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Urban Sustainability: Integrating Ecology in City Design and Planning

Alessio Russo and Giuseppe T. Cirella

Abstract Urban sustainability depends on ecosystem services and biodiversity which directly affects quality of urban life. At present, urbanization is having a drastic effect on the way human beings interact with the world around us. Urbanized environments tend to lessen the amount of habitat and increase habitat fragmentation. This important factor stresses the need for sound urban sustainability thinking as well as related urban planning and urban design processes. Adaptive urban knowhow is as the root of this chapter in which a number of exploratory concepts and notions are put forth with the intention of creating dialogue between ecosystem services and human well-being (i.e., through concerted ecological, economic, and social action). The chapter begins with a look at urban sustainability, explores sustainable urban strategies, considers a number of ideas under the umbrella of urban green infrastructure—reviewing a number of case examples—and concludes with background research in properly developing sustainable models and tools. Integrating ecology in city design and planning should support resilience-orient development and highlight a synergetic, evolutionary form of multi-disciplinary sustainability.

Keywords Nature-based solutions Ecological corridors Green infrastructure Urban ecology

1 Introduction

Humanity has become a major force of nature in this new Anthropocene epoch, and we continue to deploy the biosphere with increasing intensity across all ecosystems to withstand exponential population growth and meet the demand for natural resources [1]. To date, urbanization, an important factor in the worsening of air quality [2], has a weighted impact on the loss of the world's biodiversity and homogenization of its biota through the replacement of non-urban specialist species [3, 4]. It tends to decrease the amount of habitat and increase habitat fragmentation at the same time, while the relationship between habitat loss and habitat fragmentation, due to the urbanization phenomena, is generally "monotonic-linear, exponential, or logarithmic—[indicating that the degree of] habitat fragmentation per se increases with habitat loss" [5]. Increased impervious surfaces resulting from urbanization modifies the water cycle by reducing the infiltration of stormwater and increasing surface runoff. Even more dramatically, these impermeable surfaces contribute to increased urban flood events [6].

Achieving urban sustainability via urban planning and urban design requires complex goal-oriented decision-making processes, which consider interactions among many factors, such as economics, social and cultural context, physical environment, and ecology [7]. Urban sustainability is an "adaptive process of facilitating and maintaining a virtuous cycle between ecosystem services and human well-being through concerted ecological, economic, and social actions in response to changes within and beyond the urban landscape" [8]. In the last quarter century, the discipline of urban ecology that contributes to urban sustainability evolved from an approach that focuses on ecological structures, functioning within a more holistic manner, where the city itself is the ecosystem and human beings are the system's dominant species [9]. Within this integrated social-ecological system [10], the city is dependent on ecosystem goods and services from natural ecosystems to maintain sustainability and depend on human management and intervention to maintain viable levels of sustainable functionality [11, 12]. For the renewal of urban areas, landscape urbanists suggest that landscapes should replace buildings and transportation systems as the principal organizing structure in urban design [13]. On the other hand, traditional urbanism and new urbanism relegate green areas to places that are too expensive to develop, while landscape urbanism theorists advocate the integration of ecology in city design and planning [13]. This chapter divulges into the development processes of urban sustainability and examines the integration of ecology and green spaces in city design and planning. In doing so, there is a perception that increased tree cover and density in urban contexts are associated with increased rates of criminality even though several studies concluded the opposite [14]. For instance, in Baltimore, Troy et al. [15] found that a 10% increase in tree canopy was

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associated with roughly a 12% decrease in crime, while Escobedo et al. [16] discovered the amount of public green areas was not significantly related to homicide occurrence in Bogota, Colombia. The scope of this chapter expands discussional notions of ecological concepts and approaches for the design and planning of sustainable cities by furthering the knowledge-base of existing tools and models for measuring, modeling, and valuing city-ecosystem services. It explores urban green infrastructure, urban ecological corridors, urban biosphere reserves and reviews case study examples.

2 Urban Sustainability

2.1 Ecological Planning, Ecosystem Services, and Eco-cities

The evolution of ecological planning can be traced back to the early works of Frederick Law Olmsted Sr. and Jr., Sir Ebenezer Howard, Frank Lloyd Wright, Patrick Ged- des, Lewis Mumford, and Ian McHarg [6, 17]. Over the last decade, green infrastructure—in connotation with sustainability—has risen as a disciplinary field in which significant interest has been focused on the city and regional planning; however, this discussion is not entirely valid. Significant elements can be dated back to the work of Frederick Law Olmsted Sr., in the nineteenth century, in which rooted work in urban planning and landscape architecture professions first became evident [17]. Olmsted's work within contemporary green infrastructure theory and practice included ecosystem services and human well-being [17]. In the late nineteenth century, the first inspirations of the garden city movement were put forth by Sir Ebenezer Howard [18] when he wrote "To-morrow: A peaceful path to real reform." Howard notes Henry George's [19], "Progress and poverty: An inquiry into the cause of industrial depressions and of increase of want with increase of wealth: The remedy," in which initial attempts are put together to recreate English village life by bringing "green" back into towns and by controlling urban size and growth. The garden city movement was later replaced by the concept of the "Abercrombie Plan" [20] which was followed by the idea of Jacobs' [21] "Living City," the idea that helped formulate the concept of Disneyland. In France, ideas from the Swiss–French architect Charles-Édouard Jeanneret, known as Le Corbusier, established the "modernist" city during the 1920s and 1930s, which came to be internationally renowned and, to date, still shapes urban planning in many parts of the world. Le Corbusier held that the ideal city was tidy, well-ordered and highly controlled; cities should replace wasted space with efficient transportation corridors and residential tower blocks that separated "flowing" mono-functional zones of open space [22].

In the early twentieth century, American architect Frank Lloyd Wright promoted the ideal city in terms of low density, dispersed urban forms (i.e., each family having their own plot) [23]. Since the 1990s, a number of cities have created new neighborhoods taking environmental factors into consideration. Shanghai announced plans to build the city of the future on an island at the mouth of China's Yangtze River, and in the same way, Singapore has planned new ecological neighborhoods [24]. There is a growing interest in sustainable concepts such as the eco-city (i.e., including the sustainable city, smart city, low-carbon city, and resilient city) especially since the passing of the new millennium in which significant global proliferation of diverse policies and practical initiatives have come to the forefront [25]. One example is the European Eco-Viikki project established in Finland as an ecological residential area built between 1999 and 2004. As a planned competition, organized by the City of Helsinki and the Eco-Community Project, challenging planners to envision ecological views and integrate model solutions at the neighborhood level [26] (Fig. 10.1).

Fig. 10.1 Eco-Viikki, Finland—(left) ecological building and "green fingers" with gardening plots, (right) green roof and greenhouse. Photographs taken by A. Russo on August 15, 2012

The planning stages of urbanization lead us to explore urban strategies and scholarship and the how the rethinking of urban design can mitigate unsustainable action and promote sound development.

2.2 Sustainable Urban Strategies and Scholarship

As the world experiences unprecedented urbanization—presenting extreme challenges for contemporary urban planners, designers, and policy-makers—sustainable urban strategies and an expert level of ecological scholarship are needed. It will require boosting urban models and strategies capable of generating new knowledge and improving practical skills [27]. It is fair-minded to consider we are already living in the Age of Cities, characterized by increasing population and urban centrality in the achievement or declination of itself—reflective of region, country, or the global economy as a whole [28]. Sustainable and resilient cities have become the world's leading urban development paradigm [29]. Recently, Zhang and Li [30] highlighted the difference between urban sustainability and urban resilience, pointing out that rational urban development can only be reached when it is both sustainable and resilient. Moreover, they define urban sustainability as "the active process of synergetic integration and co-evolution between the subsystems making up a city without compromising the possibilities for the development of surrounding areas and contributing by this means toward reducing the harmful effects of development on the biosphere" [30]. Urban resilience, on the other hand, as "the passive process of monitoring, facilitating, maintaining, and recovering a virtual cycle between ecosystem services and human well-being through concerted effort under external influencing factors" [30].

The concept of urban sustainability is an inclusive characteristic of urban resilience and sustainable development needs as well as the inclusivity of how to develop resilience-oriented strategies [31]. Several critical scholars, however, have warned that resilience theories fail to tackle equity, justice, and power [32]. The official political implementation of the sustainable city started in 1972 when the significance of creating sustainable urbanization models first came to light, internationally, at the 2003 United Nations Conference on Human Environment in Stockholm [29]. According to Principle 16 of the Declaration from that conference "planning must be applied to human settlements and urbanization with a view to avoiding adverse effects on the environment and obtaining maximum social, economic, and environmental benefits for all" [33]. This principle has been strengthened by the Sustainable Development Goal 11, which aims to "make cities inclusive, safe, resilient, and sustainable" by 2030 [34].

Lately, cities and towns from around the world have been consciously encouraged to be smarter (and even smarter) and therefore more sustainable by creating and applying big data systems and applications across different metropolitan areas in the hope of achieving the necessary level of sustainability and enhancement in living standards [35]. According to the World Bank [36], "smart cities make urbanization more inclusive, bringing together formal and informal sectors, connecting urban cores with peripheries, delivering services for the rich and the poor alike, and integrating the migrants and the poor into the city. Promoting smart cities is about rethinking cities as inclusive, integrated, and livable." The application of information and communications technology (ICT) in cities can produce various benefits (e.g., reducing resource consumption, improving the utilization of existing infrastructure capacity, making new services available to citizens and commuters, and improving commercial enterprises) [37]. Specifically, the ICT smart city agenda is designed to address a wide range of urban problems (i.e., cities can increase rates of economic growth, competitiveness, and innovation while reaching sustainable goals such as emissions reduction, enhancing energy effectiveness, and enhancing quality of life) [38, 39]. Zhu et al. [40] recently unveiled potential connections between urban smartness and resilience in China, showing important findings that correlate to two. Cities can be both smart and sustainable, which require the preservation of the ecological equilibrium and social identity of urban communities embedded in tangible and intangible heritage while promoting creativity and technology in order to increase their productivity and resilience and thus improve the welfare and quality of its citizenry [41]. The United Nations Educational, Scientific and Cultural Organization (UNESCO) [41] provides several recommendations supporting sustainable urbanization by encompassing environmental, social, and economic standpoints. Its recommendations can be used by policy-makers and urban planners alike; however, there is a lack of sustainable urban development indicators which makes it difficult for urban sustainability to be properly evaluated in a number of situations. In particular, those with high sensitive, fragile ecology, and lower threshold limits [42] require a more comprehensive list of indicators and range of weightages varying according to different city-contexts. By rethinking urban design, architecture, landscape design, urban transport, and planning, we can transform our cities and urban landscapes into "urban ecosystems"—a forefront notion for mitigating climate change (e.g., sustainable transportation and clean energy) as well as urban adaptation solutions (e.g., floating houses and nature-based solutions) [43].

2.3 *Urban Green Infrastructure*

Urban green infrastructure is a "hybrid infrastructure of green spaces and built systems (e.g., urban forests, wetlands, parks, green roofs, and walls) that together can contribute to ecosystem resilience and human benefits through ecosystem services" [44]. Urban green infrastructure has been documented as providing several economic, aesthetic, cultural, and architectural benefits [44]. In particular, it provides multiple ecosystem services and goods such as carbon storage and sequestration, water and air purification as well as offset air pollution and emissions from cities. Urban green infrastructure can reduce mortality from heatwaves and improve human thermal comfort through the altering of albedo of surfaces as well as cooling of atmospheric temperatures through shading and evapotranspiration [44–48]. There is increasing evidence that contacts with nature can make a significant contribution to human health and well-being [5, 49–51]. This is because natural ecosystems provide a variety of services some of which promote basic human needs (e.g., limiting the spread of disease or reducing air contaminants) [52]. Furthermore, several systematic reviews and meta-analyses pooling data have confirmed that exposure to urban green infrastructure results in the reduction of all-cause mortality, particularly cardiopulmonary and cancer mortality [53]. Edible green infrastructure and nature-based solutions are complementary notions within the urban green infrastructural discourse and merit further discussion.

2.3.1 Edible Green Infrastructure

Food insecurity is an important health problem and an underrecognized social determinant of health [54]. Edible green infrastructure is a novel approach that can improve resilience and quality of life in cities and boost food insurance [55]. It is a sustainable planned network of edible food components and structures, within the urban ecosystem that can manage and design the provisioning of ecosystem services. Illustrations of edible green infrastructure are shown in Fig. 10.2.

Edible green infrastructure typologies are provided and macrocategorized in conjunction with eight sub-classifications of urban agriculture: (1) edible urban forests and edible urban greening, (2) edible forest gardens, (3) historic gardens and parks and botanic gardens, (4) school gardens, (5) allotment gardens and community gardens, (6) domestic and home gardens, (7) edible green roofs and vegetable rain gardens, and (8) edible green walls and facades [55]. An edible green infrastructure approach can interplay environmentally, socially, and economically to urban sustainability and food security. As noted, the typologies of edible green infrastructure can vary significantly;

Fig. 10.2 Edible green infrastructure, (left) Berlin, Germany and (right) Vancouver, Canada; left photograph taken by A. Russo on 20 June 2018, right photography taken by G. T. Cirella on September 19, 2018

however, additional factors such as ecosystem disservices (e.g., potential health risks caused by heavy metals and organic chemical contaminants often found throughout urban settings) must be considered. There are a number of recommendations and guidelines for incorporating edible green infrastructure into urban planning and design [56] that should be considered for future research.

2.3.2 Nature-Based Solutions

Nature-based solutions is a new term in environmental research, planning, and management [57]. The nature-based solutions concept is closely related to other modern approaches including sustainability, urban resilience, ecosystem services, ecosystem-based adaptation, coupled human and environment, and green–blue infrastructure; however, “nature-based solutions represent a more efficient and cost-effective approach to development than traditional approaches” [58]. At the core, “they are solutions to societal challenges that are inspired and supported by nature” [59]. The European Commission [60] has identified four principal goals for nature-based solution: (1) enhance sustainable urbanization to stimulate economic growth as well as improve the environment, make cities more attractive, and enhance human well-being; (2) restore degraded ecosystems to improve the resilience of ecosystems, enable them to deliver vital ecosystem services, and also meet other societal challenges; (3) develop climate change adaptation and mitigation to provide more resilient responses; and (4) improve risk management and resilience which can lead to greater benefits that supersede conventional methods and offer synergies in reducing multiple risks.

An urban context example of such a solution is the Semiahmoo Library in Surrey, British Columbia, Canada which houses a living wall of over 10,000 individual plants and more than 120 species (Fig. 10.3). The library’s exterior is a self-sufficient green wall with veritable shrubbery sustained by water and nutrients delivered directly from within its

Fig. 10.3 Semiahmoo Library living wall located in Surrey, British Columbia, Canada. Photographs taken by G. T. Cirella on September 20, 2018

vertical support system. This living wall, also called a bio-wall, is composed of pre-vegetated panels, vertical modules, and planted blankets [61]. The wall is constructed of three parts: metal frame, polyvinyl chloride layer, and air layer (i.e., there is no soil layer). This type of wall would support a wide variety of environments and climatic conditions. In addition, “living” architecture as in Semiahmoo Library normally has a number of secondary functions such as noise reduction (i.e., the ability to suppressive sound), insulative properties, and habitat and relating services for insects (e.g., bees) and animals (e.g., birds). Nature-based solutions are, to some degree, an all-encompassing concept. They integrate a system understanding (i.e., ecology and society) and values and benefits (i.e., biodiversity, resource efficiency, food security, disaster risk reduction, clean water, health and well-being, clean air, and climate control) with ecosystem functions and services (e.g., food, raw material, waste decomposition, recreation, climate regulation, water storage and filtration, disease control, coastal protection, and aesthetics). Noticeably, this array of interdisciplinarity places nature-based solutions at an important point of the design phase within urban green

Table 10.1 Urban ecological corridors and related concepts, adapted from Peng et al. [62]

Concept	Characteristic
Greenway	Linear landscape owning multiple functions such as ecological, cultural, recreational, and aesthetic functions
Green belt	Green open space set up in urban peripheral, used for urban and rural segmentation
Habitat and ecological network	Linear or strip landscape with the ecological, social, cultural, and other functions
Ecological infrastructure	Reticular landscape or open space with basic ecosystem services consisting of point, line, and surface

infrastructure and how subsequent future urban trends, if carefully implemented, can greatly benefit the wider urban and peri-urban ecology of cities.

2.4 *Urban Ecological Corridors*

The concepts related to urban ecological corridors include greenways, green belts, green corridors, ecological networks, habitat networks, and ecological infrastructure [62] (Table 1). There are also diverse classifications of urban ecological corridors (e.g., river corridors, green transportation corridors, biodiversity conservation corridors, heritage corridors, and recreation corridors) in which complexity in the structure and function [62] has linearity and linkage in common [63]. In cities, corridors have an important function in the conservation of biodiversity in urban domestic gardens and effectiveness in terms of the distribution of organisms with low dispersal capabilities [64]. Planning an urban ecological network can reduce landscape fragmentation and increase the shape complexity of green space patches and landscape connectivity [65]. The health benefits of green corridors have been demonstrated to be psychologically as well as biophysically beneficial [63]. Urban planners and landscape architects need ecological information to plan and design for location, spacing, and dimensions of corridors [66]. Austin [66] notes that a 10–30 m wide corridor could be sufficient for species moderately or highly adapted to human activity; however, these minimum dimensions may require site-specific adjustments (e.g., variability of the animal species, climate, vegetation, and topography).

2.5 *Urban Biosphere Reserve*

The International Coordinating Council of the Man and the Biosphere (MAB) Programme, a UNESCO working group, identified four development themes for urban biosphere reserves: zonation of biosphere reserves; governance of biosphere reserves; policy, management, and business plans; and data management and monitoring [67]. Russo and Cirella [50] extrapolated MAB's research into different urban biosphere reserve typologies in which four principle urban settings are identified (Fig. 10.4). According to Dogse [68], urban biosphere reserves are "important urban areas within or adjacent to its boundaries where the natural, socioeconomic, and cultural environments are shaped by urban influences and pressures and set up and managed to mitigate these pressures for improved urban and regional sustainability."

An example of an urban biosphere reserve is the Dublin Bay Biosphere Reserve in Ireland which includes North Bull Island, Dublin Bay, and the adjacent land which includes parts of Dublin. This enlarged biosphere is made up of grassland dunes, sand dunes and salt marsh with glasswort (*Salicornia dolichostachya* and *S. europaea*), *Puccinellia maritima*, and sea lavender (*Limonium humile*) (Fig. 10.5). It is one of the most pristine sand dunes in Ireland and globally, a first-rate example of an urban region biosphere reserve [69].

Another two noteworthy examples of urban biosphere reserves come emanate from England and Australia. First, the Brighton and Lewes Downs Biosphere Reserve located on the Southeast coast of England is apart a central unit of the hills of the South Downs National Park [70]. The reserve is centered on the Brighton chalk block that is situated between the River Adur and River Ouse. Chalk downland forms much of the terrestrial landscape, while the coastline is dominated by chalk cliffs and urbanized plains [70]. Second, the Great Sandy Biosphere located along the Fraser Coast region of Queensland, Australia, encompasses "the neighboring Gympie area and the Bundaberg coastline and puts it in the same class as the Galapagos Islands, the Central Amazon, the Everglades, and Uluru" [71]. The Great

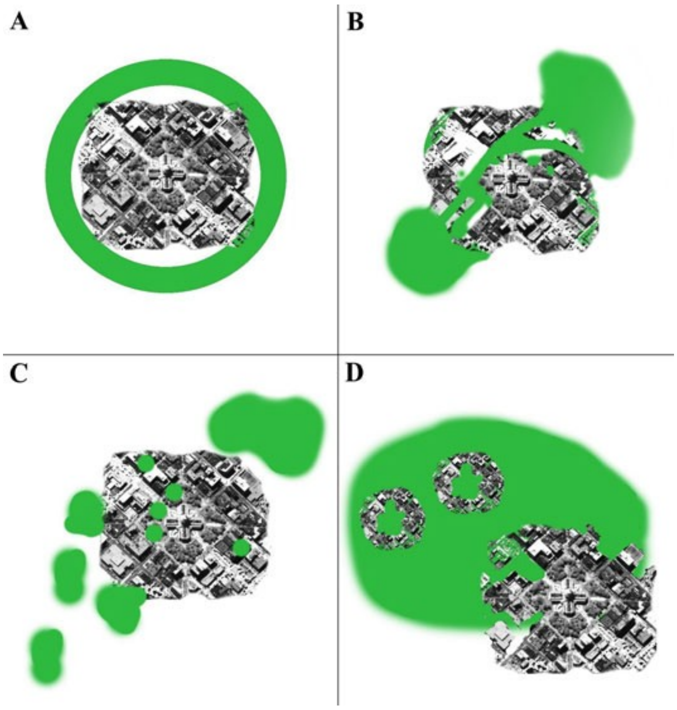

Fig. 10.4 Urban biosphere reserve typologies where **a** urban green belt, **b** urban green corridor, **c** urban green cluster, **d** urban region. Adopted from MAB [67] and reproduced from Russo and Cirella [50] using Paint.Net 4.24

Fig. 10.5 (left) Dublin Bay biosphere reserve grassland dunes where important orchids such as the (middle) bee orchid and (right) pyramidal orchid grow. Photographs taken by A. Russo on June 21, 2019

Sandy Biosphere protects natural resources while offering a balanced conservation and sustainable development platform. Nature conservation (e.g., major breeding for endangered marine turtles, the largest sand mass in the world, and some 7500 species of fauna and flora) is coupled in with the cities of Hervey Bay, Maryborough, and Gympie (Fig. 10.6).

Fig. 10.6 Hervey Bay's inlet living, a part of the Great Sandy Biosphere reserve along the Fraser Coast region of Queensland, Australia. Photograph taken by G. T. Cirella on May 18, 2014

3 Case Examples

3.1 New York City: "Green Infrastructure Plan"

The Green Infrastructure Plan presents an alternative approach to improving water quality by integrating green infrastructure. The Plan incorporates swales and green roofs, with investments to optimize the existing water system to build targeted, smaller-scale gray, or traditional infrastructure. This is a multi-pronged, modular, and adaptive approach to a complicated problem that can provide widespread, immediate benefits at a lower cost. The green infrastructure component of this strategy builds upon and reinforces strong public and government support necessary to make additional water quality investments.

One critical goal of the Green Infrastructure Plan is to manage runoff from 10% of the impervious surfaces in combined sewer watersheds through detention and infiltration source controls [72]. This blue print builds upon and extends the commitment of the sustainable stormwater management plan framed between New York Harbor and New York City. The Plan's strategy and operating costs are projected help with "reduction strategies and investments over the next 20 years and will lead to both clean waterways and a greener, more sustainable city" [72]. Similarly, to New York City, other financial capitals like London, Hong Kong, Singapore, and Shanghai have been developing their own green urban strategies that show promise and imagination in integrating ecology in city design and planning.

3.2 London: "City Plan 2036"

The City of London's Planning and Transportation Committee recently backed an ambitious local plan called "City Plan 2036." This plan's intention protects existing open spaces and requires development to provide new spaces, where feasible. The advancement and change oblige development to focus on green walls and roofs, trees, and other green features (Fig. 10.7). The Plan's objective is to assess the level of greening through a new "Urban Greening Factor which will be applied to major new development" [73]. As such, building designs and the public realm is to focalize on long-term resilience infrastructure that can withstand a variety of climate conditions (e.g., overheating and flooding). To facilitate this move, all development, transport, and public infrastructural designs must integrate with the city's sustainable urban drainage principles [73]. In London, there a common concern that the city is overly dependent on the financial and business services sector, so much so, that such that City Plan 2036 has refocused its stratagem on "diversity and resilience, promoting strong performance across more of the economy, with no single sector contributing more than 40% of gross value added or jobs growth" [74]. London's green infrastructure strategies are future-oriented and exploratory for large-scale, urbanized areas that plan to develop or implement urban-based sustainability with green-friendly design.

Fig. 10.7 London Wall Place. Photograph taken by A. Russo on June 15, 2018

4 Conclusion: Sustainable Planning and Design Tools for Measuring, Modeling, and Valuing Ecosystem Services

Many previous studies have shown that urbanization can impact not only the spatial pattern of urban green infrastructure but also the urban landscape itself which, in turn, influences its ecosystem services [75]. To better analyze and evaluate urban green infrastructure, its spatial patterns and influence on urban sustainability, we need appropriate approaches [75]. In the last few years, ecosystem services of urban green infrastructure have been assessed using available methods including computer-based modeling tools—software or web-based tools such as ENVI-met, i-Tree (i.e., Tree Eco, i-Tree Canopy, and i-Tree Landscape), and in the past, CITY green [44, 76]. These models have been developed or adapted for landscape design and urban planning [44]. There are an increasing number of tools available that aim to value urban green infrastructure such as the non-departmental public body in the United Kingdom's Natural England [77] which assessed a number of these tools in terms of their adherence to the principles of scientific and economic analysis and their applicability within to their country.

Several of these tools and applications use tree inventory data to quantify the monetary and non-monetary value of environmental and aesthetic benefits generated from urban green infrastructure [78]. Often, these available models account for ecosystem functions that are detrimental to human well-being and the related costs of management, thus allowing for a better understanding of the urban forest and strategic planning, but regrettably, they do not consider any specific ecosystem disservices to balance against the ecosystem services [78]. Scientists, city managers, and policy-makers alike need to be aware that available models and methods can produce statistically different ecosystem service estimates [79]. Evaluation and monitoring of urban green infrastructure need to use the appropriate level of scientific rigor [52] in combination with ecologically oriented thinking.

Investing in urban green infrastructure in cities, including ecological restoration and rehabilitation of ecosystems (e.g., urban rivers, lakes, and woodlands), is not only ecologically and socially desirable but also economically advantageous [80]. Urban sustainability integrates a number of overlapping concepts and methods. To evaluate ecosystem services for sustainable urban design and planning and to further advance our understanding of the complex socio-ecological processes, combined with rising levels of urbanization, we need to integrate primary research into urban design processes [81]. Best systems control and practice should support sustainable ecological planning in conjunction with urban strategies and green scholarship.

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