few, European hackberries (*Celtis australis*), London plane trees (*Platanus acerifolia*), box maples (*Acer negundo*), Norway maples (*Acer platanoides*), sycamore maples (*Acer pseudoplatanus*), horse chestnuts (*Aesculus hippocastanum*), pink sirises (*Albizzia julibrissin*), silver birch (*Betula pendula*), downy birch (*Betula pubescens*), Lebanon cedars (*Cedrus libani*), deodars (*Cedrus deodora*), blue Atlas cedars (*Cedrus atlantica* 'Glauca'), Mediterranean cypresses (*Cuppressus sempervirens*), Judas trees (*Cercis siliquastrum*), Norway spruces (*Picea abies*), silver limes (*Tilia argentea*), false acacias (*Robinia pseudoacacia*), and stone pines (*Pinus pinea*). The park was renovated by the Metropolitan Municipality of Istanbul in 2003 and has subsequently begun to function once again as a public park.

After the foundation of the new Turkish Republic, Topkapi Palace with its second, third and fourth courtyards (70,000 square metres in total) was transformed into a museum, under the control of the Directorate of Antiquities and Museums, while the remaining 630,000 square metres were left in the charge of other foundations. However, the deterioration of the gardens continued over the course of time. As a result of the construction of the coast road in the 1950s and the new Asia-Europe water pipeline in 1980, most of the walls and pavilions were demolished and many historical monuments were destroyed (Ministry of Culture and Tourism, 1983). Thus, the formerly productive outer gardens of Topkapi Palace have been fragmented and replaced by grey infrastructure (figure 4).

Figure 4
Present day situation of Topkapi Palace and its gardens (Google Earth, 2012).

Conclusion

Over time, the buildings and gardens of Topkapi Palace have evolved or been altered in the face of natural disasters, population growth and industrialisation. Although the two courtyards housing the sultan's governmental service buildings and the offices where he conducted relations with the outer world, as well as the Third Courtyard which separated the public and inner zones of the palace, have been preserved (Necipoglu, 1991) significant changes have occurred in the outer garden areas.

As demonstrated by various studies (e.g. Duran, Musaoglu and Seker, 2006; Kaya and Curran, 2006; Balik-Sanli, Bektas-Balcik and Goksel, 2008; Geymen and Baz, 2008), not only the gardens of Topkapi Palace, but also other green areas in Istanbul have been demolished by uncontrolled urbanisation. In the European part of the city, approximately 75 % of the metropolitan area, the land covered by forests and semi-natural vegetation decreased from 45 % to 39 % between 1987 and 2001. As noted by Hostetler, Allen and Meurk (2011), adjacent residential and commercial areas threaten the urban green infrastructure. Indeed, Benedict and McMahon (2002) have already directed attention to this problem by stating that fragmented patterns of green spaces are created by the modification of land by human beings; and consequently, that this fragmentation of land into smaller and more isolated patches of open space greatly alters the way in which natural systems function, threatening native plant and wildlife communities and associated ecological functions and processes. In the case of Topkapi Palace, the outer gardens have deteriorated and have been fragmented by the construction of roads and buildings, resulting in the loss of plant and animal species. Yet today, the land occupied by the palace can still be perceived within the dense urban pattern as a large green area supporting various plant species. In their work, Yaltirik, Efe and Uzun (1997) identified fifty-six species of trees and bushes existing in the Second, Third and Fourth Courtyards of the palace. While the Second Courtyard is still dominated by cypresses (*Cupressus-sempervirens*), some other plants are also to be found in this courtyard. These include London plane trees (*Platanus x acerifolia*), scarlet fire-thorns (*Pyracanthacoccinea*) and bigleaf hydrangeas (*Hydrangea macrophylla*); these species can also be seen in the Third Courtyard along with a number of other species, such as roses (*Rosa* sp.), Adam's needles (*Yucca filamentosa*) and southern magnolias (*Magnolia grandiflora*). The Fourth Courtyard also has a variety of plants including tree peonies (*Paeonia suffruticosa*), roses (*Rosa* sp.), deodars (*Cedrus deodora*), Norway spruces (*Picea abies*), and walnut trees (*Juglans regia*), to name but a few.

As Sylwester (2009) notes, green space is often perceived in terms of isolated parks, recreation sites or natural areas, whereas the term green infrastructure calls attention to the *interconnected system* of natural areas and other open spaces that are protected and managed for the ecological benefits they provide to both people and the environment. Thus, the notion of 'green infrastructure' has its origin in two important concepts. The first is the connection of parks and other green spaces for the benefit of people, and the second is the preservation and connection of natural areas to benefit biodiversity and habitat integration (Benedict and McMahon, 2002). In the case of Istanbul, while large green areas cover the northern parts of the city, patches of green areas of various sizes, associated mostly with historical places, generally lie along the Bosporus. Yet, those patches exhibit a linear interaction of blue-green infrastructure, as does Topkapi Palace (figure 5). Therefore, the remaining gardens and courtyards of Topkapi Palace, with existing monumental trees and plant species, should be preserved. These gardens should also be connected to green areas in the other parts of the city, in addition to those along the Bosporus. In this way, cultural and historical areas as well as fragmented habitat units could be integrated, and become part of a wider natural and/or constructed system. In this context then the Topkapi Palace complex would support the formation of an urban green infrastructure for the metropolitan city of Istanbul.

Figure 5
Blue-green infrastructure along the Bosporus.

As historical gardens often contain various plant (and animal) species, their preservation necessarily also contributes to the conservation of biological diversity, which is considered an integral part of the sustainability of cities and landscapes. Topkapi Palace, with its rich historical legacy in terms of the variety of species it has nurtured, thus serves as a good example in respect of the opportunities now available to support the sustainability of today's cities. Productive and recreational green spaces like the former outer gardens of Topkapi Palace could be created in cities. In this way, food could be produced in urbanised areas and the inhabitants, especially children, could witness and experience the growth of the various everyday crops which they consume. These productive green spaces could also meet the recreational needs of modern urban dwellers.

When considered as an element of urban green infrastructure, historical gardens offer not only environmental benefits, but also generate numerous social and cultural advantages. The outer gardens of Topkapi Palace, with their kiosks, sports areas and privy gardens, met the recreational needs of the sultans in the past, whereas the inner core was mainly used for official and ceremonial events. Today, the inner core of Topkapi Palace is a valuable historical and cultural asset, and is visited by great numbers of tourists. On the other hand, Gulhane Park, part of the former outer gardens, has functioned as a public park since 1913, meeting the recreational needs of modern-day users. Thus, the courtyards located in the inner core of Topkapi Palace along with Gulhane Park also contribute to social and cultural sustainability by bringing people together, and carrying the past into the present. As Manenti (2011) puts it, if we regard the concept of sustainability as related to being sustainable over time, then transmission to future generations should be considered. In this context, existing green spaces should be protected and, if necessary, be restored (Sandström, et al., 2007).

When cities are considered as entities in terms of systems, urban green infrastructure can be deemed as a subsystem of the whole urban system, and each green space within a city contributes to the formation of the urban green infrastructure. As stated by Murphy (2005), each element that makes up the system interacts with every other element, influencing the whole. In this sense, the conservation and maintenance of historical gardens, when considered as essential elements of urban green infrastructure, contribute to their own well being, the urban green infrastructure, and the urban system as a whole.

Maintaining the sustainability of cities and landscapes more generally requires holistic thinking. Therefore, historical gardens should be afforded importance not only for their environmental, cultural, historical, and aesthetic value, but also for their potential to contribute to green infrastructure planning.

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Biographical information

Dr. Pinar Koylu
Asst. Prof., Duzce University
Faculty of Forestry, Department
of Landscape Architecture
Address: 81620 Duzce, Turkey
Tel: +90 380 542 1137 (ext.3106)
Fax: +90 380 542 1136
E-mail: koylupinar@yahoo.com

Dr. Pinar Koylu is an assistant professor at Duzce University, Faculty of Forestry, Department of Landscape Architecture. She studied Landscape Architecture at Ankara University. She holds a European Masters degree in Environmental Management. She also received a Master of Fine Arts degree in Interior Architecture and Environmental Design from Bilkent University. She produced her PhD dissertation while working as a research assistant at Ankara University. Her research interests include historical gardens, landscape design and people-place relations. She is currently leading a research project focusing on the attachment of university students to particular places.

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THROUGH THE HISTORICAL LANDSCAPE TO AN URBAN GREEN INFRASTRUCTURE: THEMES AND CONTEXT

MELTEM ERDEM KAYA AND MELIZ AKYOL

Abstract

Landscapes around the world have changed dramatically during the last five decades. While new functions, new forms of land usage and increased infrastructure dominate and trigger this change, places with a rich history have become more fragile than ever before. Within contemporary urban life, historic landscapes and associated land usage gain priority by their power to define and contribute to the sustainability of green infrastructure.

This research analyzes the green heritage of Istanbul to gain a better understanding of its potential to contribute to the development of the European side of Istanbul. Accordingly, three relevant typologies: historical parks and gardens, groves and cemeteries are analyzed to reveal the different themes and contexts they represent.

The research results show that historical landscapes can be managed through a systematic approach that underlies the integration of those landscapes into the surrounding environment by evaluating those places as a part of the green infrastructure of the city. These findings suggest that conservation strategies are an effective tool to control the change within those landscapes and should be re-considered, from the perspective of contemporary design approaches, to create a robust framework for the development of an integrated green infrastructure.

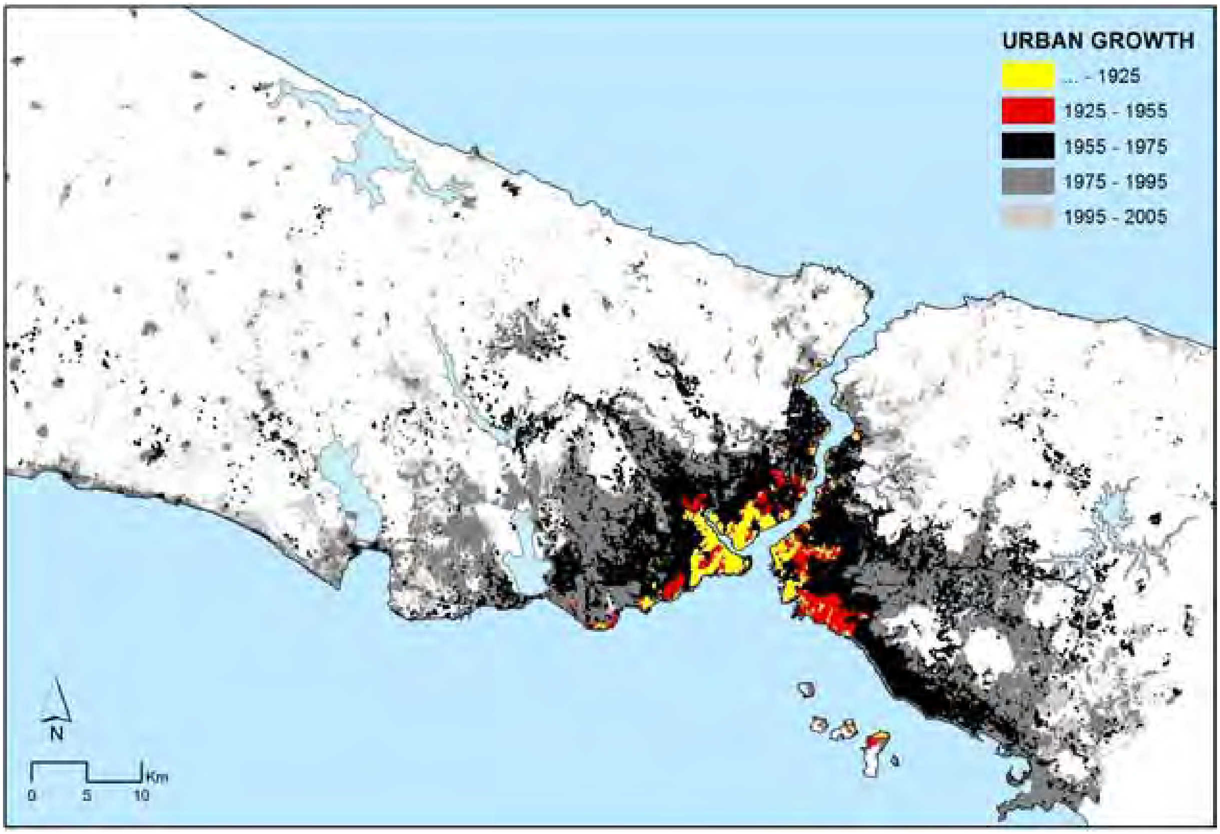
Key words:
Green infrastructure, Historic Landscape, Istanbul, Landscape

Introduction

Landscapes around the world have changed dramatically during the last 5 decades. While new functions, new forms of land usage and increased infrastructure dominate and trigger this change, places with a rich history have become more fragile than ever before. Urbanization processes and global population growth have led to an urgent call for sustainable planning and design practices to find viable ways to mitigate the negative impacts of development pressures.

Istanbul currently has a population of 14 million people and has been experiencing a dramatic urbanization process since the 1950's. Massive migration movements and the construction of the two bridges over the Bosphorus in 1973 and 1988 led urban growth expand through the east-west axis as well as through the north where the natural reserves are located. The pace and scale of spatial growth has become one of the major threats to the natural areas along the periphery of the city as well as to the green and open spaces within the city center (Kubat, et al., 2007). Figure 1 illustrates the spatial growth of the city according to different time periods. Another negative impact of the uncontrolled urbanization process can be found in the historic landscape of the city, which reflects different cultural interactions within the periods dating back to the Byzantine Period.

Figure 1
Urban Growth of Istanbul according to different time periods (Kaya, 2013).



The unique and historic landscape of the city can be considered multi-layered and can be read in multiple ways. The historical background and ecology of a landscape appear to be the best ways to understand its diverse and dynamic structure. From an ecological viewpoint, historical landscapes and their components make a considerable contribution to the ecological structure of Istanbul. Once the historic capital, it is now an urban region and the problem of urban spread toward green areas at the periphery and urban intensification in the center has led to the loss of a considerable amount of green areas and ecological sustainability. As a result, the green areas in the center have become small patches in the form of urban parks. Within this dense built environment, large green areas are represented in the form of parks, groves, large gardens and cemeteries that have a historical background dating back to the 19th century. These urban green areas are a major component of the city's green network. Istanbul's rich historical heritage demands much more attention to be paid to these green areas for their potential in maintaining the ecological sustainability of the city.

Methodology

This paper aims to analyze the potential of the historical landscape of the European side of Istanbul, which can be referred to as green heritage; contributing to the city's green infrastructure by the provision of three relevant historical landscape typologies: (a) groves, (b) parks, and (c) gardens and cemeteries. The methodology of this research is based on a descriptive inventory, which evaluates landscapes by analyzing and describing their components (Arthur, et al., 1977). The inventory is based on three steps:

1. Literature review: includes the study of existing research and literature on the historical landscape of Istanbul and the definition of different typologies
2. Site inventories: includes field observations at the 15 selected sites and examination of high altitude images, topographical maps and photographs as a source for visual information to understand the site characteristics (natural and man-made)
3. Interpretation: includes interpretation of the data collected from the sites in order to develop proposals to evaluate green heritage as a part of the green infrastructure (figure 2)

15 different sites from the European side of Istanbul are selected according to their ability to reflect different spatial characteristics, different design approaches and their potential to reflect the historical landscape character of Istanbul.

Figure 2
Methodology of the study.

Historical background and site characteristics such as natural characteristics (topography, vegetation cover, water features) and man-made characteristics (structures, spatial organization, circulation, land use, boundaries & edges) are evaluated as the main data set for the research. In this respect, each site is evaluated as a distinct landscape unit (figure 2).

According to preliminary site studies of the different typologies, a comparison chart is developed according to the size of the site, location, year of construction, management type, landscape components and vegetation type. The research, therefore, questions and investigates 3 central themes: (a) how and to which degree the historical landscape can contribute to the green infrastructure of the European side of Istanbul, (b) what the different contexts represented in those historical lands are, and finally (c) how history can be linked to the ecological structure as a green infrastructure.

Historical landscape and green infrastructure

The historical landscape of Istanbul can be considered in 3 distinct periods:

Byzantine Period (300–1453 AD): In this period Istanbul was a small citadel, which was surrounded by city walls. In common with all walled cities, there were also several villages and neighborhoods extending beyond the city walls. However, those were not able to integrate into the urban pattern. In this era, the northern part of the city was dominated by the Belgrade Forest, which is characterized by the dominance of the Quercus species (*Q. robur, Q. frainetto, Q. pertrea*) and also includes other species, such as *Fagus sativa, Carpinus betulus, Catanea sativa, Populus tremula, Corylus avellane, Acer campestre, Acer trautvetteri, Ulmus minor, Tilia argentea* (Yaltırık, Efe and Uzum, 1997). Only few settlements were seen along the Bosphorus. Thus, the general character reflected the dominance of natural and green areas. *Cupressus sempervirens* (Cyprus tree) could be seen in only few temple gardens in two fishing villages.

In the Byzantine period medical gardens had importance due to their function in producing medicine. Small house gardens were integral parts of the urban greenery. Those gardens, as the private spaces of families, were important for the production of vegetables and fruit. The size of the gardens of noble people was larger than the small house gardens. Besides vegetables and fruit, some horticultural species and flowers could be found in many gardens. Monasteries and churches had large gardens with a considerable amount of land (Yaltırık, Efe and Uzum, 1997).

Ottoman Period (1453–1922): When conquered in 1453, the city of Istanbul was almost demolished, which led to a new construction movement (Yıldızcı, 1978). In this era, while the westward growth of the city was restricted by the city walls, the Golden Horn, and the Bosphorus shoreline at Galata, Üsküdar and adjacent areas, began to extend as new neighborhoods beyond the city walls. In Eyüp, inside the city walls, and at Üsküdar on the Anatolian side, new Turkish neighborhoods emerged. Although the city kept the physical structure, which had developed during the Byzantine period, its appearance quickly changed to that of a typical Islamic city during the rule of Fatih Sultan Mehmet, the seventh sultan of the Ottoman Empire. Trees started to be used as an integral part of greenery within the city. The physical structure, defined by trees raised between houses in the cities and villages of the Ottomans, was not typical for ancient settlements and was not seen in Istanbul before the Ottoman period. In addition to private residential gardens, the greenery penetrated the urban pattern in the form of gardens connected to public buildings, such as mosques, masjids and cemeteries (figure 3 and 4). The most remarkable features of this period are the Topkapi and Üsküdar palaces and their gardens. Those gardens are characterized by a symmetrical axial system similar to Baroque and Renaissance gardens (Yaltırık, Efe and Uzum, 1997).

Figure 3 (left)
An engraving by Melling picturing Constantinapolis (Yıldırım, 2008).

Figure 4 (right)
Bosphorus, An engraving by Melling (Yıldırım, 2008).

After the establishment of Tokat garden as the first garden of Bosphorus, which was established in 1458, the number of gardens and open recreational areas along the Bosphorus increased (figure 4).

During the earthquake of 1509, a considerable amount of residential buildings were demolished, which led to the construction of new buildings (mostly one- or two-storey residential buildings). Most of these residential buildings had big gardens, which together with the natural water courses running through the city, contributed to the increase in the amount of green areas.

At the end of the 16th century there were 39 «hasbahçe» (private gardens of the sultans) inside and outside of the city. In this period, the only green areas within the Turkish neighborhoods were the gardens of the residential buildings. In addition to the groves, hasbahçes, trees planted around mosques, vegetable gardens, palace gardens and cemeteries, public squares and open recreational fields served as important green areas within the city (figure 1, 2 and 3) (Yaltırık, Efe and Uzum, 1997).

The Lale period, (1718–1730), led to another mood of life in which entertainment and joy became an integral part of daily life. This period exemplifies the first gardens designed under the influence of a more Western style, created for recreation (Yaltırık, Efe and Uzum, 1997). Sadabad in Kagıthane, Şerefabad in Üsküdar, Begıferah in Çengelköy, Emnabad in Fındıklı, Hüsrevabad in Kağıthane, Huyaunabad in between Ortaköy and Kuruçeşme, and Vezir garden in Topkapı Palace were the most important hasbahçes of this time.

In the 18th century the most important factor defining the macro-form of the city was the integration of the Golden Horn and the Bosphporus within the organic urban pattern. Although the city did not expand its boundaries considerably, as a result of this integration the citadel had lost its importance (Nazım Plan, 1995).

Figure 5
Tokat Garden (Eldem, 1973).

The 19th century brought with it new development plans. The first plan was proposed by Helmuth von Moltke, a German staff officer seconded to the Ottoman army. This plan offered a new construction plan for residential buildings, squares and streets. According to the plan, residential buildings should be built in the style of masonry building. Large squares would be designed with specific geometrical forms and dimensions. Streets were classified into four distinct dimensions; 10 – 12 – 15 – 20 m. (Nazım Plan, 1995).

Before the Republic, the most important changes in green area usage came with the Tanzimat of the 19th century. As part of a westernization process, recreational activities gained importance, and thus the public became more interested in outdoor activities. The surrounding area of the city was covered with vineyards, gardens, mulberries, plane trees and juglans trees; and within the city, vegetable gardens, meadows, riverside open spaces, hills, mulberry groves, shorelines, and open spaces near water resources became important recreational areas (Yaltırık, Efe and Uzum, 1997). Until mid-19th century, the public had used recreational open spaces, thus, there were only few parks established during the Ottoman Era (figure 5).

The first Istanbul public park was established in Sultanahmet in 1854. This park was named «Yeni Millet». Another park, established in the Ottoman Era, was Gülhane Park. Due to the expansion of the city boundaries in the second half of the 19th century, the amount of open spaces decreases. A change in lifestyle and the westernization effort of the government led to the emergence of Municipality Parks, which were designed and managed by the city municipal authority. The first of those parks was opened to the public in Büyük Çamlıca. At the end of the 19th century, Tepebaşı Municipality Garden, Taksim Municipality Garden, and Bakırköy Municipality Garden were also opened to the public (Yaltırık, Efe and Uzum, 1997).

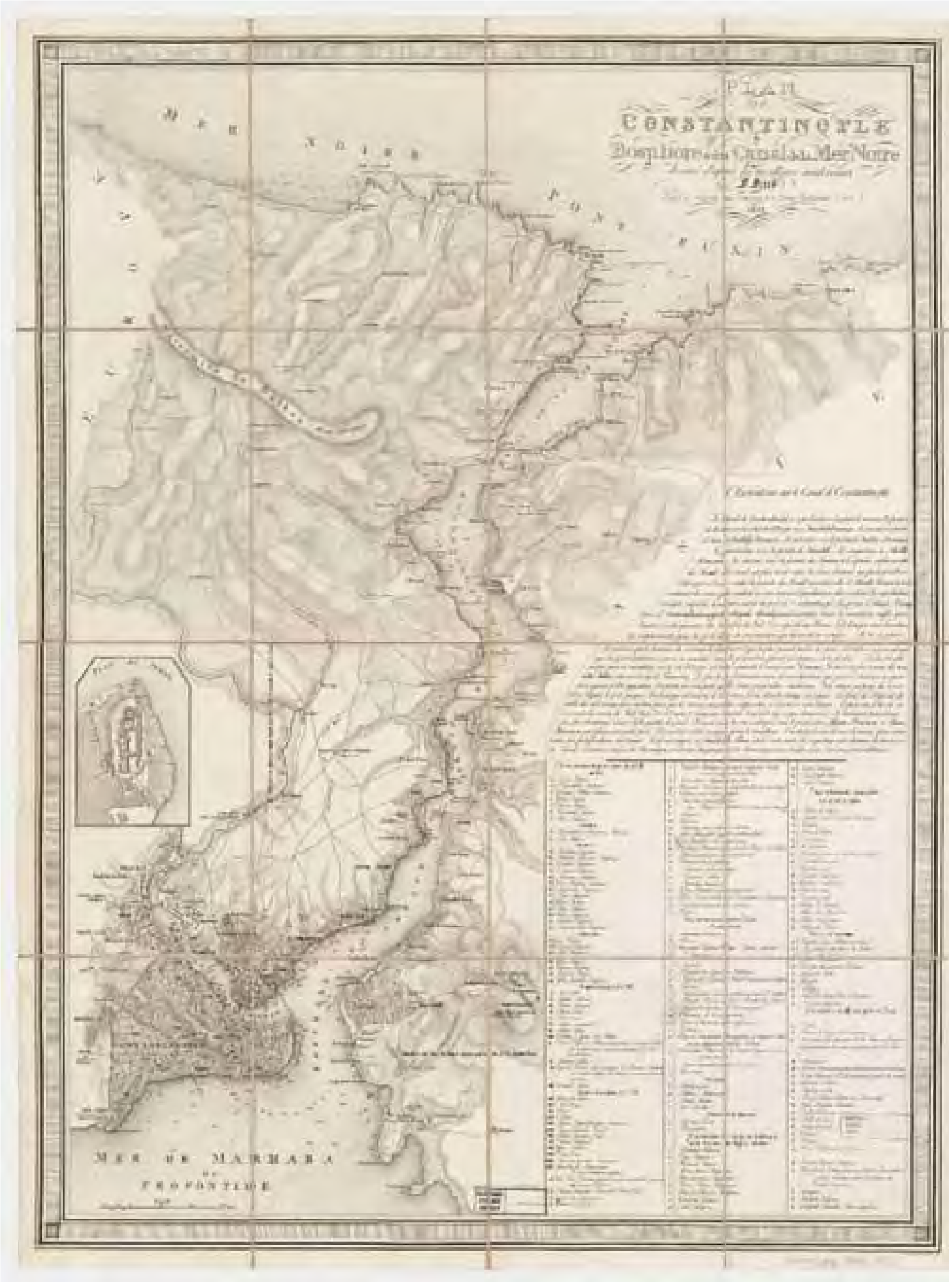


Figure 6
Map of Bosphorus, 1821 (Fried, 1821).
Harvard Hollis Archive:
http://ids.lib.harvard.edu/ids/view/7931999?width=912&height=1200&html=y

Republic Era (1923–): The first park and green area planning of Istanbul began in 1932. Famous urban planners from Europe, such as Herman Elgotz from Germany, Alfred Agache and Jacques Henri Lambert from France, were invited to prepare a report for the city of Istanbul. Their report was important for the proposals for green areas (Çelik, 2005). Among those reports and works, Henri Prost's was remarkable. His plan offered sport fields, new thematic gardens such as botanical gardens and zoos, a new green barrier in front of the old city walls, beaches and archaeological parks while emphasizing the preservation of the green areas on the Anatolian side of the city. Thus, the first example of western style green area planning started with the Prost plan. The plan also included a large green corridor, beginning at Dolmabahçe Palace, passing through Harbiye Mektebi and finishing in Taksim Square (Nazım Plan, 1995).

Prost also proposed small allotment gardens, which could be attached to residential buildings and contribute to the income of families. This plan was revised by a team led by Prof. Kemal Ahmet Aru, and took into consideration the economic and historical structure of the city (figure 6, 7 and 8).

Between the 1950's and 60's Istanbul experienced massive migration from rural areas. This rapid rise in population and urban development formed a metropolis with a historical background (Bahtiyar, 1997). The first wave of migration settled along the Golden Horn and in the industrial areas around city walls. This was followed by other migration movements; the number of squatters and illegal construction greatly increased. In the 1950's, the boundaries of the city expanded through Yeşilköy in the west, Levent in the north, and Bostancı in the east. In 1957 the Directorate of Istanbul Zoning Plan Department was founded and started working in 1958. In 1958–60 the «Transition Period Development Plan» was prepared.

The plan emphasized the preservation of the existing large green areas and the implementation of four new parks (Büyük-Küçük Çamlıca, Kağıthane Park and Eyüp Manzumesi) and raised the need to organize the green areas near the city walls (Yıldızcı, 1978). The gaps in the existing planning process inspired the establishment of the Marmara Planning Organization in 1960. In the East Marmara Preliminary Report of 1962, future land requirements were evaluated in three groups: residential, industrial and green areas outside of the city. The green area requirements per person was defined as 20 m^2 and it was estimated that 10,000 ha of green area was needed for Istanbul.

In the Istanbul Development Planning Office Report of 1971, the entire Bosporus was evaluated as an important part of urban history and defined as a recreation and natural preservation area. It was also stated that Istanbul's historic structure which can be evaluated as a unique representation of the interaction of man and environment; a whole that must be protected with its topographic, natural and visual values. As part of this complex whole, historic groves, historic recreational areas, historic hills (and vistas), other natural elements that define the landscape (silhouette or skyline), cemeteries, castles, fortresses, summer palaces, religious and civic historic structures need to be protected (Yıldızcı, 1978).

Figure 7
Istanbul European Side Master Plan at scale 1/5000, Old Istanbul, by Henri Prost, 1937 (Académie d'Architecture,1960, in Bilsel, 2011).

Figure 8
Istanbul European Side Master Plan – Principal roads indicated on a photograph at scale 1/2000, circa 1943, (Académie d'Architecture,1960, in Bilsel, 2011).

In the Republic Era, squares, play grounds, school gardens and public parks started to be planned. However, illegal housing developments continued unabated during the 1960's, and another important factor that affected the spatial character of the city was the construction of high rise apartment buildings. Vacant areas and green areas, parks and play grounds were opened for construction and were used for apartment blocks (Nazım Plan, 1995).

In the 1970's, the concept of the summer house / second home developed. Prior to this date, summer places were restricted to the Yeşilköy neighbourhood in the west, Sarıyer and Büyükdere in the north, and Suadiye, Bostancı and the Princes' Islands in the east. Now places extended through Kumburgaz and Silivri in the west, Dragos and Bayramoğlu and Yalova and Çınarçık in the east and today the area is filled with summer housing complexes, motels and summer facilities that change the landscape character of the city's periphery (Nazım Plan, 1995).

Figure 9
Study of a road network for the Old Istanbul Master Plan by Henri Prost. (Académie d'Architecture,1960, in Bilsel, 2011).

Green Infrastructure

According to the Natural England definition, a green infrastructure is

> … *a strategically planned and delivered network comprising the broadest range of high quality green spaces and other environmental features. It should be designed and managed as a multifunctional resource capable of delivering those ecological services and quality of life benefits required by the communities it serves and needed to underpin sustainability. Its design and management should also respect and enhance the character and distinctiveness of an area with regard to habitats and landscape types.* (Natural England, 2009).

The typology of green infrastructure is summarized in table 1.

Another definition of green infrastructure underlies the social aspect of the concept. Mell (2010) defines green infrastructure as «*the resilient landscapes that support ecological, economy, and human interests by maintaining the integrity of, and promoting landscape connectivity, whilst enhancing the quality of life, place and the environment across different landscape boundaries.*» (Mell, 2010, p. 255; Mell, 2013).

On the other hand, United States Environmental Protection Agency (EPA), recognize «green infrastructure» as a process, which supports sustainable communities. They define «green infrastructure» as a general process which includes the protection and improvement of habitats, energy, water, air, community, and much more. This strategy represents a valuable relation between land use planning and land conservation that works to protect natural ecosystems and services they provide.

Green infrastructure planning differs from open space planning by several key characteristics. First, green infrastructure planning considers the landscape context by not only focusing on site scale, but also by considering the strategic links of the sub-regional scale and beyond; second, green infrastructure planning considers private and public assets; and third, green infrastructure planning provides a multifunctional, connected network delivering ecosystem services (Natural England, 2009).

Istanbul's green infrastructure comprises natural landscape and man-made landscape features. Those features can be evaluated under two broad categories: natural vegetation pattern in the form of natural forests (Belgrade and Alemdağ forests), and scrubs *(Arbutus unedo, Laurus nobilis, Phillyrea latifolia*), and cultural vegetation patterns in the form of groves, parks and gardens (Yaltırık, Efe and Uzun, 1994). Historic landscapes in the context of a man-made landscape have the potential to contribute to the green infrastructure and the associated network within the city, through their different typologies and contexts. The Bosphorus, as the main artery of urban-blue infrastructure with the formation of natural bays, has always been an important attractor for settlement as well as an important infrastructure element for the distribution of green areas along the shoreline and hills.

The inherited characteristics of the historical patterns, boundaries, species combinations and spatial elements all define those special sites embedded in urban landscapes. However, since the middle of the 20th century, this unique landscape has been threatened by uncontrolled urban growth (Çelik, 2005). Decisions for intensification of the city center, as well as the spatial expansion of the city toward the periphery led to the loss of considerable amounts of green spaces and their connectivity. While the «natural character» of this landscape has been threatened by development pressures, the «man-made character» of the landscape in the form of parks, gardens, groves and cemeteries has experienced degradation and change.

Table 1
The typology of green infrastructure.

Parks & Gardens	Urban parks, country and regional parks, formal gardens
Amenity Green space	Informal recreational spaces, housing green spaces, domestic gardens, village greens, urban commons, other incidental space, green roofs
Natural and semi-natural urban green spaces	Woodland and scrub, grassland (e.g. downland and meadow), heath or moor, wetlands, open and running water, wastelands and disturbed ground), bare rock habitats (e.g. cliffs and quarries)
Green corridors	Rivers and canals including their banks, road and rail corridors, cycling routes, pedestrian paths, and rights of way
Other	Allotments, community gardens, city farms, cemeteries and churchyards

Typologies: Groves, parks and gardens, cemeteries

In this study we examine the historic landscape of the European side of Istanbul according to three distinct typologies: groves, parks and gardens and cemeteries. This study examines these different typologies according to the size of the site, location, year of construction, management type, landscape components and vegetation type. Following this we discuss ways to integrate these historic green areas into the urban pattern as part of a wider green infrastructure (figure 10). In total, 15 historic green areas were analyzed in the study;

- Parks and Gardens: Gülhane Park, Maçka Demokrasi Park, Kuruceşme Park, Topkapı Palace Garden, Dolmabahçe Palace Garden, Yıldız Palace Garden, Sultanahmed Mosque Garden, Sultaniye Mosque Garden.
- Cemeteries: Eyüp Cemetery, Okmeydanı Cemetery.
- Groves: Naile Sultan Grove, Grove of the Australian Consulate, Emirgan Grove, Yıldız Grove, Ayşe Sultan Grove.

Figure 10
A map showing green heritage along the European Side of Istanbul. 15 case studies was chosen in the categories palace-gardens, groves, parks and cemeteries.

These historic sites are selected according to their ability to represent the historic character of the landscape and their strategic location to contribute to the green network.

Analysis

In this research different historic landscape typologies are analyzed according to natural landscape features (topography, vegetation, water surfaces) and man-made landscape features (structures, circulation, pools, boundaries and edges conditions).

According to the data analysis, historic parks and gardens, cemeteries and groves have different spatial features that contribute to the ecological quality of a green area. Those differences can be seen in both the natural features and man-made features. Parks, groves and cemeteries are mostly located in hilly areas, cover large tracts of land and often contribute to the silhouette effect when viewed from the Bosphorus. Gardens are located on flat land and are associated with buildings or structures and public parks. They usually include water features, which contribute to the ecological quality of the site by providing habitat for fauna and serve as a natural water reservoir, where any runoff is collected from the surrounding area. In formally designed gardens, however, water features are used in the form of channelled pools, which limit their capacity to collect external runoff water.

Whereas groves, cemeteries and parks have a landscape character defined by the spontaneous accumulation of mature vegetation patterns, historic gardens include the horticultural usage of plants in their formally designed parterres. With their mature vegetation patterns, which evolved through the historical development process, groves, parks and cemeteries make a considerable contribution to the ecological quality of the city. Those historic landscapes include both natural and exotic species. Groves mostly include exotic trees planted 150–200 years ago, which have adapted to the native environment and have become naturalized. Those groups include: *Pinus sp., Pinus brutia, Cupressus sp., Rhamnus alaternus, Taxus baccata, Robinia pseudoacacia, Fraxinus ornus, and Magnolia sp., Acer campestre, Acer negundo, Acer pseudoplatanus, Aesculus hippocastanum, Cedrus atlantica, Cedrus deodora, Cedrus libani, Cercis siliquastrum, Cupressus sempervirens, Eriobotrya japonica, Fraxinus angustifolia, Laurus nobilis, Pinus halepensis, Pinus nigra, Pinus pinaster, Pinus pinea, Platanus x acerifolia, Salix babylonica, Syringa vulgaris, Tilia argentea, Viburnum tinus.* Cemeteries have a vegetation pattern and are dominated by *Cupressus sempervirens*.

Most of the gardens are surrounded by walls and are therefore separated from the surrounding environment and have a direct relationship with the building they are attached to. Some of them evolved as a courtyard of a palace or were designed as an inner or outer garden of the palace. Some of the groves, located on private properties, are surrounded by walls for security reasons. The spatial organization of the historic gardens reflect a formal design language based on a symmetrical, axial system and represent a framed landscape mostly defined by parterres. Those gardens typically include water features in the form of a small pool or fountain as a focal object.

Groves have a system of pathways connected to an associated building. In groves surrounded by walls, those pathways form a loop system that is closed to the surrounding environment. Groves usually occupy land in conjunction with a building. Today some of the groves located on private property have lost their vegetation density and have been turned into the back gardens of residential housing complexes. Historic parks host different activities: playgrounds, thematic gardens, waterside sitting areas, resting areas, cafes, picnic areas etc. Therefore, the spatial organization of a park developed to respond to those different activity patterns. The circulation pattern includes pathways and vehicle entrance is restricted.

Actual usage of those historic landscapes changes over time and the historic parks in Istanbul now serve as a platform for public meetings, festivals and celebrations. Therefore, public parks are subject to cultural manipulation to attract visitors. Maintenance work such as trimming, new plantations, replacement of existing trees, irrigation, drainage, installation of lawn etc. appears to be one of the major threats to historic public parks. Exotic trees, such as palm species, are introduced to the sites and change their character and context. Due to private ownership, the sustainability and maintenance of those groves relies on private efforts.

The need for conservation approaches has become more apparent in the context of a contemporary metropolis that has a remarkable historic landscape. Therefore, historic character needs to be appreciated through proper management systems that pay attention to ecological integrity, sustainability and a site's unique history.

Results from the inventory

Tables 2, 3 and 4 below present the data from the inventory of the 15 different locations, followed by an analysis and interpretation of the data. The table includes information on size of the site, location, date of implementation, management type, landscape elements and vegetation pattern. To reflect the different typologies, schematic drawings are provided to illustrate the size of the relevant sites and their landscape character as they refer to the constructed or organically evolved landscapes and edge conditions.

Table 2
Typologies of Historic Landscapes – Groves.

	Naile Sultan Grove	Grove of Avusturya Consulate	Emirgan Grove	Yıldız Grove	Ayşe SultanGrove
Typology	Grove	Grove	Grove	Grove	Grove
Size	4.9 ha	5.5 ha	47.2 ha	46.7 ha	6 ha
Location	Kuruçeşme	Kuruçeşme	Emirgan	Beşiktaş	Bebek
Date		19th century	19th century		19th century
Management	Private	Private	Istanbul Metropolitan Municipality Parks and Gardens Directorate	Istanbul Metropolitan Municipality Parks and Gardens Directorate	Private
Landscape Elements	Inclined Topography Mixed group of deciduous conifers and shrubs Organic pattern of vegetation	Hilly topography, wandering pathways, cluster of conifers and deciduous trees	Inclined topography, pathways, historic palaces,cafes, a historic barn, play grounds, landscape elements such as picnic tables,pergolas	Mixed group of deciduous, coniferous and shrubs Pathways An artificial lake Hilly topography Organic pattern of vegetation Peripheral walls	Scattered pattern of vegetation Hilly topography
Vegetation Pattern	Pinus sp., Cedrus Atlantica, Pinus brutia, Cupressus sp., Rhamnus alaternus, Taxus baccata, Robinia pseudoacacia, Fraxinus ornus, and Magnolia sp.	Tilia argentea, Acer sp., Aesculus hippocastanum, Cercis siliquastrum, Cupressus sempervirens, Pinus sp., Cedrus atlantica, Taxus baccata, Platanus sp.	Acer campestre, Acer negundo, Acer pseudoplatanus, Aesculus hippocastanum, Cedrus atlantica, Cedrus deodora, Cedrus libani, Cercis siliquastrum, Cupressus sempervirens, Eriobotrya japonica, Fraxinus angustifolia, Laurus nobilis, Pinus halepensis, Pinus nigra, Pinus pinaster, Pinus pinea, Platanus x acerifolia, Quercus coccifera, Quercus dentata, Quercus robur, Salix babylonica, Syringa vulgaris, Tilia argentea, Viburnum tinus	The grove includes more than 120 species. Cedrus, Picea and Abies sp., Taxus, Cupressus, Pinus, Juniperus, Robinia pseudoacacia, Aesculus, Sophora, Acer, Fraxinus, Quercus, Ulmus, Pistacia, Liriodendron tulipifera, Koelreuteria paniculata, Feijoa sellowiana, Lagostroemia indica.	The grove includes Pinus pinea, Cedrus atlantica, Cupressus sp., Cercis siliquastrum, Laurus nobilis, Fraxinus sp., Acer sp., Pistacia sp., Ulmus sp., Laurocerasus officinalis.

Table 3
Typologies of Historic Landscapes – Palace Gardens and Mosque Gardens.

	Topkapı Palace	Dolmabahçe Palace	Yıldız Palace	Sultanahmet Mosque	Süleymaniye Mosque
Typology	Garden	Garden	Park and garden	Garden	Garden
Size	4.9 ha	25 ha	50 ha		
Location	Sarayburnu	Beşiktaş	Beşiktaş	Eminönü	Süleymaniye
Date	15 th century	19th century	19th century	17th century	16th century
Management	Government	Government	Government	Government	Government
Landscape Elements	Inner gardens Courtyards Pathways Fountains Axial and linear path systems Planting fields defined by axes	Circular pool Surrounded by water Symetrical and axial garden layout Baroque style Series of planting beds Inner garden	Small ponds and streams Naturalistic landscape features Small bridges Wandering pathways Benches Small kiosks Formally designed small inner gardens	Garden surrounded by walls Peripheral garden Axial layout	Peripheral gardens Axial garden layout Surrounded by walls Pavilion Exotic species
Vegetation Pattern	Abies bornmülleriana, Acer negundo, Aesculus hippocastanum, Castanea sativa, Celtis australis, Cupressus sempervirens, Fraxinus angustifolia, Pinus pinea, Platanus acerifolia, Ulmus glabra, Magnolia grandiflora, Juniperus sabina, Buxus sempervirens, Taxus baccata	Tilia argentea, Acer sp., Aesculus hipocastanum, Cercis siliquastrum, Cupresus sempervirens, Pinus sp., Cedrus atlantica, Taxus baccata, Platanus sp., Abies bornmülleriana, Acer palmatum, Camellia japonica, Cedrus atlantica, Cryptomeria japonica, Fagus slyvatica, Liriodendron tulipifera	Acer negundo, Acer pseudoplatanus, Aesculus hippocastanum, Cedrus atlantica, Cedrus deodora, Cedrus libani, Cercis siliquastrum, Cupressus sempervirens, Eriobotrya japonica, Fraxinus angustifolia, Laurus nobilis, Pinus halepensis, Pinus nigra, Pinus pinaster, Pinus pinea, Platanus x acerifolia, Quercus coccifera, Quercus dentata, Quercus robur, Salix babylonica, Syringa vulgaris, Tilia argentea, Viburnum tinus, Ligustrum, Populus sp., Robinia sp., Sequoiadendron	Acer negundo, Celtis siliquastrum, Chamaecyparis lawsoniana, Pinus nigra, Platanus orientalis, Tilia argentica, Robinia pseudoacacia, Populus nigra, Laurus nobilis, Ficus carica, Cedrus deodora	Ailanthus sp., Biota orientalis, Laurus nobilis, Ilex aquifolium, Olea europea, Platanus acerifolia, Salix caprea, Ulmus glabra, Tilia argentea, Yucca filamentosa

Table 4
Typologies of Historic Landscapes – Parks and Cemeteries.

	Gülhane Park	Kuruçeşme Park	Maçka Demokrasi Park	Eyüp Cemetery	Okmeydanı Cemetery
Typology	Park	Park	Park	Cemetery	Cemetery
Size	1 ha.	1 ha	4-5 ha	100 ha	150 ha
Location	Fatih	Beşiktaş	Maçka	Eyüp	Okmeydanı
Date	20 th century	20 th century	20th century	20th century	20th century
Management	İstanbul Metropolitan Municipality Parks and Gardens Directorate	İstanbul Metropolitan Municipality Parks and Gardens Directorate	İstanbul Metropolitan Municipality Parks and Gardens Directorate	Government	Government
Landscape Elements	The park includes seating areas, open theater, restaurants, play grounds, a small zoo, cafes, botanical park and a cistern with a small aquarium and historic statues from Roman period Wandering pathways Composition of different trees and shrubs Exotic species	Wandering pathways Composition of different trees and shrubs Open theatre, Play grounds, Rock garden, Lawn, Cafes Water Garden	Park is located on slopes of a valley Pool, wandering pathways, Cafes, sport and play fields, pools, running pist, pathways, exhibition areas, sport club Dense vegetation pattern	Garden surrounded by walls Peripheral garden Axial layout	Dense vegetation pattern Pathways
Vegetation Pattern	Celtis australis, Platanus occidentalis, Aesculus hippocastanum, Albizia julibrissin, Betula péndula, Cedrus deodora, Cedrus libani, Cupressus sempervirens, Pinus brutia, Pinus nigra, Pinus pinaster, Tilia argentea, Robinia pseudoacacia, Salix babylónica, Sophora japonica	Abelia grandiflora, Abies bornmuelleriana, Acer negundo, Aesculus hipocastanum, Albizia julibrissin, Acuba japonica, Betula sp., Catalpa bignonoides, Cedrus atlantica, Cedrus deodora, Celtis australis, Cercis siliquastrum, Chamaecyparis lawsoniana, Cotoneaster horizontalis, Cotoneaster salicifolius, Crataegus oxycantha, Cupressus arizonica, Cupressus sempervirens, Eleagnus angustifolia, Euonymus japanicus, Fatsia japonica, Ficus carica, Juglans regia, Tilia argentea, Punica granatum, Prunus sp.	Abelia grandiflora, Abies bornmuelleriana, Acer negundo, Aesculus hipocastanum, Albizia julibrissin, Acuba japonica, Betula sp., Catalpa bignonoides, Cedrus atlantica, Cedrus deodora, Celtis australis, Cercis siliquastrum, Chamaecyparis lawsoniana, Cotoneaster horizontalis, Cotoneaster salicifolius, Crataegus oxycantha, Cupressus arizonica, Cupressus sempervirens, Eleagnus angustifolia, Euonymus japanicus, Fatsia japonica, Ficus carica, Juglans regia, Lagerstromia indica, Laurocerasus officinalis.	Cupressus sempervirens, Cupressus arizonica, Ailanthus sp., Acer negundo, Celtis siliquastrum, Pinus nigra, Platanus orientalis, Tilia argentea, Robinia pseudoacacia, Populus nigra, Laurus nobilis, Ficus carica, Cedrus deodora	Ailanthus sp., Cupressus sempervirens, Cupressus arizonica, Platanus acerifolia, Salix caprea, Acer sp.

Discussion and conclusions

As a metropolitan city, Istanbul has a unique historic urban landscape that has emerged through its unique historical development process. It has become increasingly important for historic cities to cope with various development pressures and their impact on the historic landscape. Green heritage contributes to this unique landscape and has the potential to sustain ecological integrity.

In this study we have examined three relevant historic landscape typologies for their potential to contribute to the development of green infrastructure for the European side of Istanbul. These landscape typologies are: parks & gardens, groves and cemeteries, Furthermore, this research has examined all three different typologies according to site characteristics, which are natural characteristics (topography, vegetation, water surfaces) and man-made characteristics (structures, circulation, landscape elements, etc.).

The research showed that the rapid urbanization process threatens the landscape and leads to the loss of green areas within the urban context. Protecting and connecting these historically and ecologically valuable green areas is vitally important for sustaining the green infrastructure of the city. According to the inventory studies and field observations, each typology has a different potential to contribute to the green infrastructure. Parks, groves and cemeteries have the potential to contribute to the emergence of a green network by providing mass and mature vegetation patterns, whereas palace gardens have less potential to sustain ecological value or to sustain the continuity of the green network due to their isolated structure as an inner garden. Indeed, these small scale sites are usually fragmented by massive structures such as walls and in the case of the palace, they are open to manipulation, for instance by introducing exotic and ornamental species that are preferred for their aesthetic appearance. Historic groves are a major component of the green infrastructure with their large scale and dense vegetation pattern. In addition to their importance for urban heritage, urban groves play a vital role in urban ecology because of their various functions such as controlling microclimatic effects, regulating air humidity, controlling surface runoff and erosion and reducing air pollution. Today, however, many groves are managed by private companies and are subject to manipulation. The groves, which are owned by the government still maintain their vegetation quality, whereas the groves, which are managed privately have lost their original vegetation pattern and density; consequently these sites opened for construction. A comparison of site scales shows that private groves usually occupy approximately 1–3 ha, whereas groves, which are owned by the government, occupy larger sites in the urban center.

Most of the historic groves and parks and gardens are declared as preservation sites by the Code of protection of cultural and natural properties. As defined by law, those sites are in need to be protected and sustained by proper maintenance and restoration work. However, today one of the major problems with these sites appears to be the lack of maintenance and improper restoration work.

It is clear that historic green areas are threatened by new interventions. The unique qualities of the city's past are being lost. In particular, the design approaches developed for the historic parks should correspond more precisely to the existing site characteristics by paying more attention to its historical identity. In this respect, conservation and well-balanced use of the site should be carefully defined in order to maintain a high degree of sustainability for future generations. Another important fact is that these sites are scattered within the urban pattern; we believe that if approached properly, these sites can contribute to the identity of a place by providing a reference to its past.

New design approaches can be developed to sustain and enforce this identity. Thematic green corridors (with historical references) may be promoted to connect those scattered green areas within the urban context. Small scale groves and parks can be considered as stepping stones that function as green stations of a wider green infrastructure. Attempts to prevent further fragmentation will contribute to the sustainability of this green network and provide the opportunity for circulation between areas. Integration of the historic landscape into the dynamics of the contemporary city by using the concept of green infrastructure is much more vital for cities that are experiencing a rapid urbanization process. Therefore, a well-organized management and monitoring system may sustain the existing historical character as well as promote sustainable development. These areas should be evaluated as being part of a wider environmental context, thus, the connection between those areas, as well as major green spots, should be reorganized by paying more attention to their connectivity.

Today, it becomes an imperative for cities, which have a historic urban landscape, to address the problems of urbanization and historical heritage. This research shows that history can be linked to ecology by evaluating the historically developed landscape as a part of the green infrastructure and strengthened with innovative design and planning approaches for future projects.

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Biographical information

Dr. Meltem Erdem Kaya
Assist. Prof.
Istanbul Technical University,
School of Architecture
Address: Taskisla, Taksim,
Istanbul, Turkey
E-mail: erdemme@itu.edu.tr

Assist. Prof. Dr. Meltem Erdem Kaya is currently working at Istanbul Technical University, School of Architecture, Department of Landscape Architecture. She worked as a visiting scholar at Landscape Ecology, Perception and Design Lab. at University of Michigan, USA, between 2010–2011. She got her Ph.D. degree with the thesis titled «An Evaluation Matrix Proposal for Identification, Preservation and Development of Landscape Characteristics of Rural Settlements». Her research interests are focused on contemporary approaches in landscape architecture, natural systems and design, rural landscape planning and design.

Biographical information

Meliz Akyol
Istanbul Technical University,
School of Architecture
Address: Taskisla, Taksim,
Istanbul, Turkey
E-mail: melizakyol@gmail.com

Meliz Akyol is a landscape architect from Istanbul, Turkey. Currently she is working as a research assistant at Istanbul Technical University at the Landscape Architecture Department where she also received a Master's degree in Landscape Architecture, and she is also a Ph.D. candidate. She has been studying topics of urban agriculture history and remote sensing with GIS applications.

NORDISK ARKITEKTURFORSKNING
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GREEN INFRASTRUCTURE: CONDITION CHANGES IN SIX USA URBAN FORESTS

CHARLES A. WADE AND J. JAMES KIELBASO

Abstract

This study is one of the first to consider both public and private trees in an urban forest in the United States of America. The size and health conditions of urban forest trees are determined by many factors ranging from the genetics of the individual trees to environmental factors and anthropogenic issues. Tree size was measured by dbh (diameter at breast height, which is measured at a height of 1.4 meters in the United States) and tree health conditions were calculated by a point system. Tree health was assessed by identifying signs of decline or hazards on the crown, trunk, branches, base and roots. Then, the decline signs were counted and a value was assigned based on the number of decline signs. Our data indicates that there is a general tendency for the smallest trees to have the best health condition. When considering the relationship between the size of the trees and overall tree health conditions, we can state with certainty, that there is a strong negative correlation between the size of urban trees and the health condition of urban trees; conditions decrease or worsen as size increase.

Key words:
Urban forest ecology; urban trees; tree condition; tree size

Introduction

The size and health condition of urban trees are the result of many interacting factors, often classified as being either abiotic or biotic. The abiotic factors that influence the growth of urban trees include: soil properties (physical and chemical), soil moisture availability, soil compaction and soil volume (Ware, 1990; Day, et al., 2001). The biotic factors that influence the growth of urban trees are competition with other trees, competition with other plants, pathogens, and insects (Kielbaso and Kennedy, 1983; Lakovoglou, et al., 2001).

Factors that can impede growth include restricted root zones, soil compaction, competition and sometimes allelopathies. Restricted root zones will produce stunted trees relative to the same species and the same age growing in more favorable situations. Soil compaction may create situations that are similar to restricted root zones and trees may be stunted sufficiently leading to the death of the tree. Competition is always for resources/limiting factors (i.e. sunlight, nutrients, and water) (Close, et al., 1996a; 1996b; Fox, Bi and Ades, 2007) and space. This competition is generally with other trees in natural areas, and with turf in urban areas, which can take in enormous amounts of these resources before the trees can access them. As trees grow, the competition and retention of resources may become restrictive. The effects of allelopathy from certain trees in urban areas can range from abnormally slow growth, e.g. black cherry, sugar maples, and black spruce, to death, e.g. white pine, red pine and white birch (Chick and Kielbaso, 1998).

The size and health conditions of trees are an integral part of the analysis of the urban forest. It is generally thought among arborists and urban foresters that as trees get older and larger, there is an increasing chance that the trees will become damaged or diseased. This may lead to tree conditions that are dangerous or hazardous. Healthy, vigorous trees are more likely to withstand such impacts as root injury, minor wind damage, and other physical damages to the tree structure. Trees that have extensive wood rot, broken branches, weak branch attachments, and other structural damages which may lead to failure will need attention in order to prevent damage to people and property (Matheny and Clark, 1991; Shigo, 1991; Harris, Clark and Matheny, 1999).

The size of trees is generally expressed as height, crown spread, or as in this study, the diameter of the trunk (dbh). Inventories, such as this one, rely primarily on the tree diameter. The other size measurements, height and crown spread, are usually made in order to address particular management problems (Miller, 1997; Peper, Mcpherson and Mori, 2001). Tree size can be related to problems that may persist in trees. Small trees, depending on the species, may be weak and less able to withstand ice, snow and wind storms. Larger trees, depending on the species, may be more prone to decay and breakage.

Tree health directly affects the ecosystem services and functions of the urban forest (McPherson, 1990; Rowntree and Nowak, 1991; McPherson, 1993; McPherson, 1994; Nowak, 1994; Qi, Favorite and Lorenzo, 1998; Scott, Simpson and McPherson, 1999; Beckett, Freer-Smith and Taylor, 2000; Cumming, et al., 2001; Xiao and McPherson, 2002). The urban forests not only provide aesthetic and recreational benefits, they also reduce air pollution and storm runoff, conserve energy, store carbon, provide protection from ultraviolet radiation, create habitat for wildlife, and moderate temperatures (Xiao and McPherson, 2005).

This is a unique study where all of the urban trees, on both public and private land, were surveyed in certain city blocks. This comprehensive study is the first to take a complete picture of the urban forest instead of relying on just the city street trees to represent the entire urban forest. City street trees make up only 10 % of the entire urban forest in the United States (Kielbaso, et al., 1993; Wade, 2010).

The concept of urban and urbanization is defined by population density as determined by the U.S. Census Bureau (2007). An urban area is described as a densely populated settlement which has a population in excess of 386 people/km^2. Another urban category that the U.S. Census Bureau recognizes is the urban cluster (suburban or peri-urban areas) which has a population between 193 and 386 people/km^2. This study takes place in the Midwestern United States. It is the region of the USA which includes the Great Plains and the Great Lakes area of the country. The Midwest is made up of twelve states having a population of approximately 65 million inhabitants.

The rationale for this study was to look at twenty-five years of changes in a human dominated ecosystem, which had never been done before. The purpose of this study is to give researchers, arborists and planners an understanding of the conditions and sizes of the urban trees in the Midwestern United States. It is meant to give assistance to someone considering what trees should be planted. It is also intended to give an appreciation of what can be expected in the tree health condition and size, over the lifetime of an urban tree.

Methods

This study follows the procedures that were established by Cannon and Worley at the USDA-Forest Service in 1980 and repeated by Kielbaso, et al. in 1993. Six cities (Bowling Green, Bucyrus, Delaware, and Wooster, OH; Lincoln, NE and Hutchinson, MN) were inventoried. The city blocks were sampled in age categories, which were established by the age of the homes on the different blocks in 1980. The age categories were: younger than 10 years in 1980, 10 to 40 years old in 1980, and more than 40 years old in 1980. In 1980, three city blocks were inventoried from within each of the age categories. All of the blocks were residential.

In Bowling Green and Lincoln, three city blocks were surveyed from each of the age categories; a total of nine blocks in each city. The number of blocks was a little different in Hutchinson, where there were four blocks that were younger than 10 years, three blocks that were 10 to 40 years, and four blocks that were older than 40 years. All trees over 5.1 cmdbh were measured. Then in 1992, Bowling Green and Lincoln were re-surveyed by Kielbaso (1993). At that time, another block was added to each of the age categories in Bowling Green and Lincoln and three were added from the downtown area, so that there were 12 total blocks. Hutchinson was not re-surveyed in 1992. In 2003, all three cities were re-surveyed. However, only seven blocks from the original study in 1980 could be relocated in Hutchinson because the original data addresses were not available. The seven blocks were located with the assistance of the city forester, Mark Schnobrich. The blocks that were missing are due to re-development (e.g. new supermarket).

In 2005, five city blocks were inventoried in each city from each age category for a total of 15 city blocks for each of the cities. These new city blocks were chosen with the help of the city foresters, cooperative extension agents, and county mapping offices. All of the new city blocks were chosen randomly, without first seeing the blocks. This was done to minimize any bias that might have developed after seeing the sites.

The unique and important aspect of this study is that both public street trees and private property trees were inventoried. Variables collected for each tree were: ownership (public/private), species, dbh, and the overall tree health or condition. The ownership of the trees was defined by the sidewalk. If the tree was growing between the street and the sidewalk, then it was considered a public tree If there was no sidewalk, then trees growing within the right a way from the center of the street were considered public trees. All of the other trees in the front, side, and back yards were considered private trees. The dbh for every tree was measured and the trees were placed into size classes: (1) 5.1 to 10.2 cm, (2) 10.3 to 25.4 cm, (3) 25.5 to 40.6 cm, and (4) greater than 40.7.

Evaluating urban tree condition can be highly subjective (Webster, 1978). To eliminate subjectivity between years, we used a point system that was used in the original study in 1980 which was based on the number of visible decline signs that could be easily identified. Tree health was assessed by identifying signs of decline on the crown, trunk, branches, base and roots. Examples of decline included: decay, girdling roots, broken branches, included bark, etc. Decline signs were summed. If the tree had zero or one sign it was rated a (1), if the tree had two decline signs, it was rated a (2), if it had three or four decline signs, it was rated a (3), if it had five or more decline signs it was rated a (4), and if it was dead or was obviously in the process of dying it was rated a (5). This system was used in the original study and has produced reasonably consistent comparison with current ISA/CTLA evaluations guide procedures (Kielbaso, et al., 1993).

ANOVA with a Tukey's HSD (honestly significant difference) post hoc test was used to establish differences between categories ($p < 0.05$). The ANOVA was used to establish any differences, and then Tukey's HSD was used to find where the differences were between the categories. Correlations between tree size and condition were analyzed using chi-square ($p < 0.05$). Then Cramer's V was calculated as a measure of association to verify if there was a correlation in the categorical variables. The Cramer's V test takes the square root of the Chi-square value, divided by (N) the number of trees, then divided by three, which is the degrees of freedom for the rows in the contingency table. Cramer's V values are between zero and 1.0. The magnitude and strength of the relationship between the size and condition of the urban trees were then described (Cohen, 1988; Gravetter and Wallnau, 2007). Cohen (1988) proposed that, after adjusting for the degrees of freedom, if the Cramer's V value is between 0.0 and 0.06, there is no relationship; 0.06 to 0.17, there is a small relationship; 0.17 to 0.29, there is a moderate relationship; and if the value is greater than 0.29, there is a strong or large relationship.

Results

The six cities of this study are all found in the Midwest region of the United States. However, there were many differences. See table 1 for a comparison of the six cities.

Tree Condition – None of the tree conditions changed significantly during the study period. Overall tree condition averaged in 1980 was 1.4 ±0.009 and it was 1.6 ±0.008 in 2003/2005 (figure 1). The average public tree condition remained the same over the years at 1.7 with a standard error of ±0.03 and ±0.02 in 1980 and 2003/2005, respectively The average private tree condition over the six cities was basically the same as the overall trees averages, in 1980 it was 1.4 ±0.009 and in 2003/2005 it was 1.6 ±0.008 (figure 1).

When comparing conditions from the years 1980 and 2003/2005, there was a large difference in the number of trees in each of the condition categories, $F_{4,5} = 33.91$, $p < 0.001$. Further tests indicated that the number of trees in the condition category 1 (excellent rating) was significantly greater than in all of the other condition categories, (Tukey = $p < 0.01$) and the other four condition categories were not different from one another. The private trees showed the same trend as was seen in the total trees conditions. The public trees in 1980 and 2003/2005 were significantly different from one another, $F_{4,5} = 22.02$, $p < 0.01$ and, $F_{4,5} = 34.53$, $p < 0.001$, respectively.

Table 1
A comparison of selected urban forest descriptor data of the six Midwestern, USA cities in 1980 and 2003/2005.

		1980	2003/2005
Bowling Green, OH	Number of Trees	2 280	2 279
	Lots Surveyed		237
	Average Tree Condition Rating	1.32	1.66
	Average Tree Size (inches)	5.73	9.61
Bucyrus, OH	Number of Trees	876	1 111
	Lots Surveyed		228
	Average Tree Condition Rating	1.65	1.59
	Average Tree Size (inches)	7.48	11.02
Delaware, OH	Number of Trees	2 486	3 515
	Lots Surveyed		442
	Average Tree Condition Rating	1.44	1.51
	Average Tree Size (inches)	6.334	9.33
Hutchinson, MN	Number of Trees	704	654
	Lots Surveyed		155
	Average Tree Condition Rating	1.74	1.80
	Average Tree Size (inches)	9.17	10.34
Lincoln, NE	Number of Trees	953	1 049
	Lots Surveyed		220
	Average Tree Condition Rating	1.73	1.69
	Average Tree Size (inches)	9.11	11.56
Wooster, OH	Number of Trees	1 682	2 316
	Lots Surveyed		289
	Average Tree Condition Rating	1.32	1.66
	Average Tree Size (inches)	17.3	22.6
Summary of the urban forrest discriptors	Number of Trees	24.86	10 924
	Lots Surveyed		1 579
	Average Tree Condition Rating	1.53	1.68
	Average Tree Size (inches)	18.9	25.7

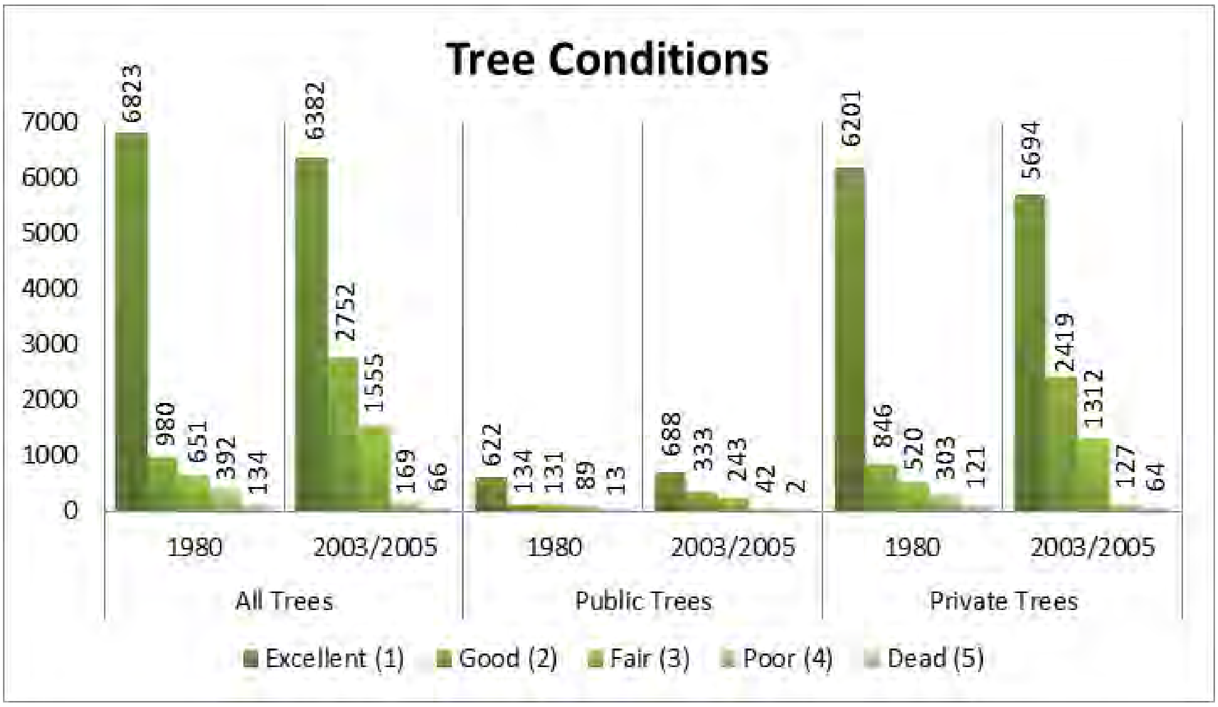

Figure 1
Tree condition rating in the six Midwestern, USA cities' urban forests that were surveyed in 1980 and in 2003/2005.

The average health condition of the 25 most common tree species between 1980 and 2003/2005 shows that the trees were getting significantly worse with time, $F_{1,48} = 5.08$, $p < 0.05$ (table 2). The public trees showed no real difference while the private trees fared significantly worse in 2003/2005 than in 1980, ($F_{1,48} = 7.57$, $p < 0.01$).

In 1980, considering all cities combined, there were a significant number of trees in excellent condition with a rating of 1. When the ages of the blocks were considered, there were still a significant number of trees in the best condition classes in each of the age categories. The public and private trees showed the same trend as was observed in the total trees, with an overwhelming number of trees being in excellent condition. In 1980, in the blocks that were less than 10 years old, more than 80 % of the trees had a condition of 1 and each of the other four conditions each had a rating less than 10 %. The blocks that were 10 to 40 years old followed the same trend as the trees that were on the blocks that were less than 10 years old. In the blocks that were more than 40 years old, condition 1 accounted for only 60.5 % and the other four conditions had percentages that tended to be slightly higher than the other two block ages.

In 2003/2005 the trend was the same, but the number of trees in condition 1 was fewer than in 1980. The other condition values were generally greater. In blocks that were younger than 10 years old, 61 % were in condition 1, while in the blocks that were 10 to 40 years old, condition 1 had 52 % of the trees; and in the blocks that were greater than 40 years old, condition 1 had 57 % of the trees.

Table 2
The 25 most common tree taxa in 1980 and 2003/2005 and their overall average condition** in the six Midwestern, USA cities; reported by public, private and total trees.

Taxa	1980				Taxa	2003/2005			
	Number of Trees	Average Condition				Number of Trees	Average Condition		
		Public	Private[1]	Total[2]			Public	Private[1]	Total[2]
Silver Maple (*Acer saccharinum*)	957	2.7	1.4	1.6	Arborvitae (*Thuja occidentalis*)	980	1.8	1.5	1.5
Blue Spruce (*Picea pungus*)	621	1.0	1.1	1.1	Silver Maple (*Acer saccharinum*)	942	1.9	1.8	1.8
Crabapple (*Malus sp.*)	458	1.1	1.2	1.2	Norway Maple (*A. plataniodes*)	701	1.9	1.6	1.7
American Elm (*Ulmus americana*)	418	2.6	1.5	1.8	Blue Spruce (*Picea pungus*)	676	1.1	1.3	1.3
Ash (*Fraxinus sp.*)	389	1.5	1.4	1.4	Ash (*Fraxinus sp.*)	634	1.5	1.6	1.5
Sugar Maple (*A. saccharum*)	355	1.7	1.6	1.6	Crabapple (*Malus sp.*)	523	1.7	1.7	1.7
Arborvitae (*Thuja occidentalis*)	327	1.0	1.1	1.1	Norway Spruce (*P. abies*)	506	1.0	1.7	1.7
Norway Spruce (*P. abies*)	323	1.6	1.1	1.2	Sugar Maple (*A. saccharum*)	334	2.2	1.8	2.0
Norway Maple (*A. plataniodes*)	305	1.6	1.4	1.5	White Pine (*Pinus strobus*)	321	1.0	1.6	1.6
Cherry (*Prunus sp.*)	276	1.7	1.8	1.8	Pin Oak (*Quercus palustris*)	292	1.9	1.6	1.6
Red Maple (*A. rubrum*)	262	2.0	1.5	1.6	Redbud (*Cercis canadensis*)	280	1.9	1.6	1.6
Pin Oak (*Quercus palustris*)	254	1.4	1.4	1.4	Red Maple (*A. rubrum*)	268	1.9	1.6	1.7
Dogwood (*Cornus florida*)	246	2.0	1.5	1.5	Mulberry (*Moris sp.*)	265	1.0	1.7	1.7
Apple (*Malus sp.*)	237		1.5	1.5	Pear (*Pyrus sp.*)	248	1.7	1.5	1.5
White Pine (*Pinus strobus*)	233	1.5	1.1	1.1	Dogwood (*Cornus florida*)	238	1.0	1.3	1.3
Redbud (*Cercis canadensis*)	207	1.0	1.5	1.5	Cherry (*Prunus sp.*)	224	2.3	1.7	1.7
Plum (*Prunus sp.*)	203	1.7	1.5	1.5	Black Walnut (*Juglans nigra*)	200	1.5	1.4	1.4
Birch (*Betula sp.*)	195	2.2	1.5	1.5	Honeylocust (*Gliditsia triacanthus*)	193	1.5	1.7	1.7
Scotch Pine (*P. sylvestris*)	187	1.0	1.3	1.3	Apple (*Malus sp.*)	171	2.0	1.8	1.8
Juniper (*Juniperus sp.*)	171		1.5	1.5	Hackberry (*Celtis occidentalis*)	164	2.4	1.6	1.7

(Table 2 cont'd)

Taxa	1980 Number of Trees	1980 Average Condition Public	1980 Average Condition Private[1]	1980 Average Condition Total[2]	Taxa	2003/2005 Number of Trees	2003/2005 Average Condition Public	2003/2005 Average Condition Private[1]	2003/2005 Average Condition Total[2]
Honeylocust *(Gliditsia triacanthus)*	161	1.1	1.4	1.3	Juniper *(Juniperus sp.)*	161	2.3	1.4	1.4
Black Walnut *(Juglans nigra)*	149	2.5	1.4	1.6	Linden *(Tilia sp.)*	147	1.7	1.5	1.6
Lombardy Poplar *(Populus nigra 'Italica')*	136	1.0	1.8	1.8	Hemlock *(Tsuga canadensis)*	145		1.6	1.6
Mulberry *(Moris sp.)*	117		1.9	1.9	Birch *(Betula sp.)*	139	2.0	1.5	1.5
Hawthorn *(Crataegus sp.)*	112	1.1	1.2	1.2	Magnolia *(Magnolia sp.)*	130		1.2	1.2
Total trees	7 299	1.6	1.4	1.5	Total trees	8 882	1.7	1.6	1.6
Sum of all trees	8 980				Sum of all trees	10 924			

** Conditions: 1 = excellent, 2 = good, 3 = fair, 4 = poor and 5 = dead

[1] Private tree conditions are highly significantly worse between 1980 and 2003/2005, $p < 0.01$

[2] Total tree conditions are significantly worse between 1980 and 2003/2005, $p < 0.05$

The most common signs of decline in 2003/2005 were broken branches and lawnmower damage to the base of tree and/or surface roots. There were also many trees with improper pruning which was causing abnormal callus growth and the wounds were not closing very efficiently.

Tree Size – The average size class for the top 25 species in 1980 and 2003/2005 is shown on table 3. A comparison of the average size classes for all of the trees was 1.2 and 2.2 in 1980 and 2003/2005, respectively, which is a highly significant growth in dbh over the years, $F_{1,48} = 20.26$, $p < 0.0001$. The average size class for the public trees in 1980 was 1.7 and in 2003/2005 were 2.6, which is also a highly significant increase in the dbh size class, $F_{1,43} = 14.59$, $p < 0.001$. The average size class for the private trees was similar to all the trees. The 1980 average size class was 1.2 and in 2003/2005 it was 2.2. Again, this is a highly significant increase in the dbh size class, $F_{1,48} = 19.11$, $p < 0.0001$.

The average dbh in 1980 was 17.2 cm, and in 2003/2005 it was 25.2 cm an increase of 8.0 cm (figure 2). The average public tree dbh in 1980 was 24.3 cm, and it was 29.1 cm in 2003/2005, an increase of 4.8 cm. The average private tree dbh in 1980 was 15.9 cm, and in 2003/2005 the average dbh was 24.7 cm, an increase of 8.8 cm which was a significant increase.

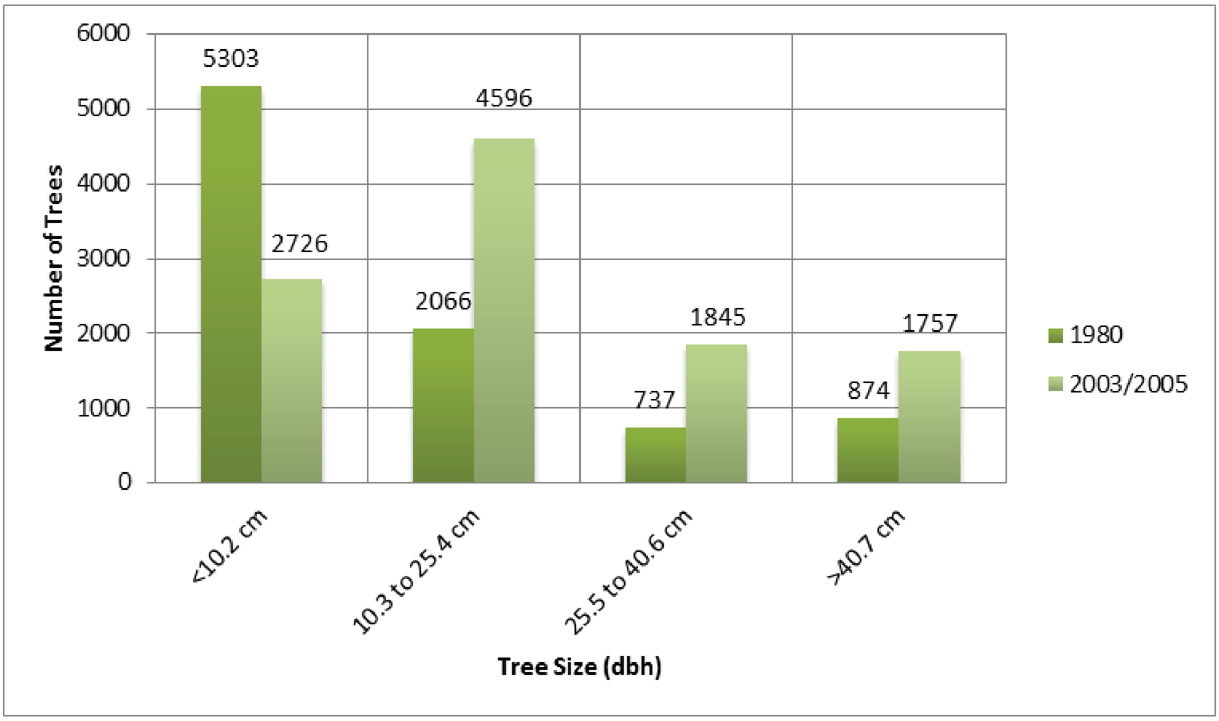

Figure 2
Tree size distribution in the six Midwestern, USA cities' urban forests that were surveyed in 1980 and in 2003/2005.

When comparing the public trees to the private trees within the different years, there was no significant difference between the public and private average tree size in 1980. However, there was a significant difference between the public and private average tree size in 2003/2005, $F_{1,46} = 4.38$, $p < 0.05$.

There was no significant difference between the size of the trees in the less than10 years old blocks and 10 to 40 years old blocks in 1980. However, the trees that were greater than 40 years old, public and private, showed a significant difference, $F_{1,6} = 12.52$, $p < 0.05$. In 2003/2005, there was significant difference in all three of the age categories between public and private trees; < 10 years old, $F_{1,6} = 6.79$, $p < 0.05$, 10 to 40 years old, $F_{1,6} = 21.5$, $p < 0.01$, and >40 years old, $F_{1,6} = 11.64$, $p < 0.05$.

When comparing the tree size categories per block age, in 1980 the smallest trees, less than 10.2 cmdbh, were the most common at almost every block age. However, in 2003/2005 the 10.3 to 25.4 cm trees were the most common.

Tree Size and Condition Relationship – The Cramer's V value was 0.338 ($p < 0.05$) for the 2003/2005 data. There was a strong negative relationship between size and condition; as the trees get larger, the health condition gets worse.

Table 3
The six Midwestern, USA cities 25 most common tree species in 1980 and 2003/2005 and the overall average size**; public, private and total trees.

Taxa	1980				Taxa	2003/2005			
	Number of Trees	Average Size				Number of Trees	Average Size		
		Public¹	Private²	Total³			Public¹	Private²	Total³
Silver Maple *(Acer saccharinum)*	957	3.2	2.1	2.2	Arborvitae *(Thuja occidentalis)*	980	1.9	1.6	1.6
Blue Spruce *(Picea pungus)*	621	1.1	1.3	1.3	Silver Maple *(Acer saccharinum)*	942	3.2	3.3	3.2
Crabapple *(Malus sp.)*	458	1.1	1.3	1.3	Norway Maple *(A. plataniodes)*	701	2.2	2.2	2.2
American Elm *(Ulmus americana)*	418	3.3	2.0	2.4	Blue Spruce *(Picea pungus)*	676	2.7	2.1	2.1
Ash *(Fraxinus sp.)*	389	1.5	1.8	1.7	Ash *(Fraxinus sp.)*	634	2.3	2.5	2.4
Sugar Maple *(A. saccharum)*	355	2.5	1.7	2.0	Crabapple *(Malus sp.)*	523	1.9	1.9	1.9
Arborvitae *(Thuja occidentalis)*	327	1.0	1.2	1.2	Norway Spruce *(P. abies)*	506	4.0	2.5	2.5
Norway Spruce *(P. abies)*	323	2.0	1.7	1.7	Sugar Maple *(A. saccharum)*	334	2.9	2.9	2.9
Norway Maple *(A. plataniodes)*	305	1.6	1.7	1.7	White Pine *(Pinus strobus)*	321	3.0	2.2	2.2
Cherry *(Prunus sp.)*	276	1.7	1.5	1.5	Pin Oak *(Quercus palustris)*	292	3.7	3.4	3.5
Red Maple *(A. rubrum)*	262	1.5	1.8	1.7	Redbud *(Cercis canadensis)*	280	2.1	1.6	1.7
Pin Oak *(Quercus palustris)*	254	3.3	2.3	2.5	Red Maple *(A. rubrum)*	268	2.1	2.2	2.2
Dogwood *(Cornus florida)*	246	1.0	1.0	1.0	Mulberry *(Moris sp.)*	265	1.0	1.8	1.8
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White Pine *(Pinus strobus)*	233	1.0	1.3	1.3	Dogwood *(Cornus florida)*	238	1.3	1.5	1.5
Redbud *(Cercis canadensis)*	207	1.2	1.3	1.3	Cherry *(Prunus sp.)*	224	2.6	2.1	2.1
Plum *(Prunus sp.)*	203	1.0	1.2	1.2	Black Walnut *(Juglans nigra)*	200	3.7	2.3	2.4
Birch *(Betula sp.)*	195	1.2	1.3	1.3	Honeylocust *(Gliditsia triacanthus)*	193	2.7	2.9	2.9
Scotch Pine *(P. sylvestris)*	187	1.0	1.2		Apple *(Malus sp.)*	171	2.0	1.9	1.9

(Table 3 cont'd)

Taxa	1980				Taxa	2003/2005			
		Average Size					Average Size		
	Number of Trees	Public[1]	Private[2]	Total[3]		Number of Trees	Public[1]	Private[2]	Total[3]
Juniper *(Juniperus sp.)*	171		1.6	1.6	Hackberry *(Celtis occidentalis)*	164	4.0	2.0	2.1
Honeylocust *(Gliditsia triacanthus)*	161	1.5	2.1	2.0	Juniper *(Juniperus sp.)*	161	2.0	1.6	1.6
Black Walnut *(Juglans nigra)*	149	2.0	2.3	1.3	Linden *(Tilia sp.)*	147	2.5	2.4	2.5
Lombardy Poplar *(Populus nigra 'Italica')*	136	2.0	1.5	1.5	Hemlock *(Tsuga canadensis)*	145		1.6	1.6
Mulberry *(Moris sp.)*	117		1.9	1.9	Birch *(Betula sp.)*	139	3.0	2.1	2.1
Hawthorn *(Crataegus sp.)*	112	1.1	1.2	1.2	Magnolia *(Magnolia sp.)*	130		1.6	1.6
Total trees	7 299	1.7	1.6	1.6	Total trees	8 882	2.6	2.2	2.2
Sum of all trees	8 980				Sum of all trees	10 924			

** Sizes: 1 = <10.2 cmdbh, 2 = 10.3 to 25.4 cmdbh, 3 = 25.5 to 40.6 cmdbh, and 4 = >40.7 cmdbh

[1] Public tree sizes were highly significantly bigger between 1980 and 2003/2005, $p < 0.001$

[2] Private tree sizes were highly significantly bigger between 1980 and 2003/2005, $p < 0.0001$

[3] Total tree sizes were highly significantly bigger between 1980 and 2003/2005, $p < 0.0001$

Discussion

Tree Condition – The tree condition was a measure of categories and it was not a measure of continuous data for the condition of the trees. Therefore, the average conditions are not precise, but approximate values. When comparing the average values for condition for each species, it is hard to discern any differences. However, if the average total condition is compared for all trees over the years, then differences can be observed.

When comparing the six cities to one another in 1980, three of the cities are very different from the rest, the tree condition was worse in Delaware, Hutchinson, and Lincoln. In the other three cities, Bowling Green, Bucyrus, and Wooster, there was no real difference in the condition of the trees. Delaware, Hutchinson, and Lincoln have had urban tree ordinances since the beginning of this study and have had an urban forester or arborist to oversee the care of each city's trees. These differences may also simply be the result of geography, Nebraska vs. Minnesota vs. Ohio. Or, it may be the dissimilarities involving the particular ecosystems that these cities are situated in, Lincoln is in the prairie; Hutchinson is found in the «*Big Woods*» section of the «*Maple-Basswood Region*» (Braun, 1950) and Delaware «*Beech-Maple Region*» (Braun, 1950).

Then in 2003/2005, mean conditions were identified in Bowling Green and Delaware. One explanation is that Delaware is where the USDA-Forest Service North eastern Forest Experiment Station is located and is the hometown of the original researchers for this study, each of whom was, and still is, active in the planning and oversight of the urban forest. Bowling Green has had a few different urban foresters or arborists and at times has had no one to help and counsel about tree issues. Next, the mean condition in Wooster is different from Bucyrus, Bowling Green, Delaware and Hutchison. Wooster's mean condition is similar to the mean condition in Lincoln. No explanation for this is evident.

The reasons for the decline in percentage of condition 1 in the greater than 40 year old blocks of trees are not apparent, but one suggestion is that the older the blocks, the older and larger the trees, and the more the chance the trees will have decline signs and/or be damaged.

The reason for the differences in percentages between 1980 and 2003/2005 may be bias by the data collectors or the inexperience of the students who did the survey in 1980, or the trees may simply be in a worse condition today. Another explanation may be that in 1980 huge numbers of trees were in the smallest dbh class which indicates that they were relatively new, young, vigorous trees. In 2003/2005 the greatest percentage of tree size shifted, and the largest size category was the 10.3 to 25.4 cmdbh. This means there are fewer small trees.

Tree Size – It should not be surprising to see that as time goes on, the average tree size gets larger. In a comparison between the tree sizes in the different years that data were collected, Delaware, Bucyrus, Hutchinson and Wooster were statistically different in the size between years, which generally indicates that the trees are growing. It can alternatively be interpreted that not as many small trees were being added to the urban forest. If trees were continuously being planted or volunteer trees were becoming established, there would not be that significant of an increase in tree size over the years.

In 1980, the trees in Wooster and Hutchinson were notably larger than in all of the other cities. The tree sizes in the other four cities were basically the same. In 2003/2005 there were no real recognizable differences in the tree sizes in any of the cities or geographical areas.

The reasons why it was so hard to detect any specific reason why a city's tree sizes are similar or different are numerous. First, the environment must be taken into consideration. Lincoln, NE is situated in a prairie where the trees are subjected to strong seasonal droughts and relentless competition from perennial herbs and graminoids; Hutchinson, MN is in the «*Big Woods*» section of the «*Maple-Basswood Region*» of the eastern deciduous forest (Braun, 1950) where the winters are relatively long and severe; and the other four cities, Bowling Green, Bucyrus, Delaware and Wooster, Ohio are in the «*Beech-Maple Region*» of the eastern deciduous forest (Braun, 1950) which has relatively mild summers and winters compared to the other two cities. So the individual cities' environments are varied and some conditions are more conducive for tree growth than other conditions.

Second, urban trees are under tremendous amounts of stress, and some microclimates are simply more favorable for tree growth than others. These stresses stem from manmade conditions such as soil compaction, improper pruning, soil pH irregularities, etc., to natural phenomena like competition, diseases, and parasites (Close, et al., 1996a; 1996b).

Third, are new trees being planted? Some cities have comprehensive plans and budgets for the planting of new trees and the replacement of dead or hazardous trees. If the city is not planting new trees, then the average size will continue to get larger. If new trees are being added to the urban forest, usually trees with a relatively small dbh, then the average size of the city's trees will remain roughly the same or even decrease. All of the cities in this study have a comprehensive tree planting plan except for Bucyrus, OH.

Finally, does the public value trees? If so, then trees are going to be cared for and their growth will be valued. It has recently been shown that the presences of trees in urban settings generate many psycho-social benefits, including: lower levels of fear, less violent behaviors, and better neighbor relationships (Kuo, 2003). When people understand this, they will be more apt to value the trees that are currently growing in cities and to spend money to plant and care for more trees. With this, it is hard to quantify how the public values trees (Kuo, 2003).

The main difference in the size categories, when comparing the age of blocks between 1980 and 2003/2005 was that the 4 to 10 inch dbh size category was the largest category in 2003/2005, where in 1980 the less than 4 inch category was the largest. This was due in part to in-growth; the trees in the smallest size category have grown. Another explanation is that this may indicate that fewer trees were being planted since 1980, so there were fewer small trees. This trend was evident in all of the block ages, and in both the public and private trees.

Tree Size and Condition Relationship – Intuitively, many think that as trees get larger, they become hazardous because their health conditions worsen. This mindset has been brought about because as the trees get larger, there is more chance that they will become damaged or diseased. Testing the association between tree size and tree condition tells us if the variables are dependent or independent of each other. It was found that the association between the tree size and tree condition is a moderately strong relationship. Therefore, we can state with certainty, that there is a strong negative correlation between the size and health condition of urban trees. Conditions decrease or worsen as size increases. This may simply be, not surprising, as the trees age there are more chances of damage or pests.

Conclusion

The importance of this research is to assess the entire urban forest, not just the street trees. The trees growing on privately owned property make up a preponderance of the trees in the urban forest and need to be included in any summaries and conclusions that are made about the urban forest.

This study has shown statistically that over time, the condition of the trees is worsening and not surprisingly, the tree dbh has increased, but if trees were being planted at the same earlier rates this would not likely be the case. What is surprising is the number of trees in each of the size categories. In 2003/2005 there were many more trees in the 10.3 to 25.4 cm category than in the less than 10.2 cm category, as opposed to 1980, when most of the trees were in the less than 10.2 cm size category. This indicates that fewer trees were being planted; even if the urban forester or arborist has increased the public tree planting, the private property owners have not.

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Biographical information

Charles A. Wade
C.S. Mott Community College
Department of Biology
Address: 1401 East Court Street
Flint, MI 48503
United States of America
Phone: 810-762-0283
Fax: 810-762-0466
E-mail: chuck.wade@mcc.edu

Dr. Charles A. Wade (Ph.D., Michigan State University, 2010) is a Professor of Biology at C.S. Mott Community College in Flint, Michigan, USA. Over the years Dr. Wade has taught such classes as General Biology (Non-Science Majors), Applied Botany, Environmental Science, General Botany, Michigan Flora, Local Trees and Shrubs, General Ecology and Field Biology. Research interests include urban forest ecology, urban ecosystem services, changes in the urban forests over time and the sustainability of the urban forest vegetation. Dr. Wade is also interested in helping educate people on the selection of the correct tree for a desired location as well as the health and conditions of the urban and peri-urban forest.

Biographical information

James J. Kielbaso
Michigan State University
Department of Forestry
Address: 123 Natural Resources
Building, East Lansing, MI 48824
United States of America
Phone: +517-355-7533
Fax: +517-432-1143
E-mail: kielbas3@msu.edu

Dr. James Kielbaso retired in 2004 as Professor Emeritus in the Department of Forestry at Michigan State University, USA. He taught arboriculture and urban forestry courses among many others at Michigan State for 38 years. He also conducted research on topics such as improving compacted soils for planting, the status of street trees nationally, management practices of U.S. urban foresters, herbicide use by U.S. utilities and social attitudes toward neighborhood trees. Dr. Kielbaso has served on the National Urban and Community Forestry Advisory Council, the International Society of Arboriculture's Board of Directors and the Michigan Forestry and Park Association's Board of Directors. Dr. Kielbaso received a bachelor's degree from University of Dayton and master's degree and doctorate in forestry from Michigan State University.