Urban Green Space

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Urban Green Space: Enhancing Quality of Life in Cities

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1. Introduction

While 'urban sprawl' and its implications have been a topic of discussion and research for many years, recent attention has been focused on the importance of green space in its different forms and the role it can play in maintaining and enhancing the quality of life for urban residents. While past efforts have been geared towards the conservation of natural environments and biodiversity on the urban fringe, it is becoming increasingly important to look at the immediate environment of city residents. This is where the majority of people will spend the majority of their time and will be the place where direct health implications will be most strongly felt. High-density urban environments do not often provide for private outdoor space, and while this can be seen as an incentive for greater use of public outdoor spaces, the design and availability of such areas is of critical importance.

Urban growth and an ever-increasing urban population are making considerable changes to urban environments. The implications of these changes can be far-reaching and directly affect the quality of life, as well as the health and well-being of urban residents. The loss of natural habitat and an increase in urban temperatures, as well as elevated pollution levels resulting from a predominance of building and paving materials, a reduction of vegetation, and an increase in motorized transport, have health implications.

In land-use planning, urban green space is open-space areas reserved for parks and other "green spaces", including plant life, water features - also referred to as blue spaces - and other kinds of natural environment.

Most urban open spaces are green spaces, but occasionally include other kinds of open areas. The landscape of urban open spaces can range from playing fields to highly maintained environments to relatively natural landscapes.

Generally considered open to the public, urban green spaces are sometimes privately owned, such as higher education campuses, neighborhood/community parks/gardens, and institutional or corporate grounds. Areas outside city boundaries, such as state and national parks as well as open space in the countryside, are not considered urban open space. Streets, piazzas, plazas and urban squares are not always defined as urban open space in land use planning. Urban green spaces have wide reached positive impacts on the health of individuals and communities near the green space.

Urban greening policies are important for revitalizing communities, reducing financial burdens of healthcare and increasing quality of life. Most policies focus on community benefits, and reducing negative effects of urban development, such as surface runoff and the urban heat island effect.

Historically, access to green space has favored wealthier, and more privileged communities, thus recent focus in urban greening has increasingly focused on environmental justice concerns, and community engagement in the greening process.

In particular, in cities with economic decline, such as the Rust Belt in the United States, urban greening has broad community revitalization impacts.

Urban areas have greatly expanded, resulting in over half of the world's population being located in urban locations.

As the population continues to grow, this number is predicted to be at two-thirds of people living in urban areas by 2050.

In case of our city (AL Sulaymaniyah city) the population has increased very rapidly in the last 20 years due to many reasons, the most important is the immigration from the rural areas toward the city because of lack of services in the villages, government doesn’t support the villagers in the field of agriculture and livestock, as well as water scarcity.

Another reason is the immigration from other cities in middle and south of Iraq to Al Sulaymaniyah city because of wars and unstable security situation of those cities.

2. Standards of Urban Green Spaces

Functional level	Maximum diatance from home (m)	Minimum surface (ha)
Residential green	150	
Neighbourhood green	400	1
Quarter green	800	10 (park: 5 ha)
District green	1600	30 (park: 10 ha)
City green	3200	60
Urban forest	5000	>200 (smaller towns) >300 (big cities)

Source: Herzele and Wiedemann, 2003.

Region/Country/ City	Estimated size of urban green space/woodland resource
Europe	The study of 386 cities suggests 18% average woodland cover. Another study suggests 18.5% cover within municipal limits of 26 large European cities, i.e., about 104 m^2/ inhabitant (Konijnendijk 2003).
France/Paris	About 80 m^2 of urban forest per inhabitant in Greater Paris region (Konijnendijk 2003).
The Netherlands	Average green space cover is about 19% for 22 largest Dutch cities, i.e., about 228 m^2/inhabitant (Konijnendijk 2003).
Australia/ Canberra	Estimated crown cover of about 24 million metre square amounting to 80 m^2/inhabitant (Brack 2002).
USA	Average green space cover is about 27%, i.e., about 32 m^2/ inhabitant
China/Nanjing/ Wuhan	On an average China's cities have 32.54% green cover. This varies greatly in Chinese cities like Nanjing and Wuhan, i.e., 44.3 m^2 /person and 10.3 m^2/person respectively (Jim and Wendy 2009).
Hong Kong	Average green space cover is about 1.81%, i.e., about 3 m^2/ inhabitant
Singapore	Average green space cover is about 17.8%, i.e., 7.5 m^2 per capita
India/Delhi	Average tree and forest cover is about 20% of geographical area and about 21 m^2/ inhabitant (FSI 2009, as per population data 2001).
India/Chandigarh	Average tree and forest cover is about 35.7% of geo-graphical area, i.e., about 55 m^2/inhabitant (Action Plan 2009-10, as per population data 2001).

Ratio of Urban Green spaces in Al Sulaymaniyah city is as following:

- Number of public parks: 7 parks for the total area of 745.143m^2
- Number of neighborhood parks : 507 parks for the total area of 1,152,412m2
- Number of medians: 83 medians for the total area of 1,352,038m2
- Total green space area: 3,249,593m2

3. Importance of Urban Green Space

By 2050, 68% of the global population will live in cities. That's 2.5 billion more people than today. In Europe, three out of four of them already live in urban areas, and the consequences of that are becoming clear.

Researchers estimate that nine million people die every year as a direct result of air pollution. In London, two million people - of which 400,000 are children - are living in areas with toxic air.

Why do we need nature in urban areas?

As our cities grow and more people move into already crowded spaces, what do we need to do to transform our urban areas into healthy places to live? An increasing body of research tells us that we should be letting nature back in.

Dr Cecil Konijnendijk is a Professor of Urban Forestry at the University of British Colombia (UBC). He studies the role of nature and green spaces in cities and towns, and how we can use the natural world to make urban environments healthier and more livable.

'Research shows really clearly that we need nature in our surroundings. We need trees in our streets, plants in our gardens and flowers on our balcony. We need nature as our neighbor all the time.'

'We have a responsibility as human beings to take care of nature in our cities. In return, the benefits to our health would be huge.'

Growing a mini meadow of wildflowers in your garden or in a pot on a balcony can be beneficial to our health and make life better for pollinating insects.

The urban heat island effect

Green spaces in cities mitigate the effects of pollution and can reduce a phenomenon known as the urban heat island effect, which refers to heat trapped in built-up areas.

The urban heat island effect appears in towns and cities as a result of human activity. The heat generated by people, transport, shops and industry is trapped in

the narrow roads and concrete structures, unable to escape to the atmosphere. This can bring the temperature in urban areas up 3-4°C higher than the surrounding countryside, and with that comes a vicious cycle.

Increased temperatures in summer leads to an increased demand for cooling. This expands our energy consumption, which in turn intensifies fossil fuel consumption, increasing pollutants in the air and harmful smog on our streets.

Hotter pavements also damage the water cycle. In summer, surface temperatures can be a staggering 50°C hotter than the surrounding air, and that heat is transferred to the rainwater that drains into our sewers, which in turn raises water temperatures as it is released into streams, rivers and lakes. This can be destructive to aquatic ecosystems, as changes in water temperature can be stressful or even fatal for marine life.

The benefits of green spaces in cities

Planning cities to include green spaces wherever possible is the first step in making our urban areas healthier. For example, adding a layer of vegetation to rooftops and creating green roofs has proven to reduce the urban heat island effect.

Having soil, plants and greenery on our roofs would both reduce surface temperature and serve as insulation for the structures below, reducing the energy needed to heat and cool the buildings. Green roofs can also help regulate rainwater, trapping it as it falls and filtering out pollutants.

(**Figure 1**). Singapore's Gardens by the Bay is a great example of a city bringing

biodiversity into its center. The tall structures pictured make up the sky garden's Super tree Grove. These vertical gardens are home to a wide variety of plants including orchids, vines and ferns. © Fabio Achilli (CC BY 2.0) via Flickr

Trees in our streets also play their part, and a variety of tree species can have a profound effect.

'By increasing the diversity of trees on our streets we can create miniature forests,' Cecil explains. 'This has already started to be implemented in cities like Singapore, where they are mixing human structures with many different tree species.'

'These miniature forests in our cities create ecosystems, bringing a diversity of insect and bird species which, in turn, keep the trees healthy. If we allow ecosystems to flourish, we have to spend less resources on maintaining them.'

Cecil recommends going beyond creating pockets of nature within a city. He says, 'If we give space to natural processes and link up our green spaces, we can create flourishing and wild ecosystems in man-made environments. There were no sightings of the critically endangered smooth-coated otter in Singapore for decades. Now they are returning to the city, because of its dedication to nature.'

Green cities mean giving up some control of our surroundings - but for our long-term benefit.

'We need to get used to letting go and try not to manage everything. Some natural spaces are messy, but that's a good thing! Messy nature isn't just a great habitat for wildlife but it's good for children to play in. Children's depression and ADHD is on the rise and one of the reasons is our disconnect from nature.'

Simply having access to green spaces in cities can do wonders for our stress levels and concentration at work.

Cecil says, 'People need to interact with nature whenever the opportunity arises. Something as simple as a five- to ten-minute break during the workday can improve well-being and boost productivity.'

Democratizing our green spaces

Right now, however, accessing to green spaces isn't universal - what's more, it can be a driver of inequality in our societies.

In 2008, a Lancet study by Dr Richard Mitchell and Frank Popham of 40 million British people found a link between income inequality, access to green spaces and life expectancy.

The study revealed that in rural areas with plenty of access to green spaces, the life expectancy of those on the highest and lowest incomes was roughly the same.

However, in urban environments, the gap in life expectancy was staggering. People on the lowest incomes living in cities are expected to live 10 years less than those on the highest incomes. This is due in part to the green spaces available to the richest people, who often live in open, leafy areas, while the poorest are often left living in overcrowded, heavily concreted areas.

Mitchell and Popham's results showed that as you move along an axis of increasing access to green spaces, the difference in life expectancy decreases. But the problem can't be solved just by creating green spaces in poorer areas.

Dr Matilda van den Bosch is a physician and an assistant professor at UBC, with a PhD in landscape planning and public health.

She says, 'It's not as simple as just creating green spaces in certain areas. The situation we have at the moment is that high-quality urban areas, with good access to nature, are more expensive to live in.'

'What's happening is that green spaces are being created, but suddenly those areas become more desirable and housing costs go up - often pricing out the people currently living there. It's a kind of green gentrification.'

'What we need is for there to be an effort to recognize that green spaces are vital for everyone, and that everyone should feel the benefit. Parks should be easily accessible, democratic spaces - somewhere you can go without the pressure to spend money, and meet people from all walks of life within your community.'

It will take some effort to truly bring nature into the heart of our cities, especially to sprawling urban jungles.

But there is plenty that all of us can do right now to protect what we have and encourage nature to flourish. By caring for and using the parks and green spaces near us, we show councils that these precious places are cherished.

4.Benefits of Urban Green Spaces

The benefits that urban open space provides to citizens can be broken into four basic forms; recreation, ecology, aesthetic value, and positive health impacts. Psychological research shows that benefits gained by visitors to urban green spaces increased with their biodiversity, indicating that 'green' alone is not sufficient; the quality of that green is important as well.

Recreational

Sad Janka Kráľa park in Bratislava (Slovakia)

Urban open space is often appreciated for the recreational opportunities it provides. Recreation in urban open space may include active recreation (such as organized sports and individual exercise) or passive recreation. Research shows that when open spaces are attractive and accessible, people are more likely to engage in physical activity. Time spent in an urban open space for recreation offers a reprieve from the urban environment and a break from over-stimulation. Studies done on physically active adults middle aged and older show there are amplified benefits when the physical activities are coupled with green space environments. Such coupling leads to decreased levels of stress, lowers the risk for depression as well as increase the frequency of participation in exercise.

Ecological

Blackstone Park Conservation District, an urban conservation area in Providence, Rhode Island.

The conservation of nature in an urban environment has direct impact on people for another reason as well. A Toronto civic affairs bulletin entitled *Urban Open Space: Luxury or Necessity* makes the claim that "popular awareness of the balance of nature, of natural processes and of man's place in and effect on nature – i.e., "ecological awareness" – is important. As humans live more and more in man-made surroundings – i.e., cities – he risks harming himself by building and acting in ignorance of natural processes." Beyond this man-nature benefit, urban open spaces also serve as islands of nature, promoting biodiversity and providing a home for natural species in environments that are otherwise uninhabitable due to city development.

By having the opportunity to be within an urban green space, people gain a higher appreciation for the nature around them. As Bill McKibben mentions in his book *The End of Nature*, people will only truly understand nature if they are immersed within it. He follows in Henry David Thoreau's footsteps

when he isolated himself in the Adirondack Mountains in order to get away from society and the overwhelming ideals it carries. Even there he writes how society and human impact follows him as he sees airplanes buzzing overhead or hears the roar of motorboats in the distance.

Aesthetic

The aesthetic value of urban open spaces is self-evident. People enjoy viewing nature, especially when it is otherwise extensively deprived, as is the case in urban environments. Therefore, open space offers the value of "substituting gray infrastructure." One researcher states how attractive neighborhoods contribute to positive attitudes and social norms that encourage walking and community values. Properties near urban open space tend to have a higher value. One study was able to demonstrate that, "a pleasant view can lead to a considerable increase in house price, particularly if the house overlooks water (8–10%) or open space (6–12%)." Certain benefits may be derived from exposure to virtual versions of the natural environment, too. For example, people who were shown pictures of scenic, natural environments had increased brain activity in the region associated with recalling happy memories, compared to people that were shown pictures of urban landscapes.

Impact on health

The World Health Organization considers urban green spaces as important to human health. These areas have a positive impact on mental and physical health. Urban open spaces often include trees or other shrubbery that contribute to moderating temperatures and decreasing air pollution. Perceived general health is higher in populations with a higher percentage of green space in their environments. Urban open space access has also been directly related to reductions in the prevalence and severity of chronic diseases resulting from sedentary lifestyles, to improvements in mental well-being, and to reductions in population-wide health impacts from climate change.

Mechanism of urban open space health effects

Access to urban open space encourages physical activity and reduces ambient air pollution, heat, traffic noise and emissions. All are factors which contribute to the risks of chronic disease and mental illness. Individuals and

families who lived closer to ‘formal’ parks or open space were more likely to achieve the recommended amounts of physical activity. Better respiratory health is associated with cleaner air quality. Cleaner air quality affects rates of chronic disease in populations exposed. “High concentrations of ambient particles can trigger the onset of acute myocardial infarction and increase hospitalization for cardiovascular disease”. Besides an association with lower BMI/obesity rates, this physical activity can increase lung function and be a protective factor against respiratory disease. Exposure to nature improves the immune system. The contact of the human body with soil, turf, forest floor, exposes it to many microorganisms which boost the immune system.

Reductions in chronic disease rates

Improved access to green space is associated with reductions in cardiovascular disease symptoms, improved rates of physical activity, lower incidence of obesity, and improved respiratory health. Lower rates of cardiovascular biomarkers are associated with access to green space, showing a reduction in cardiovascular disease risk in populations living within 1 km of green space. Not only does access to urban green space reduce risk of cardiovascular disease, but increased access has been shown to improve recovery from major adverse cardiovascular events and lower all-cause mortality. Relationships have been found between increased access to green space, improved rates of physical activity, and reduced BMI. The percentage of sedentary and moderately active persons making use of an urban park increased when access to the park was improved.

Reductions in mental illness rates and improvement of social cohesion

Mental illness has been a major taboo and concern in the current fast-paced world in which time to relax is undervalued. Globally, mental illness is linked to eight million deaths each year. In urban areas, limited access to green space and poor quality of green spaces available may contribute to poor mental health outcomes. The distance an individual lives from a green space or park and the proportion of land designated as open space/parks has been shown to be inversely related to anxiety/mood disorder treatment counts in the community. Improved mental health may therefore be related to both measures - to distance from open space and proportion of open

space within a neighborhood. Even when physical activity rates are not shown to increase with greater access to green space, greater access to green space has been shown to decrease stress and improve social cohesion.

Effects on respiratory health

Adequate urban green space access can be associated with better respiratory health outcomes, as long as green space areas meet certain requirements. A new study showed that mortality due to pneumonia and chronic lower respiratory diseases could be reduced by minimizing fragmentation of green spaces and increasing the largest patch percentage of green space. Vegetation type (trees, shrubs and herbaceous layers) and lack of management (pruning, irrigation and fertilization) has been shown to affect a higher capacity to provide the ecosystem services of air purification and climate regulation within green urban spaces. The types of plants and shrubs are important because areas with large tree canopies can actually contribute to asthma and allergic sensitization.

Impacts on mental health

The advocacy for mental health is becoming increasingly rampant, given the psychiatric illnesses that contribute significantly to morbidity and mortality in the United States. Health disparities existing within and amongst communities make this issue of paramount importance. The correlation between psychological distress and socioeconomic status (SES) has previously been examined. Sugiyama demonstrates that psychological distress is positively correlated with lower SES. A contributing factor to this socioeconomic disparity is the higher amounts of green space among residents with higher SES. Access to and active utilization of urban green space results in decreased rates of anxiety and depression, which are among the most common mental health illnesses. The positive association between mental health and green space was also supported by Van den Berg. The positive influence of urban green space on a community's perceived sense of mental wellness is achieved through uplifted moods, decreased stress levels, relaxation, recuperation, and increased human contact, which in itself promotes mental well-being. Given the burden of mental illness in the United States, it is important to examine the impact of urban green space on mental health

and utilize this information to promote mental well-being across communities.

Modern research evidence demonstrates urban green space has positive impacts on population level mental health. Evidence shows that designated green space in urban areas facilitates social interaction, fosters well-being, increases opportunities for exercise, and contributes to improvement in common mental health problems such as anxiety, depression, and stress. One randomized trial studied two groups: one composed of residents living in a neighborhood that had a greening intervention and one that did not. Among the participants who now live in a green neighborhood, those feeling depressed decreased by 41.5% and self-reported poor mental health decreased by 62.8%. Another study indicates that "the difference in depressive symptoms between an individual living in an environment with no tree canopy and an environment with tree canopy is larger than the difference in symptoms associated between individuals who are uninsured compared with individuals with private insurance". Incorporating green space into urban design is an impactful, equitable, affordable, and accessible way to decrease the burden of mental health.

Further research on urban open spaces have recently found a positive link associating a mental health and well-being with increased access to green spaces in urban areas. The RESIDE Project, for example, has found a dose-response effect where the total area of public green spaces is associated with a greater overall wellbeing. Based on the study participants' survey responses, urban neighborhoods with more access to green spaces are more likely to report increased optimism, perception of usefulness, confidence, social interaction, and interest in new activities. Additionally, individuals living in neighborhoods within walking distance of parks have more opportunities to participate in recreational activities which is also associated with positive health outcomes. Another study published in the Journal of Epidemiology compared the effect of green spaces on 2,169 pairs of twins. After adjusting for genetic confounders and childhood environments, researchers found significant association between green spaces and decreased depression. Both examples of green spaces in urban areas illustrate how individual's environment can affect mental health and highlight the importance of access to green spaces.

Impacts on high temperatures

Urban areas tend to have higher temperatures than their surrounding undeveloped areas because of Urban Heat Islands, UHIs. Urban heat islands are areas with man-made infrastructure that contribute to the increased temperatures. The average temperature during the day in cities can be 18-27 degrees Fahrenheit higher than in the surrounding rural regions. This is an example of one type of UHI, surface heat islands. Surface heat islands encompass the area from the ground to the top of the tree-line. It is usually higher during the day when direct sunlight reaches urban structures (often with darker materials than natural areas) including the main contributor, pavement. The other type of UHI, atmospheric heat islands, are from above the tree-line to the level in the atmosphere where the urban area no longer has an effect. This type of heat island has increased heat at night due to the release of heat from infrastructure that built up throughout the day.

Green spaces within urban areas can help reduce these increased temperatures through shading and evapotranspiration. Shading comes from the taller plants, such as trees, planted in green spaces that can contribute to lowering the surface heat island effect. The shade provides protection from the sun for vulnerable populations, such as children, during periods of increased temperature, during the summer months or during a heat wave. Tree cover prevents some solar radiation from reaching the ground with its leaves and branches. This reduces the effect of surface urban heat islands. Open spaces that include any type of vegetation help offset the high temperatures through the natural process of evapotranspiration. Evapotranspiration releases water into the air therefore dissipating heat. There are many elements of an urban open space that can contribute to the mitigation of urban heat islands including the type of open space (park or nature reserve), type of plant species, and the density of vegetation. Green spaces contribute to the reduction of local heat, decreasing the overall effect of UHIs. The larger the distribution of green spaces, the bigger the area of heat reduction. Green spaces that are clustered together will have an additive heat reduction resulting in a greater decrease in temperature in the local area compared to surrounding areas.

Impacts on air quality

Human activity has increased air pollution in the Earth's atmosphere and trees play an essential role in removing human-made pollutants from the

air, aka particulate matter (PM). Trees produce oxygen and absorb CO_2. In urban green spaces, trees filter out man-made pollutants. Air quality data collected on cities with and without urban green space has shown that areas with an abundance of trees have considerably less air pollutants, i.e. O_3, PM_{10}, NO_2, SO_2, and CO. As air pollutants accumulate in the atmosphere, vulnerable populations, such as children, may suffer from increased incidences of respiratory disease. Particulate matter or particle pollution with a diameter of 10 microns (PM10) or 2.5 microns (PM2.5) is associated with heart diseases and respiratory diseases including lung cancer.

Globally, particulate matter has increased over 28% in indoor air and 35% in outdoor air. Children spend most of their time at school, around 10 hours daily, and the indoor and outdoor air has a large impact on their health. Schools located in urban areas have higher particulate matter than schools in rural areas. Compared with children in schools located in rural areas, children who attend schools located in industrial areas and urban cities have higher levels of urinary PAHs (polycyclic aromatic hydrocarbons) metabolites, which is linked to air pollution.

There are two different ways that green spaces can reduce the pollution of particulate matter including preventing distribution of particulate from pollutants or by reducing the particulate matter from traveling to other places. There is a disagreement about the association of living near green spaces or having high exposure to greenness and illness such as allergies, rhinitis, and eye and nose symptoms. Higher exposure to tree canopy and pollen was associated with a high risk of prevalence rhinitis, allergic sensitization, wheezing, and asthma among children 7 years-old. More studies are needed to explain the effect of urban green spaces on children relating to air quality. These studies should take into consideration the interconnectedness of tree species, geographic areas, temperature, and other pollutant-like traffic.

For children and adolescents

Impacts on physical health

The adolescent years are extremely important for children due to it being a time of growth, development, and instillation of habits. When children are given the opportunity to be active, they typically take advantage of it. Children with a greater access to parks and recreational facilities through urban green space have been found to be more active than children who

lack access. The access to green spaces has shown an association with recreational walking, increased physical activity, and reduced sedentary time in all ages. In coordination, it has been seen that higher residential green space is associated with lower BMI scores. If children are given the opportunity to be active and maintain a healthy BMI in their adolescent years, they are less likely to be obese as adults.

Impacts on mental health

Children exposed to urban green spaces have the opportunity to expend energy by interacting with their environment and other people through exercise. One study has shown that without access to urban green spaces, some children have problems with hyperactivity, peer interactions, and good conduct. The important interactions with nature, animals, and peers have been positively influential in child development and reduction in behavioral issues such as Attention Deficit Hyperactivity Disorder (ADHD). Urban green spaces allow children to expel their extra energy and improve their ability to focus when needed both at school and home.

In addition to behavioral problems, and likely connected, access to urban green space has been proven to be helpful for cognitive development. With urban green space giving children the opportunity to get outside and expend energy, children are more focused in school and have a better working memory and reduced inattentiveness.

- Another facet of urban green space improving mental health is giving children access to a other children and develop a social circle and social skills in general. Children with a good social network community. Recreational activities and playing at the park gives children opportunities to interact with Green cover and open spaces are important in towns and cities because they provide health, wellbeing and ecological benefits. Examples of green cover and open spaces include natural and semi-natural areas, such as remnant bushland, parks, gardens and infrastructure such as plant walls and green roofs.
- Green cover and open spaces provide natural cooling of air and surfaces, and support water management in urban areas. The vegetation used in these areas absorbs carbon dioxide, helping to offset greenhouse gas emissions.
- Climate change is causing more severe and frequent heatwaves, drought, rainfall and storms. These extreme weather events affect our towns and cities, and impact green cover and open spaces, reducing their ability to mitigate against future impacts.

- Increasing the amount of green cover and open spaces can help to combat the effects of climate change. This is achieved by providing natural cooling of air and surfaces, supporting water management in urban areas and capturing carbon dioxide from the atmosphere. This will help to keep our cities and towns resilient and livable in the future.

5. Designing and Planning Urban Green Space

Urban land use is the main cause of environmental impacts at both local and global scales . Even though it represents only 2% of global land use, about half of the world's population lives in urban areas and most of the industrial activities are located here .In 2019, the urban population in the European Union was already 75% of the total population, while the ratio in North America was 80% and in Asia it was about 40%. The number of cities with at least one million inhabitants will be almost duplicated until 2030: in 2000, the amount was 371 and it is predicted to rise to 706 in 2030 .Approximately 90% of urban growth happens in developing countries, and Asia will have more than 60% of the urban population of the world by 2050. Additionally, the number of megacities (with over 10 million inhabitants) will grow, especially in Asia and Africa.

The use of green infrastructure (GI) is mainly based on the conditions that the city is experiencing: the size of the city, how fast it is growing, the economic situation and opportunities to support the green approach in urban renewal. In an ideal situation, GI has two different components, hubs and links, where the hubs are based on different kinds of green areas (for example public spaces, parks, forests etc.) and the links are the interconnections between the areas facilitating the flow of ecosystems, working as green corridors. Another aspect is what kind of role urban GI has in urban planning; many rapidly growing cities are already lacking sufficient green spaces and infrastructure. claimed that the main reasons for not adapting urban GI in planning relate to a lack of knowledge regarding its costs, benefits and impacts.

One option to manage the lack of GI has been the launching of different systems to support a sufficient number of green areas, namely the Green Space Factor (GSF) or Biotope Area Factor (BAF) or Green Index monitoring inspired by different models and organizations, such as the World Health Organization (WHO). The development of green area factors started in the city of Berlin in

1984; since then, several greater cities have been adapting different models developed to meet their local needs.

Urban land-use may produce adverse effects on the land energy budgets and biogeochemical cycles. This is due to the capacity of the city to be a sink of carbon and nitrogen and to simultaneously increase their concentrations. Activities carried out in urban areas emit carbon dioxide (CO_2), which is responsible for global climate change. Furthermore, pollution has negative effects on human health at the local scale. Epidemiological studies have shown that increased concentrations of ozone (O_3) and particulate matter (PM) levels are associated with an increase in mortality due to respiratory and cardiovascular diseases. Urbanization, with the constructions of buildings, roads, squares, waste treatment etc., thus represents an important driving function of the weather and climate conditions. Urban areas usually experience increased air and surface temperatures with respect to the surrounding rural area known as the Urban Heat Island (UHI) phenomenon. The UHI increases with the growth of urban areas and industrialization as a direct consequence of structural and land cover changes from free space (natural or agricultural land) to the high density of urban structures, such as buildings, roads, paved squares etc. This is due to the increased heat-absorbing surface, the increase in heat production from anthropogenic sources, the stagnation of air, pollutants and heat and the reduction of vegetation evapotranspiration. The main negative consequences of UHI include human discomfort and health, increased energy consumption during the summertime and impaired air and water quality. The UHI also affects air quality because of the increasing energy consumption with elevated gas emissions. Moreover, high temperatures facilitate the formation of tropospheric O_3, a harmful pollutant generated as nitrogen oxides react with volatile organic compounds (VOCs) during the daytime. Finally, the growth of impervious surfaces, combined with an increase in the frequency and intensity of precipitation events, makes urban areas more vulnerable to flooding.

It is expected that the urban population will reach 70% of the total human population by 2050; therefore, this will produce an increase in urban areas with a potential increase in the demand for natural resources, particularly energy and water, with negative effects on human health. It is, thus, necessary to develop models, strategies and policies of urbanization that are able to increase the quality of human life in urban areas and mitigate the impact at both a local and global scale.

Urban green spaces are widely recognized to mitigate the land use impact of urbanization and represent “publicly owned and accessible open spaces within urban and peri-urban areas that are wholly or partly covered by considerable amounts of vegetation”. They include forests, road trees, trees in parks, gardens and nature conservation areas. Parks, public gardens, road trees etc. are intrinsic

elements in urban planning as there are specific indications in urban plans that regulate the relationship between green and built spaces. The concept of ecosystem services synthesizes human–environmental interactions that link biophysical structures and ecological functions with goods and services that are useful to humans (**Figure ٢**). The next aim is stimulating the creation of green spaces that are functional to the development of ecosystem services within the areas that are often designed in a monofunctional way, such as built spaces or grey infrastructures. For this purpose, it is important to understand the ecological functions that can be developed considering the integration of natural-based solutions in built environments or grey infrastructures, and the relative benefits or disservices that may derive from them, considering the interaction of the vegetation and context and their purpose.

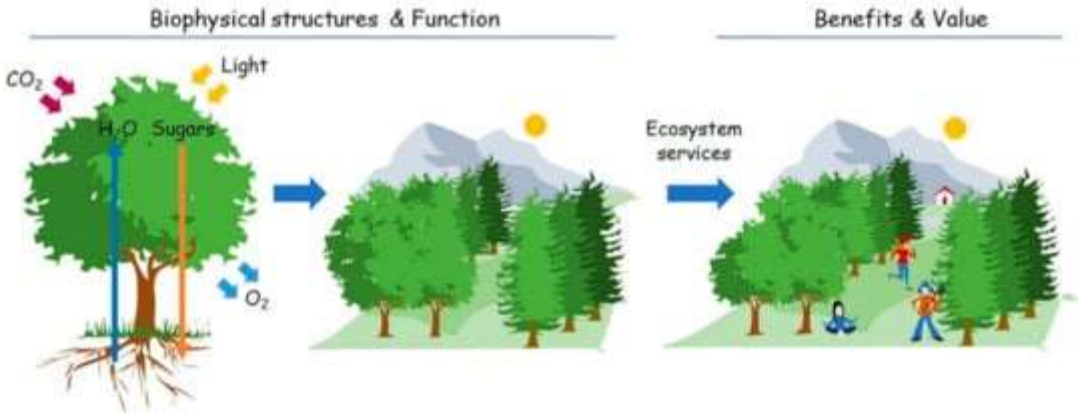

Figure ٢. Schematic illustration of the concept of ecosystem services (inspired by de Groot et al. representing benefits and values for human well-being, deriving from plants and/or biophysical structures and functions implemented in green spaces.

In this context, the scope of this paper is to provide an overview of the benefits and limitations of applying an ecosystem services approach in designing GI, focusing on green roofs and community gardens. Many roofs are characterized by impermeable surfaces that have a direct effect on UHI, due to their vulnerability to flooding and energy consumption, and indirect effects on emission gases. The gardens of private and public spaces, such as closed gardens with ornamental vegetation, are often planned without considering the direct interaction between vegetation species, environmental matrix and social activities and needs. This produces a poor efficiency in the use of urban space. Therefore, the integration of solutions with roofs and gardens can create GI which can represent strategies to

provide ecological and social multifunctionality to waterproofed surfaces connected to the buildings and low-exploited gardens being the main areas that affect dense urban settlements. Therefore, stimulating an inclusive design of ecosystem services can help to increase the well-being of the population and reduce the negative impacts of urbanization.

Moreover, the role of urban stressors or the urban context as a driving force of urban GI is not always well understood and employed in the planning of green spaces. This is partly due to a knowledge gap between different science disciplines that operate on different scales, from single processes of the plants (which focus on plant responses to environmental stresses affecting human well-being) to urban ecosystems (which focus on the biodiversity and urban space planning–human well-being relationship). This can create a paradox, as green spaces that are not adequately designed might not produce the expected effects.

The design of green spaces to increase ecosystem services needs to adapt different scientific disciplines at different ecological and urban scales, such as single plant interactions with the surrounding environmental matrix, or the relationship of the vegetation with the municipality (macro-scale), neighborhood (meso-scale) and individual buildings (micro-scale). Therefore, the green space has to be planned crossing various disciplines at a different survey scale to reduce the gap in the knowledge of single sectors or expertise.

Such an approach is based on a new transdisciplinary vision of urban ecosystem services that is not limited to the simple introduction of vegetation in urban areas but makes vegetation an active part of the urban space design, focusing on its effect on human well-being. Therefore, the intent here is to also provide a vision of the potential interactions between abiotic and biotic components that can affect individual plants in the urban context, as that can influence the ability of the vegetation to support the ecosystem services at different scales.

Materials and Methods

Following the illustration in **Figure ٢**, a review has been carried out to identify the main ecosystem services supported by urban green spaces with a focus on green roofs and urban community gardens. The aim is to show a link between ecological functions, ecosystem services and benefits for human health. This can be useful in the ecological urban planning of green spaces, such as mitigation actions focused on introducing specific human benefits to reduce urban land use impacts.

The review was performed following the procedure suggested by Moher et al. Specifically, the initial identification was done by searching for articles using the Scopus, Web of Science and Science Direct platforms in addition to the articles

known to the authors. The search was carried out in early 2020. The keywords searched were green infrastructure, ecosystem services, urban ecosystem services, green spaces, green roofs, urban garden, urban agriculture and community gardens. Moreover, to consider issues related to the connection between human health and not well-planned vegetation in urban areas, other keywords were used, such as environmental stressors, ecosystem disservices, vegetation stressors, abiotic stressors and secondary metabolites. Only papers written in the English language were considered. The screening of the outputs was manually performed to first remove duplicates, and then by checking the abstract, methodology and conclusions; only those fitting the topic of the paper were selected as eligible.

Results

1. Ecosystem Services Provided by Urban Green Spaces

Table 1 summarizes the main ecosystem services and related human benefits provided by urban green spaces. Specifically, urban green spaces reduce the heat-absorbing surface, increase solar protection, enhance cooling by shading and evapotranspiration (which help to mitigate the microclimate in the urban area), represent a sink for pollution, mask noise, filter out environmental pollutants by improving air quality and increase natural water retention ,Therefore, ecosystem services directly linked with urban green spaces are air filtration (gas regulation; carbon sequestration), micro-climate regulation, rainwater drainage (water regulation or stormwater management) and sewage treatment (waste treatment), the mitigation of disturbance regimes, with the increase of species diversity and composition, and cultural and educational values.

Table 1. Example of the main ecosystem services provided by green spaces in urban areas considering the TEEB classification (from 1 to 6 provisioning services; from 7 to 15 biological services; from 16 to 17 habitat services; and from 18 to 22 cultural and amenity services), with selected references useful for a further reading. The table was structured following the ecosystem services classification and the link between ecological processes and benefits.

Urban green spaces also decrease stress to visitors, increase property values and make urban areas more attractive. The interactions of people with green spaces promote psychological wellness, improve mood and attention and reduce stress and a

Table 1. Example of the main ecosystem services provided by green spaces in urban areas considering the TEEB classification (from 1 to 6 provisioning services; from 7 to 15 biological services; from 16 to 17 habitat services; and from 18 to 22 cultural and amenity services)

Ecological Processes	Ecosystem Services	Benefits
Energy flow from solar radiation into edible plants and animals	Food	Fruits Small scale subsistence
Influences on material and energy flow of the ecosystem in biogeochemical cycles (CO_2, ozone layer etc.)	Air quality regulation	Reduction of the respiratory and cardiovascular illnesses and allergies
Evapotranspiration	Climate regulation	Increase of shade and thermal comfort Reduction of heat-related illnesses Reduction of greenhouse gas emissions
Increase of surface albedo		
Flood prevention	Water treatment	Reduction of disturbance events Increasing run-off volumes Discharge rates
	Moderation of disturbance events	
Filtering, retention and storage water	Water regulation	
Accumulation of organic matter	Erosion prevention Maintenance of soil fertility	Maintenance of soil productivity
Living space suitable for wild plants and animals’	Pollination Biological control	Support biodiversity and genetic diversity

Ecological Processes	Ecosystem Services	Benefits
growth and reproduction	Maintenance of life cycles of migratory species Maintenance of genetic diversity	
Attractive landscape elements	Aesthetic information	Promotion of green lifestyles Increase of community engagement Provision of recreational green spaces Reduction of anxiety Positive effect on behavior Attentional restoration Reduction of mental fatigue Improvement in cognitive functions, and ability to perform tasks Aesthetic appreciation Increased inspiration Increased recreational activities Improve the quality of physical function and/or health
Diversity in the recreational use of the urban space	Opportunities for recreation and tourism	
Diversity in the values of cultural and artistic natural elements	Inspiration for culture, art, and design	
Diversity in the values of the spiritual and historic natural elements	Spiritual experience	
Diversity in the values of nature with scientific and educational implications	Information for cognitive development	

Urban green spaces also decrease stress to visitors, increase property values and make urban areas more attractive]. The interactions of people with green spaces promote psychological wellness, improve mood and attention and reduce stress and anxiety .Other services such as food production and erosion control could have lesser value in the urban

context, but may be considered relevant in metropolitan or regional areas Other services such as food production and erosion control could have lesser value in the urban context, but may be considered relevant in metropolitan or regional areas.

Positive effects of green space on the direct and indirect production of ecosystem services are still not well acknowledged and new perspectives can be opened by the implementation of new technologies. For instance, thermochemistry is a consolidated tool for detecting the release of contaminants from human activities over time and is applicable to tree sprawl that has been present for many years in the urban context, for example. Consequently, the urban ecosystem characterized by trees can offer important spatial-temporal information that is classifiable as services and benefits (not included in the TEEB classification) that can be incorporated into urban planning processes.

However, the provision of ecosystem services in public urban spaces is not sufficient to guarantee the quality of human life in growing cities. Private actions in private space need to take social responsibility; for example, by developing urban elements integrating functional biodiversity that is able to support ecosystem services to reduce the environmental impacts and increase human well-being. It is important to apply multifunctional land use actions to guarantee the simultaneous use of space for human activities such as housing, and ecosystem services production such as stormwater retention, energy conversion and habitat creation, involving both the public and private sectors.

2. Green Roofs

Green roofs represent a strategy to transform the sealed and solar radiation heat surfaces of a rooftop into multifunctional ecological spaces. In general, a green roof consists of vegetation, growth medium (substrate) and many other layers (drainage layer, waterproofing membrane etc.) to prevent negative effects of the interaction between vegetation and building structures and the healthiness of the building. Considering the thickness of the substrate and the type of vegetation that it can sustain, green roofs are classified as follows:

- "Extensive green roof" with a substrate thickness lower than 15 cm and a weight of up to 100 kg/m^2. It can be "single-course extensive", with a thickness of 10 cm and characterized mainly by grass vegetation, or "multi-course extensive", with a thickness of 15 cm and characterized by a mix of grass and shrubs;
- "Intensive green roof", with a thickness larger than 15 cm and an average weight of up to 1000 kg/m^2. It can be distinguished into "semi-

intensive", with a thickness from 20 cm to 30 cm, and "intensive", with a thickness larger than 30 cm.

The first type can support grass and shrubs, whereas the second can support shrubs and low trees.

Green roofs are natural-based solutions used in public and private buildings to increase ecosystem services with positive effects on energy consumption, urban heat island impacts and greenhouse gas generation in urban areas.

Table 2 summarizes the main ecosystem services and the related human benefits they provide.

Table 2. Ecosystem services and main environmental benefits provided by green roofs

Ecological Processes	Ecosystem Services	Benefits
Energy flow from solar radiation into edible plants and animals	Food	Fruits Small-scale subsistence
Influences on material and energy flow of the ecosystem in biogeochemical cycles (CO_2, ozone layer etc.)	Air quality regulation	Evacuation of air pollutants such as particulate matter, carbon dioxide, nitrogen dioxide, carbon monoxide and Sulphur dioxide Carbon sink Reduction of carbon footprints
Evapotranspiration	Climate regulation	Mitigation of heat flux into the building Reduction of energy demand for space climate conditioning Mitigations of the urban heat island effect Increase of thermal comfort
Increase of surface albedo		

Ecological Processes	Ecosystem Services	Benefits
		Reduction of urban energy consumption Reduction of carbon footprints Decrease of cooling and heating
Flood prevention Filtering, retention and storage water	Water treatment	Reduction of stormwater volume Decrease of the burden of the water treatment facilities Improvement of rainwater use
	Moderation of disturbance events	
	Regulation of water flows	
Living space suitable for wild plants and animals' growth and reproduction	Pollination Biological control Maintenance of life cycles of migratory species Maintenance of genetic diversity	Provision of habitat for insect and animals Implementation of vegetation biodiversity and improved landscape
Attractive landscape features	Aesthetic information	Relaxation and recreation Provision of recreational space Decrease of the noise pollution
Diversity in the recreational use of the urban space	Opportunities for recreation and tourism	
Diversity in the values of cultural and artistic natural elements	Inspiration for culture, art and design	

Ecological Processes	Ecosystem Services	Benefits
Diversity in the values of the spiritual and historic natural elements	Spiritual experience	
Diversity in the values of nature with scientific and educational implications	Information for cognitive development	

The intensive green roof can produce more ecosystem services and better sustain human health in the city with respect to extensive ones, emphasizing the use of public spaces and raising aesthetic expectations. However, it needs more building structural support, with costs related to its realization and maintenance. On the other hand, the extensive green roof presents less weight, does not require irrigation and has lower capital and maintenance costs; therefore, this is the most commonly used. It has also been proven to be effective in mitigating floods. Indeed, it was estimated that it has the capacity to reduce the stormwater volume from 50% to 60% of total annual precipitation.

Introducing vegetation onto the roof may help to increase biodiversity in urban areas. However, since green roofs are artificially created habitats with different environmental conditions with respect to natural conditions, such as high radiation and temperature, the use of autochthonous vegetation may be difficult to apply and not always feasible. Therefore, the use of green roofs has to disregard conservation actions that require the use of local vegetation because it could make this strategy ineffective and expensive. Different vegetation can be planned: officinal plants, aromatic plants, fruits etc. with the idea to create widespread urban gardens. This could be a characterizing element of a neighborhood and a point of attraction. In this perspective, green roofs could become enjoyable areas for social activities.

The green roof can mix built and green areas and the multifunctionality, in this case, represents the capacity to produce a stratified use of the urban space passing from the mono-functional use of specific urban space into integrating different functionalities that are capable of increasing ecological and social human well-being (an example is provided in **Figure ٣**). However, to incorporate green roof technology into urban strategies around the world, it is crucial to develop solutions that are able to reduce the costs of installation considering the roof weight limitations and appropriate management practices.

Figure ٣. Example of overbuilding (**left**) which would benefit from strategies using green roofs (**right**).

New Frontiers of Green Roofs

Recently, hybrid photovoltaic (PV) green roofs have been proposed as a new perspective of the natural-based solution in the green roof industry, since they enhance the electrical yield. The vegetation can reduce the surrounding temperature of PV panels, while at the same time being less exposed to the sun by PV panels. The increase in the energy efficiency of PV green roofs has been estimated to range from 1.3% to 8.3% compared to the traditional installation of PV systems.

In this perspective, an important example is represented by the solution introduced from the Korea Institute of Civil Engineering and Building Technology. It developed a “green-blue roof” that provides the possibility to introduce a green area and water storage in the roof in one solution. The roof is characterized by a vegetation layer on the water layer. This solution can store more water, decreasing the runoff and avoiding flash flooding effects, and can store the water that can be employed for domestic use.

The recent project idea proposed by Semeraro et al., starting from the surface of the existing roof-top, suggested the possibility of designing a green roof, such as a Phyto depuration system, for the grey water for a building with 26 flats. The idea started from the consideration that using the roof space to introduce the photovoltaic system is not sufficient to meet the energy needs for each apartment. On the other hand, the surface of the building is sufficient to create an engineered habitat provisioning ecosystem services, such as water treatment for the reuse of grey water in the building. The use of recycled water, for example for the toilet flush, can save 35% of clear water, as well as the benefits reported in **Table 2**. This can reduce the use of clear water in those geographical regions with a scarcity of

water, mainly in the summer. The main differences from the green-blue roof and the green roof for water treatment are in the choice of vegetation, in the latter case with selected vegetation that is able to support the phytoremediation.

These extreme solutions can be reconsidered when analyzing natural resource availability in the future. For instance, the World Resources Institute estimated that there will be a reduction in water availability for human use in many parts of the world by 2050. These events have not happened to date, although the first real water crisis occurred in Cape Town between 2017 and 2018, when the population lived on 50 liters of water per day; the inhabitants were forced to adapt their daily habits, and the main security problem was water theft.

3. Community Gardens

The concept of urban community gardens is generally linked to the practice of growing crops in urban and peri-urban areas. It provides food products, as well as aromatic and medicinal herbs, ornamental plants etc. Urban agriculture does not have a fixed dimension or preferable urban space but can be performed in any shape and in different places, such as brownfield sites, roofs, greenfield sites (i.e., parks, gardens) etc. In the urban context, agriculture can represent a multifunctional land-use strategy, because it can integrate agriculture activities with social and ecological function purposes.

In the context of biodiversity loss, food insecurity and social alienation due to urbanization, urban community gardens can represent sites for urban residents to reconnect with nature in a social environment creating common spaces and new forms of community interaction and corporations. Ecosystem services and related benefits for human well-being are summarized in **Table 3**.

Table 3. Ecosystem services and main environmental benefits provided by urban community gardens, with selected references useful for a further reading. See **Table 1** for details.

Ecological Processes	Ecosystem Services	Benefits
Energy flow from solar radiation into edible plants and animals	Food	Fruits Small-scale subsistence Food security Raising awareness of the inhabitants Food production and processing Energy consumption and production
Influences on Material and energy flow of the ecosystem in biogeochemical cycles (CO_2, ozone layer etc.)	Air quality regulation	Evacuation of air pollutants such as particulate matter, carbon dioxide, nitrogen dioxide, carbon monoxide and Sulphur dioxide Carbon sink

Ecological Processes	Ecosystem Services	Benefits
		Reduction of carbon footprints
Evapotranspiration	Climate regulation	Mitigation of the urban heat island effect Increase of thermal comfort Reduction of urban energy consumption Reduction of carbon footprints linked to the food Decrease of cooling and heating loads Reduction of gas emissions for food supplying
Increase of surface albedo		
	Water treatment	

Ecological Processes	Ecosystem Services	Benefits
Flood prevention Filtering, retention and storage water	Moderation of extreme events	Reduction in stormwater volume Stormwater retention
	Regulation of water flows	
Accumulation of organic matter	Erosion prevention Maintenance of soil fertility	Retention of soil nutrients Organic waste and production of compost
Living space suitable for wild plants and animals' growth and reproduction	Pollination Biological Maintenance of life cycles of migratory species Maintenance of genetic diversity	Provision of habitat for insect and animals Implementation of vegetation biodiversity Improvement of landscape agrobiodiversity of plants grown

Ecological Processes	Ecosystem Services	Benefits
Attractive landscape features	Aesthetic information	Relaxation and recreation Provision of recreational space with safety and security perception Horticultural practices and maintenance Community support, funding and volunteer management Cultivating psychological well-being Constructing Community Building social bonds Breaking down social barriers Cleaning up vacant lots Reclaiming the city Cultural identity
Diversity in the recreational use of the urban space	Opportunities for recreation and tourism	
Diversity in the values of cultural and artistic natural elements	Inspiration for culture, art and design	
Diversity in the values of the spiritual and historic natural elements	Spiritual experience	
Diversity in the values of nature with scientific and educational implications	Information for cognitive development	

Specifically, urban community gardens contribute to ecological sustainability by providing agroecosystems that can improve soil quality and reduce soil erosion rainwater runoff. They can also impact on climate change/urban microclimates and stimulate the productive reuse of urban organic waste, thus reducing the urban resource footprint. The social and economic goods and benefits of community gardens include increasing access to fresh fruits and vegetables, building community ties and community economic revitalization, and regenerating vacant, neglected, or disturbed urban spaces. The community gardens are useful for promoting a sense of individual well-being and health in urban areas where there is social isolation and cultural diversity, promoting cross-cultural communication. Moreover, community gardens can improve cultural and educational ecosystem services by connecting people to the cycles of the earth, biodiversity and natural processes and improving people's practical gardening skills.

Community gardens can reinforce people's relations using food production, such as the urban activity of social and cultural connections, by bringing together diverse groups of people, stimulating the sharing of agricultural and culinary knowledge, and creating stronger bonds in the community. Community gardens are also considered "participatory landscapes" of resistance to racism and marginalization through collective work and self-reliance.

New Frontiers for Urban Community Gardens

The new frontiers for urban community gardens are to combine food and urban design to produce material pushed from strong synergies between waste production in the building and the capacity of urban community gardens to recycle urban waste, such as organic matter, wastewater and waste heat. This combination can develop an urban system that is able to reuse residential or industrial waste resources with benefits including food production for local consumption and the reduction of the consumption of natural resources. This strategy can be achieved by creating a low or even "no-input system" around a sustainable food infrastructure that produces a "closed-loop entity" in terms of waste recycling that is able to reduce pollution. The connection of urban needs, ecological and productive activities at the scale of the building is a strong ambition that can support the sustainability of the cities, reducing the environmental impacts generated by urban waste.

Urban community gardens could also be used as a strategy to provide a temporary new functionality to spaces which are no longer able to meet current social and economic needs (those areas are often fenced and prey to devastation and misuse, such as illegal housing and drug dealing). For instance, in Baltimore, the urban community gardens began as vacant spaces that were considered "crime-

ridden eyesores". Residents worked together to change the status of the neighborhoods, transforming these abandoned spaces into community gardens, clearing the lots of rubble, mowing the weeds and eliminating trash and drugs. The residents stated that community gardens made their neighborhoods safer and more stable.

4. Counterbalancing Ecosystem Disservices

Urban ecosystems can support functions with negative effects for human well-being called ecosystem disservices (some of those are summarized in **Table 4**). For example, trees can cause problems such as allergies generated by pollens, leaves blocking stormwater drains, roots cracking pavements, trees falling along avenues, causing material damage to things and people, and residents' fearing increased crime. These can produce several urban issues related to safety and security, health, mobility and the environment. Specifically, green roofs and urban community gardens can have negative effects on human health, therefore creating ecosystem disservices if they are not adequately designed. For example, in urban areas nitrogen, phosphorus, potassium and other nutrients may accumulate in garden soils due to the indiscriminate application of fertilizers, polluting urban stormwater runoff or the emission of exhaust gases of different natures.

Table 4. Examples of disservices provided by urban GI (modified from Gómez-Baggethun and Barton and von Döhren and Haase)

Ecosystem Functions	Disservices	Examples
Photosynthesis	Air quality problems	Emission of the volatile organic compounds (VOCs) Concentrations of particulate matter (PM)
Vegetation biomass growth	Blockage of landscape view	Limit of the scenic views by trees located in front of the windows of the buildings

Ecosystem Functions	Disservices	Examples
Flow of floral gametes such as pollen	Allergies and/or intoxication	Allergic reactions
Plants aging	Accidents	Break up of trees and branches falling in roads causing damage of matter and people
Dense development of the plants	Fear and stress	Dark green areas perceived unsafe
Decomposition and biomass root fixation	Damages to infrastructure	Breaking up of pavements
Habitat provision for animal species	Habitat competition with humans Abundance of undesired species Introduction of invasive species Contamination of crops with pathogenic organisms or residues of agrochemicals and other pollutants through contaminated soil, water or air	Animals/insects perceived as scary, unpleasant and/or disgusting Animal species can be vectors of diseases (e.g., avian influenza, rabies) Population development of invasive species

Ecosystem Functions	Disservices	Examples
Water supply	Decrease in water quality/quantity inappropriate drawing of water sources threat of local water sources or underground water contamination due to uncontrolled treatment of fertilizers, pesticides or rich manure from animals	Amount of water used for plant growth Water pollution
Soil erosion	Poor environmental conditions of land, further depletion of soil quality	Use of fertilizers that can alter the quality of the soil

The distinction between ecosystem services and disservices is not absolute, but highly dependent on the combination of ecological processes that characterize the vegetation, the purpose of the green spaces and the application of the ecosystem services design. Moreover, ecosystem services may be affected by several factors, such as age, education, cultural values, attitudes, health conditions, knowledge of the person making the evaluation and context of reference. Therefore, a choice of plant species that does not consider the context and the stakeholders involved could produce unintentional results.

For example, hemp can be used in agricultural activities to produce raw materials for different uses, therapeutic oils etc. Hemp also has a high capacity to absorb heavy metals from the soil. The absorption of soil and air pollutants represents an ecosystem service, since the ability of some plant species—including edible species—to efficiently absorb and accumulate pollutants such as heavy metals can be successfully applicable in planning specific green urban areas for phytoremediation. However, for agricultural purposes, the absorption of heavy metals can be considered a disservice because it could lead to unusable products if they have high concentrations of metals.

Planning Community Gardens to Avoid Disservices

The benefits of urban community gardens are mainly limited to crop species with both compact growth and rapid cycling. Generally, the horticultural species suggested for urban community gardens are lettuce and leafy green vegetables. Other vegetables of eligibility are carrots, zucchini, peppers, tomatoes and onions, but other species can be chosen based on specific secondary metabolites that are important for human health. Plant sources of carbohydrates (e.g., potatoes) and proteins (e.g., legumes) can also be included in planning urban gardens. In planning urban gardens, a balance of pros and cons should be considered (e.g., the cultivated vegetables should be safe and nutritious). The main factors impacting on the agricultural urban space design are: exposure to pollutants (type, concentration, distance from the source, length of exposure), meteorological conditions, plant species with reduced capacity of accumulation of toxic substances and soil properties (**Figure 3**). For example, the exposure to pollutants such as SO_2 (Sulphur dioxide), NOx (nitrogen oxides such as nitrite, nitrate etc.) or a variety of hydrocarbons can cause accumulation as surface deposits either in the soil or on the leafy parts of plants. Exposed leaves start to lose their color and turn brown; eventually, plant growth will be severely impaired.

Figure 3. Representation of pollution stress for the vegetation employed in urban community gardens. An inadequate design of GI can influence the quality of urban green spaces due to the presence/production of environmental stressors and the related capacity to provide ecosystem services.

Furthermore, excessive lead (Pb) accumulation in plant tissues severely impacts important physiological and biochemical functions, resulting in altered uptake of microelements, and stomatal closure inducing a deficient CO_2 uptake. Leafy, tuberous vegetables and beans tend to accumulate higher concentrations of lead than cereals and fruit crops such as tomatoes. For example, Zhou et al. investigated the heavy metal accumulation in different vegetable species to assess the human health risks derived from the consumption of these vegetables. The highest concentration of heavy metals was reported in leafy vegetables, more than stalk vegetables, root vegetables, solanaceous species and legumes, whereas the lowest accumulator was melon, indicating that these species are more suitable for cultivation on urban soil.

Some ecosystem disservices can be due to the interaction of plant-environmental stressors (**Figure 3**). In fact, the exposure to environmental and/or abiotic stresses is an important stimulus to produce a number of "chemical responses" in plants, which are the direct biochemical products of their metabolism. Examples of metabolites produced by plants as a defense response with protective and ecological functions, but potentially toxic or anti-nutrient for animals and humans, are some alkaloids, cyanogenic glucosides or some organic

acids such as oxalates. For example, cyanogenic glucosides are chemical compounds produced by plants for self-defense from stressors, whose ingestion in high amounts can cause intoxication in animals and humans. However, they are normally found in several plants, most of them with edible parts, such as almonds, apples, apricot, plums and peaches, particularly in the seeds of such fruits. The cyanogenic glucosides can be produced following nitrogen supply of soil (i.e., with nitrogenous fertilizers) and stressful growth conditions induced by environmental factors, such as light, temperature and drought. Therefore, it would be important to exclude the use of edible plants that are strongly affected by this interaction in common gardens in very polluted neighborhoods or streets.

Therefore, ecosystem disservices due to the interaction of plant-environmental stressors can create a paradox, because if green spaces are not adequately designed in relation to the context, they can also have negative effects on the quality of the green space and the capacity to produce services.

4. Discussion

An analysis of the existing literature highlights that green roofs and community gardens are a good strategy for developing ecosystem services such as air quality and climate regulation, the mitigation of extreme events and regulation of water flows, thus reducing the negative impacts produced by the impervious surfaces that mainly causes UHI and flooding events. Green roofs and community gardens can also promote vegetation biodiversity, create biodiversity connections between habitats for insects and animals (**Figure 4**), improve mental and physical health etc. In growing cities, where there is the presence of different cultures, community gardens seem to provide an important contribution to the reduction of racism and social problems.

Figure 4. Example of how simple holm oak plants positioned on the balcony can be used by bees for foraging.

However, the design of GI must also consider appropriate plants based on the purpose to be achieved and the problem to be addressed, as well as the energy and material flow that can arise between plants and the surrounding environment. Such energy and material flows characterize the ecological functions that are the basis of ecosystem services and disservices which may produce benefits or negative effects on human well-being, respectively. In this sense, vegetation should not be considered a simple element of street furniture but as an element interacting with the environment.

Currently, the application of green roofs and community gardens is sporadic and often linked to single buildings and private actions. There are some examples around the world of the applications combining green roofs and community gardens with grey infrastructures or examples linked with specific social and economic activities

((Figure 5).

Figure 5. Images showing the situation of some famous green roof (base maps from Google Maps).

Despite the consolidated scientific knowledge on the enormous benefits that GI can produce if appropriately designed, in rapidly growing cities, planners and decision-makers do not pay enough attention to its development. For example, the industrial sector still has a poor appreciation of the benefits of green technologies. The industrial area represents a built environment located on the boundary of cities or, in some cases, absorbed by cities, and represents a big impermeabilization of the urban surface compared to the dimension of cities. **Figure 5** shows that such areas present few green areas in many cities. As for green roof technologies, the industrial sector is probably scared off by the initial cost of installation compared to the standard roof construction, not considering the long-term benefits in saving energy and management cost.

Many countries, such as Germany, Canada and the United States, have forecast incentives to push the use of green technologies such as green roofs. However, these incentives cannot represent the solution, because in their absence, companies will lose interest in adopting green technologies. Furthermore, the incentives can alter the market because the companies can adopt the solutions indicated by the incentives, and not just the best solution for the problem at hand. Thus, the incentives could produce an inefficient result or solutions that are not desirable. Furthermore, they do not solve the problem of the absence of green areas in already existing industrial areas, which currently occupy the main urban area, and therefore, influence the generation of impacts on human health. Indeed, in the red area of **Figure 6**, it is possible to note the low presence of green spaces and the absence of green roofs on the whole. The use of green technologies in the industrial sector should instead be driven by a sustainable approach for industrial processes. The land use changes associated with industrialized areas must produce a mutual advantage for ecological, social and economic aspects. Therefore, it is important to develop strategies and green solutions that can represent an investment for the companies to improve management business processes incorporating ecosystem services for reducing the cost and producing benefits for local populations. In this regard, it would be useful to develop economic tools that make it possible to quantify the added value produced by ecosystem services for companies. There have been different attempts to develop toolkits to estimate the monetary value of GI, but they are still under development.

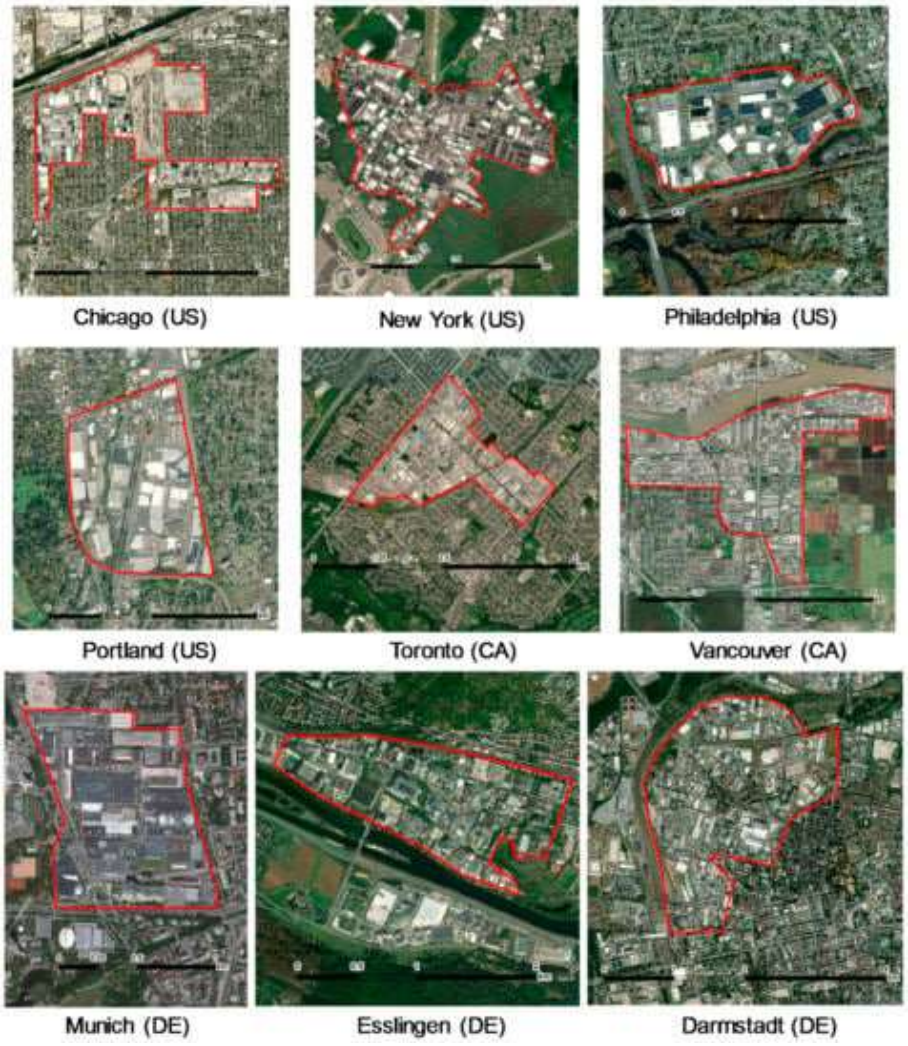

Figure 6. Images showing the situation of the green spaces in industrial areas in cities where economic incentives for the installation of green roofs have been developed (base maps from Bing Maps).

It is clear that planning GI must be implemented through a transdisciplinary approach, which involves different experts from different disciplines, such as biologists who operate at different ecological scales ranging from single plants to the entire ecosystem, and planners who can operate at different urban scales, ranging from micro-, to meso- and macro-scales. It is crucial to generate interactions and the exchange of ideas between different disciplines through a multi-scale approach to maximize the benefits. Moreover, the planning must involve both institutional decision-makers and individual stakeholders who work on the regeneration of cities to develop an awareness of the social, ecological and economic benefits provided by GI. Planners have to consider green spaces as a social ecological system where there is a strong interaction between environmental

conditions, economic purposes and social needs to identify ecosystem services issues. The ecological planning of GI in an urban space is not trivial but needs to consider specific questions following a specific framework, which can be seen in **Figure 7**.

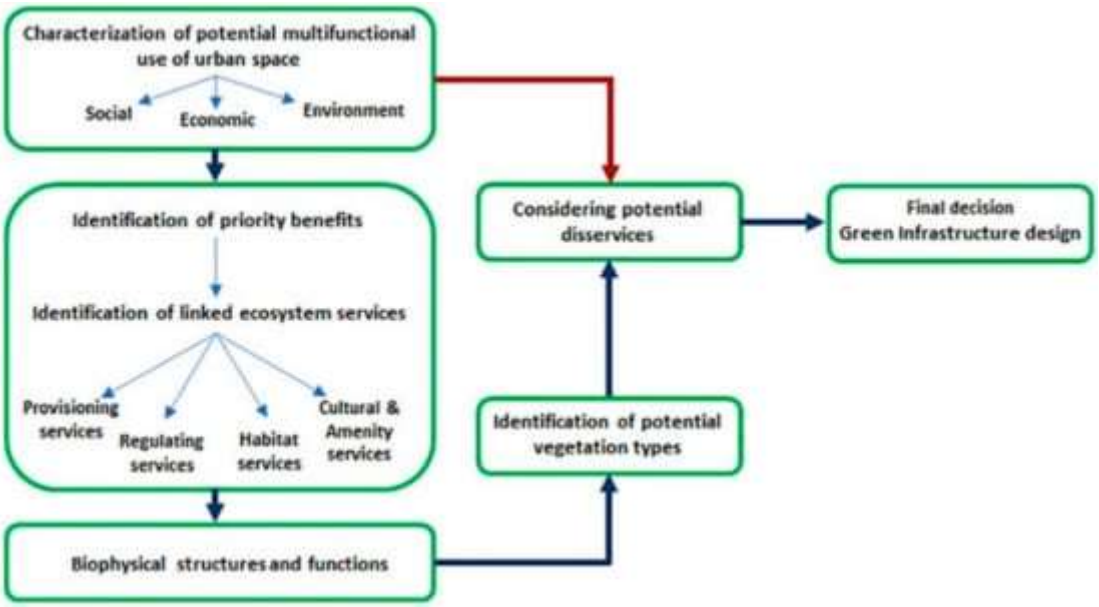

Figure 7. Schematic flow chart tailored to the ecological planning of green infrastructure.

6. Maintaining and Managing Urban Green Space

The management of urban green spaces concerns existing urban open spaces such as public parks, playgrounds and residential green spaces. It involves many different actors and organizations and its practice is of importance for the sustainable development of cities. As a research field, it needs further theoretical development and common definitions. For example, the central term ‘management’ is seldom defined in the relevant literature regarding an urban landscape context, and public participation in management processes is unusual. This paper introduces urban landscape management as an overarching concept that brings together knowledge

about management of urban landscapes from fields such as urban forestry, park management and landscape planning. Based on a literature review, a common understanding of management in an urban landscape context is proposed, including organizational and strategic aspects of managerial activities. Our approach is that urban landscapes are ultimately managed to provide user benefits. Urban landscape management can be viewed as a complex process that includes a number of different actors, elements and relationships, mutually affecting each other. This view supports future studies of urban landscape management and its role in sustainable urban development.

The recent increase in urban populations (United Nations, 2009), expansion of urban areas (UN-Habitat, 2009) and approaches to developing existing cities through compact city concepts has put pressure on existing urban and peri-urban landscape structures. The importance of these structures is emphasized through the increased focus on sustainable urban development and related green solutions such as local and global climate regulation. The management of existing landscape structures can therefore be expected to be of particular importance in the present and future development of urban areas. Management and governance of green space were identified by James et al. (2009) as aspects of sustainable urban development that need more understanding and development. This is also acknowledged in the political treaty of the European landscape convention (Council of Europe, 2000), where green spaces management is defined as:

… action, from a perspective of sustainable development, to ensure the regular upkeep of a landscape, so as to guide and harmonies changes which are brought about by social, economic and environmental processes.

Green spaces management is thus acknowledged to be important for sustainable development. However, in order to identify ways in which it can support such development, we first need to build up a comprehensive and shared understanding of what landscape management means in an urban context.

Urban green spaces management is introduced here as an overarching concept for the knowledge area that concerns the management of, mainly green, open space in urban landscapes, an area in need of development and definition. It is closely related to fields such as landscape planning, urban forestry and park management. These separate fields can provide

knowledge about the actors, organizations and processes related to the management of certain kinds of open spaces, both green and other types. However, in order to achieve holistic and sustainable development, there is also a need to consider the whole urban landscape, including all open and green spaces, and its management as one and the same knowledge area. Similarly, Bergstrom et al. (2006) argue the need for integrative approaches to urban landscape management to increase cross-scale interactions in the development of green areas. The terms ‘urban’ and ‘urban landscape’ can be defined in many ways. Here they simply refer to the fact that the landscapes concerned are built environments and not rural or natural, i.e. that we are focusing on open space in the urban landscape context. The line between what is urban and rural in this context can be rather fluid, but we do not expand on this issue.

The lack of an effective theoretical basis and common models concerning the management of, e.g. urban green space has been identified as a weakness. One central issue is what the term management refers to in relation to urban landscapes. Within the professional discipline of landscape architecture, management is commonly distinguished from planning and design (Marshall, 1981, Rodiek, 2006, ECLAS, 2008). One way of describing the difference is to regard planning and design as being about defining new structures in the landscape, but on different scales, while management mainly deals with existing landscape structures. However, management can still include many different activities. It can encompass development and maintenance and refer to activities connected to such aims, but this is not always the case. In fact, the meaning of management in relation to urban landscapes varies in previous studies. Moreover, what is meant by management is seldom defined. According to the European landscape convention (Council of Europe, 2000) management should, just as planning and design, involve procedures to ensure public participation. Today, in the planning and to some extent also design of the urban landscape, it has become common to have some kind of public participation, but this is still unusual in the practice of landscape management. If the convention is to be realized, we will therefore have to alter the meaning of ‘management’ in a way that needs careful prior discussion.

7. Challenges in Urban Green Space Management

The compact city approach has gained global impact as a planning approach for sustainable development in areas with increasing urban population. Through densification and compact building, the approach aims to counteract negative effects of urban sprawl in terms of ineffective land-use and related environmental problems. In spite of its benefits various problems and challenges are associated with implementing the compact city approach. This review looks at the effects of urban densification and compact city development on urban green space and its planning. It identifies problems, challenges and strategies of urban green space planning during densification processes. Findings confirm that urban densification processes, including consolidation and infill development, can pose a threat to urban green space. However, the literature on the compact city approach often lacks specific suggestions for urban green space conservation and planning. Provision of urban green space in compact city environments and during densification processes is described as a major challenge. Loss of private urban green space rarely seems offset by provision of more public green space. Several ways are identified to deal with these challenges, while also highlighting research gaps, e.g., as to how loss of green space quantity can be offset by increased green space quality.

Worldwide, the percentage of people living in urban areas will increase from 50% in 2010 to nearly 70% by 2050 (United Nations, 2013). This will result in expansion and/or densification of urbanized areas. As migration to urban areas is ongoing globally, the need for sustainable urban development is becoming increasingly important. In an urban context this implies creation of both resource efficient systems and good, engaging urban design for attractive cities with good quality of life. Urban sustainability has been related to urban form and alternative, more sustainable urban forms than urban sprawl have been suggested. Urban sprawl can be defined as urban development with low-density housing, both residential and commercial, segregated land-use, high level of automobile use combined with lack of public transport, which is in high demand for land. Related problems are non-efficient use of resources e.g., of land and energy causing a larger urban footprint, loss of biodiversity, environmental problems, and social inequalities. Even urban areas with a declining population can expand in terms of area. Alternative, more sustainable urban forms include neo-traditional development, urban

containment, the compact city and the eco-city, and in particular compact or dense city form, since it aims to counteract the negative effects of urban expansion and sprawl. The ‘compact city’ is characterized by high density housing, mixed use, well-functioning public transport (transit oriented development) and promotion of cycling and walking.

Nevertheless, negative effects of certain aspects of city densification are increasingly evident (e.g., crowding, lower living quality) and certain positive characteristics assigned to the dense city are being questioned

. One issue identified is the lack of urban green space in densified urban areas and the removal of green space when densifying city areas

Planning and management of urban green space is a crucial issue in the context of the compact city concept, as these spaces provide essential benefits to urban dwellers, while also offering crucial habitat for wildlife. Green space multifunctionality has often been emphasized as relating to recreation, social interaction, aesthetics, cultural heritage and ecological functions. Many of these functions, which are seen as important for sustainable urban development, have to be realized within limited space. The concept of ecosystem services, embodying the human benefits derived from ecosystem functions, has also been applied to urban green spaces, water and climate regulation, carbon storage and stormwater regulation are important examples. They are also crucial for biodiversity conservation within urban areas.

There is also an increasing interest in the perception of urban nature by humans, relationships between biodiversity and health benefits and generally in human–environment interactions. Cultural ecosystem services such as recreation, aesthetics and cultural heritage, are often prioritized in planning, design and management of urban green spaces. Urban green spaces offer possibilities for restoration, physical activity, and social interaction and community attachment. Because of the considerable health benefits urban green space provide access to green space has been a central issue in green space research in relation to human well-being.

Provisioning services of urban green space have gained increasing attention over last decade, e.g., concerning urban agriculture and community gardening. The importance of studying interrelations, especially synergies of ecosystem services or functions has been highlighted.

Provision of vital multiple ecosystem services makes urban green space a fundamental part of sustainable urban development.

As urban sprawl can threaten countryside areas, densification processes in town and cities can potentially threaten urban green spaces. There is evidence that urban green space is under pressure due to densification processes such as infill development. Green space planning and management can be very challenging, especially in city areas under densification, since important ecosystem services are supposed to be delivered by limited green spaces. Therefore existing studies need to be reviewed that have looked at urban green space planning in cities undergoing densification.

8. Urban Green Space and Mental Health

Rates of living alone, especially in more urbanized areas, are increasing across many industrialized countries, with associated increases in feelings of loneliness and poorer mental health. Recent studies have suggested that access to nature (e.g. parks and green spaces) can reduce the stressors associated with loneliness, partly through providing opportunities to nurture personal relationships (relational restoration) and engage in normative community activities (collective restoration). Such associations might vary across different household compositions and socio-demographic or geographical characteristics, but these have not been thoroughly tested. Using data collected across 18 countries/territories in 2017–2018, we grouped urban respondents into those living alone (n = 2062) and those living with a partner (n = 6218). Using multigroup path modelling, we tested whether the associations between neighborhood greenspace coverage (1-km-buffer from home) and mental health are sequentially mediated by: (a) visits to greenspace; and subsequently (b) relationship and/or community satisfaction, as operationalization of relational and collective restoration, respectively. We also tested whether any indirect associations varied among subgroups of respondents living alone. Analyses showed that visiting green space was associated with greater mental well-being and marginally lower odds of using anxiety/depression medication use indirectly, mediated via both relationship and community satisfaction. These indirect associations were equally strong among respondents living alone and those living with a partner. Neighborhood green space was, additionally, associated with more visits among respondents living with a partner, whereas among those living alone, this was sensitive to the green space metric. Within subgroups of people living alone, few overall differences were found. Some indirect pathways were,

nevertheless, stronger in males, under 60-year-olds, those with no financial strain, and residents in warmer climates. In conclusion, supporting those living alone, as well as those living with a partner, to more frequently access their local greenspaces could help improve mental health via promoting relational and collective restore

The number of people living alone is increasing across OECD countries, especially in northern Europe (Eurostat, 2022b, Organization for Economic Co-operation and Development, 2016)). Between 2009 and 2021, the number of one-person households without children increased by 28.5% in the European Union; and the increase was evident in all adult age groups, and for both females and males (Eurostat, 2022b).

Although living alone is not equivalent to being lonely, living alone increases the risk of experiencing social adversities such as social isolation and loneliness (as well as having poor physical and mental health . The detrimental effects of loneliness, in particular, have been recognized as major risks for coronary heart disease and premature mortality. Measures to reduce loneliness and social isolation are currently being developed in academic research, and implemented at the policy level (e.g. the 'loneliness strategy' in the United Kingdom;
Single-person households tend to be more common in cities compared with rural areas in almost all countries in the European Union. In urban areas, availability of accessible green spaces such as parks and forests is often worse than in rural areas. Green spaces, nevertheless, have been consistently shown to benefit mental and physical health. These associations might be particularly important in urban areas at least partly due to green areas' potential role in mitigating urban environmental stressors such as air pollution, noise, and the urban heat island effect. A recent systematic review, however, found the evidence to support this effect modification by urbanicity overall mixed. Nevertheless, mental health was not included as an outcome in this review, although it is one of the most consistently linked health outcomes in relation to green space and issues with mental health tend to be more prevalent in urban areas.
Most studies examining green space in relation to mental health have assessed green space exposure by geospatial metrics linked with residential location but lacked information on actual exposure such as visits to or views of green space. Earlier theoretical and empirical work have suggested that merely viewing green space or other types of natural environments is beneficial for mood and health, and this effect has also been demonstrated in experimental studies on short-term mood outcomes. Recent evidence has, nevertheless, highlighted that in everyday life, regular visits seem to be the key type of exposure associated with mental health

compared with indicators reflecting neighborhood green space or viewing green space. Furthermore, the association between green space exposure and health has overall shown heterogeneity in different demographic and socio-economic subgroups. One of the identified demographic groups that have been shown to visit green spaces less often is those who live alone or who are not married, even when controlling for the amount of neighborhood green space.

While there are a number of potential mechanisms linking visits to green space with mental health, recent theoretical and empirical advances have stressed social restoration processes. Theoretically, two types of processes have been identified. First, relational restoration theory proposes that green spaces can strengthen the quality of interpersonal relationships by providing avenues to meet one's current restoration needs on a regular basis. This can mean not only spending time with people with whom one has developed personal relationships (such as family, friends, colleagues and neighbors), by providing an opportunity to nurture those relationships, but also spending time alone in a restorative setting, by providing restoration for personal needs which may, in turn, positively reflect on personal relationships. Second, collective restoration theory (CRT), suggests that restorative experiences can spread from individuals to their wider communities by, for example, positive emotional contagion. This might occur, for instance, in situations where people unknown to each other have pleasant encounters in public places such as parks, or merely witness others engaging in similar activities at similar times, both leading to a collective sense of trust through positive informal interactions and/or shared normative behavior's.

Both RRT and CRT (jointly referred to as 'social restoration processes' hereon) highlight the idea that the restorative benefits of being in contact with natural environments can spread from individuals to their personal relationships and communities more widely. The majority of previous studies focusing on social aspects of restoration in relation to green space exposure have, nevertheless, been conducted at the individual level, often assessing loneliness as the outcome. Loneliness can entail social, emotional, and existential aspects. Theoretically, both relational and collective restoration experiences alleviate loneliness, which can consequently lead to better mental health.

Supporting the idea that social restoration processes take place in green areas, found that momentary feelings of loneliness tend to be less common when visiting green spaces and other natural areas as opposed to densely populated or overcrowded locations. Evidence on the population level has supported this finding by showing that loneliness is less common in greener neighborhoods. What is more, recent longitudinal evidence suggests that the protective effect of green space on loneliness may be particularly pronounced among people living alone.

However, empirical studies assessing relational and collective restoration are relatively scarce, and mainly rely on small experimental or geographically restricted samples. Furthermore, studies have rarely accounted for household composition, although people living alone tend to live in more urbanized areas, at least in Europe, and experience social isolation more commonly than those who do not live alone. Regarding different household compositions, having a stable intimate partner, often defined by being married or cohabiting, has been identified as a one of the factors that are consistently associated with better mental health. Despite the results showing that living alone is, on average, associated with a lower level of mental health, people living alone have shown high heterogeneity in terms of perceived mental and general health. Some of these health disparities among people living alone can be explained by socio-demographic factors such as gender and age, with male gender and mid-adulthood typically associated with worse health status. Similarly, there are large cross-national variations in not only the prevalence of living alone and mental health symptoms, but also urban green space availability and associated nature-based recreation patterns . Hence the way these factors are connected might also vary by geographical location.

The present study aimed to address these research gaps in the topic of social restoration processes (i.e. small sample sizes, lack of geographical variation, and no information on household composition or visits to green space), and examine the potential mediating role of social restoration processes in the mental health-green space association. With harmonized samples from 18 countries/territories around the world (including 14 in Europe), we assessed the following three research questions:

- 1)For people living alone in urban areas, is the relationship between exposure to green space and mental health mediated by relationship satisfaction (suggestive of relational restoration), and community satisfaction (suggestive of collective restoration)?
- 2)Are these mediation pathways different for people who live with a partner?
- 3)Are these mediation pathways different among subgroups of people living alone (based on gender, age, financial strain, and geographical location)?

Furthermore, we considered both neighborhood green space and visits to green space, with the assumption that greater coverage of residential greenery is associated with more visits, but visits are required to experience relational and collective restoration (illustrated in Fig. 8). These patterns were assessed with path modelling, suitable for assessing complex interconnected relationships and specifically recommended to be used in the assessment of mechanisms linking green space and health.

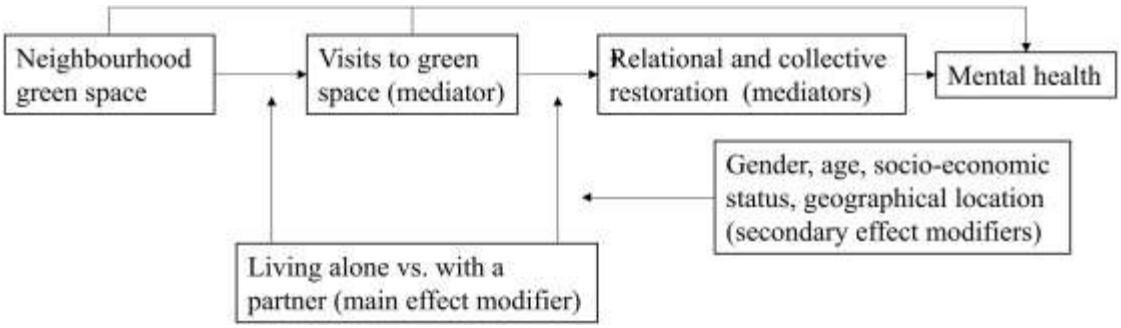

Fig. 8. Theoretical model linking exposure to green space to mental health via social restoration processes.

Materials and methods

1. Dataset

The cross-sectional Blue Health International Survey was collected in four waves, covering all seasons, during 2017–2018, from 18 different countries/territories: Queensland (Australia), Bulgaria, California (USA), Canada, Czech Republic, Estonia, Finland, France, Germany, Greece, Hong Kong (China), Ireland, Italy, Netherlands, Portugal, UK, Spain, and Sweden. YouGov collected the data using online participant panels in each country/territory and ensured representative quota samples from each country/territory, typically based on gender, age and geographical region, across the four seasonal waves. Recruitment emails were sent gradually throughout the data collection period, until approximately 250 responses per wave/country were obtained. More details on the data collection procedure are documented in Elliott and White (2020).

To link the responses with area-level geospatial information, the respondents were asked to identify their current home location by placing a pin on a Google Maps API. The coordinates of the home locations were subsequently rounded to three decimal degrees to minimize the risk of individual identification while maintaining good precision. Exact details on the survey procedure are provided in the technical report (Elliott and White, 2020).

The original sample consisted of 18 838 cases. After excluding potentially inattentive respondents ("straight liners", n = 202) and possibly unreliable home locations (n = 1186; Elliott and White, 2020), we restricted the sample to those living in urban areas, defined as living within a 1 km^2 grid cell that had a population density of >150 inhabitants (Dijkstra and Poelman, 2014; Elliott and White, 2020). The urban sample consisted of n = 11 390 cases, of whom n = 8460 were included in the main analyses based on their living alone status (that is, n = 2549 cases who live with people other than their partner excluded; see the next section). Sensitivity analysis was run with a higher population density cut-off at

>300 inhabitants to identify the sample living in more densely populated areas (Dijkstra and Poelman, 2014). The measure for population density was obtained from Gridded Population of the World (Version 4), adjusted to match the 2015 Revision of the United Nation's World Population Prospects country-level totals (Center for International Earth Science Information Network, 2017).
The survey procedure conformed to the ethical principles of the Declaration of Helsinki, and was approved by the University of Exeter Medical School Research Ethics Committee (Ref: Aug16/B/099).

2. Measures

2.1. Living alone versus with a partner (main effect modifier)

Household type was based on both household size and marital status. *Living alone* was defined as a household size of one person and not being married/cohabiting/in common law marriage by marital status. *Living with a partner* was defined as a household size of two or more people and being married/cohabiting/in common-law partnership by marital status (thus, these households may or may not have included children). Those who chose 'prefer not to say' for their marital status were excluded.
Respondents *living with people other than their partner*, that is, whose household size was two or more and who were single/divorced/widowed/other by their marital status, were expectedly heterogenous group potentially containing e.g. single parents and adults living with roommates or their aging parents, but who nevertheless likely lack continuous presence of a stable partner. Accordingly, to ease interpretation of the results, our primary interest was in the potential differences between the groups 'living alone' and 'living with a partner', and we provide the main models for the 'living with other people'

2.2. Mental health (outcomes)

Reflecting the dual continuum model of mental health, we used indicators of both positive and negative mental health. *Mental well-being* (i.e. positive mental health) was measured with the World Health Organization (WHO) 5-item mental well-being scale (WHO-5) which asks about how the respondent has felt over the last two weeks. Each item is positively phrased and rated on a scale from 0 "At no time" to 5 "All of the time". According to conventions, the responses were summed and scaled to range between 0 and 100. The scale is widely used internationally and has good psychometric properties. The Cronbach's alpha reliability of the scale was 0.92.

An indicator of negative mental health, the use of *anxiety or depression medication* was assessed with the European Health Interview Survey question "During the past two weeks, have you used any medicines for any of the following conditions that were prescribed for you by a doctor?" (Yes or No). We merged the responses to the options "Depression" and "Tension or anxiety" into a binary variable indicating whether or not the respondent had been prescribed either (or both).

2.3. Green space – residential (exposure) and visits (mediator)

Neighborhood green space coverage (%), a continuous measure, was obtained from Global Land Cover 30 dataset, a 30 m-resolution raster dataset based on Landsat and Landsat-like image data that was based on landcover in 2010. The types of green space included were cultivated land, forest, shrubland, and grassland. In our main analyses we used a 1 km buffer zone calculated from each respondent residential location in line with previous evidence on a similar topic - showing stronger associations between green space and loneliness-in larger buffer sizes. To check if the results are sensitive to the choice of neighborhood green space metric, we ran additional sensitivity models with the following green space indicators: a) a 300-m buffer, b) green land cover categorized into 0%, >0–25%, and >25%; and c) Normalized Difference Vegetation Index (NDVI) at 1000 m resolution. The NDVI data was obtained from MODIS Terra satellite imagery from the data collection period (June 1st, 2017 to March 31, 2018), using the product "MOD13A3 vegetation indices monthly L3 global 1 km". A home geocode was assigned an NDVI value of the 1 km pixel it fell in; this was the average of the best available images of that pixel from across the study period to reduce seasonal biases. The finest 30 m resolution was not feasible due to issues with computational power in this global dataset. Image quality evaluation was based on pixel reliability rank, in which the highest quality was not available for 1055 residential locations in this sample, and hence the sample was smaller in this model.

The number of green space visits was calculated as the total number of reported visits to 12 different types of green space categories in the past four weeks (e.g. large urban parks, woodlands, allotments etc.), following the procedure in. To reflect the same time frame as the outcome (i.e., last two weeks), this was divided by two. Furthermore, these visits were capped at 28 which is equivalent of visiting green space twice a day over a two-week period.

7. Urban Green Space and Climate Change Adaptation

How green cover and open spaces can help us adapt to climate change

Increasing the amount of green cover and open spaces has many benefits in protecting us from the effects of climate change. Protecting local green spaces and creating urban networks of green space can help to minimize the impacts of urban heat in our cities and towns.

Vegetation included in urban design has the added benefit of absorbing and storing carbon dioxide, helping to limit the rate of climate change. A mature tree can absorb up to 150 kg of carbon dioxide every year – planting 12 trees can offset one year's worth of a person's entire carbon dioxide emissions.

Government policies and strategies such as the Sydney Green Grid and Greener Places Framework are supporting the establishment of a network of green cover and open space in our largest city. Delivering a network of open spaces will help keep the city cool, encourage healthy living, enhance biodiversity an ensure ecological resilience. The NSW Government is also committed to delivering 2 of the Premier's Priorities for a better environment:

- Greener Public Spaces – where the NSW Government is looking to create green public spaces by increasing the proportion of homes in urban areas within 10 minutes' walk of quality green, open and public space by 10% by 2023. Incorporating more vegetation and green spaces into urban areas will help balance temperatures and reduce the urban heat island effect.
- Greening Our City – with a goal to increase the tree canopy and green cover across Greater Sydney by planting 1 million trees by 2022. This is part of the broader 5 Million Trees program that aims to plant 5 million trees by 2030 and help reach the Greater Sydney Region Plan's target of 40% canopy for Greater Sydney.

Using green cover and open spaces offers a way to adapt to climate change that can be applied across many urban settings. However, it is important to ensure that local conditions are properly considered and planned for.

In partnership with the Clean Air and Urban Landscapes (CAUL) Hub, the NSW Government has delivered a baseline dataset to assess urban heat and green cover in the Sydney Greater Metropolitan Area. This allows planners and policy makers to assess ways to adapt urban areas to create more livable cities.

Through CAUL, local decision makers will be able to understand and monitor tree and shrub cover in local government areas. This enables decision makers to look at green cover at the street level in their districts.

The idea for Cool River City began when Western Sydney was cloaked in a blanket of smoke. Arts practitioner and educator Hayley Coghlan had been holidaying on the New South Wales South Coast over Christmas 2019 when she found herself caught in the Black Summer bushfires.

Hayley is the Co-chair of Pari, an artist-run space in Parramatta, on the traditional lands of the BareMetal people of the Dharuk nation.

“When I returned to Sydney the whole city was choked in smoke. I felt so devastated by the bushfires and I wanted to do something to help my community develop skills to adapt.”

Drawing on Pari's deep network of arts practitioners, Hayley developed a plan for seasonal, in-person workshops to be brought to life with the help of a NSW Government grant. But with Covid-19 challenges around every corner, “the project demanded a lot of adapting,” Hayley, who prefers to use she/they pronouns, notes.

“In some ways, Covid became a blessing in disguise. We had to slow down, pause, sometimes stop all together and surrender to the sense of the unknown.”

Taking the time to slow down allows us to observe the changing seasons. On Drug land, there are not four seasons with fixed dates. Instead, there are many overlapping “micro seasons” that occur with the blooming of a particular flower or the movement of certain animals.

These micro-seasons are being disrupted by climate change, but by understanding and observing them, we can learn to better care for Country.

Tim Bishop introduced workshop participants to the Indigenous mindfulness practice Wayapa Wuurrk

Cool River City kicked off in Autumn 2021 – the time of fog, stars and yam seed – with a series of emotional resilience workshops. Tim Bishop introduced workshop participants to the Indigenous mindfulness practice of Wayapa Wuurrk. “This is a holistic movement and meditation practice that helps people consider their connection to the earth and how they can keep that connection healthy,” Hayley says.

Tai Chi, yoga and eco-therapy workshops were also held during the autumn session. “We chose a variety of practices because there isn't one way to strengthen emotional resilience.”

Then, as Pari pivoted away from live education, the focus turned to the development of written resources and shareable video content. Sixteen artists, healers, writers, bush regenerators and architects contributed their knowledge to the Cool River City Our cities are damaging our health. Here's how plants can help us.

By 2050, 68% of the global population will live in cities. That's 2.5 billion more people than today. In Europe, three out of four of us already live in urban areas, and the **consequences of that are becoming clear**.

Researchers estimate that **nine million people die every year** as a direct result of air pollution. In London, two million people - of which 400,000 are children - are living in areas with **toxic air**.

feel socially included, promoting more confidence and well-being in their everyday lives. Overall, the bonding experiences that result from urban green spaces tie in with a child's cognitive and social development.

A 2020 study suggested that increased access to urban green space increased the IQ of children by

As our cities grow and more people move into already crowded spaces, what do we need to do to transform our urban areas into healthy places to live? An increasing body of research tells us that we should be letting nature back in.

Dr Cecil Konijnendijk is a Professor of Urban Forestry at the University of British Colombia (UBC). He studies the role of nature and green spaces in cities and towns, and how we can use the natural world to make urban environments healthier and more livable.

'Research shows really clearly that we need nature in our surroundings. We need trees in our streets, **plants** in our gardens and flowers on our balcony. We need nature as our neighbor all the time.'

'We have a responsibility as human beings to take care of nature in our cities. In return, the benefits to our health would be huge.'

Growing a mini meadow of wildflowers in your garden or in a pot on a balcony can be beneficial to our health and make life better for pollinating insects.

16. Conclusion

In land-use planning, **urban green space** is open-space areas reserved for parks and other "green spaces", including plant life, water features - also referred to as blue spaces - and other kinds of natural environment. Most **urban open spaces** are green spaces, but occasionally include other kinds of open areas. The landscape of urban open spaces can range from playing fields to highly maintained environments to relatively natural landscapes.

Generally considered open to the public, urban green spaces are sometimes privately owned, such as higher education campuses, neighborhood/community parks/gardens, and institutional or corporate grounds. Areas outside city boundaries, such as state and national parks as well as open space in the countryside, are not considered urban open space. Streets, piazzas, plazas and urban squares are not always defined as urban open space in land use planning. Urban green spaces have wide reaching positive impacts on the health of individuals and communities near the green space.

Urban greening policies are important for revitalizing communities, reducing financial burdens of healthcare and increasing quality of life. Most policies focus on community benefits, and reducing negative effects of urban development, such as surface runoff and the urban heat island effect. Historically, access to green space has favored wealthier, and more privileged communities, thus recent focus in urban greening has increasingly focused on environmental justice concerns, and community engagement in the greening process. In particular, in cities with economic decline, such as the Rust Belt in the United States, urban greening has broad community revitalization impacts.

Urban areas have greatly expanded, resulting in over half of the world's population being located in urban locations. As the population continues to grow, this number is predicted to be at two-thirds of people living in urban areas by 2050.

People living in cities and towns generally have weaker mental health in comparison to people living in less crowded areas. Urban green spaces are pieces of nature in the cities designed to try to solve the problem.

Most research on the topic focus on urban green spaces. The WHO defined this as "all urban land covered by vegetation of any kind".

When doing research, some experts use "urban open space" to describe a broader range of open areas. One definition holds that, "As the counterpart of development, urban open space is a natural and cultural resource, synonymous with neither 'unused land' nor 'park and recreation areas'." Another is "Open space is land and/or water area with its surface open to the sky, consciously acquired or publicly regulated to serve conservation and urban shaping function in addition to providing recreational opportunities." In almost all instances, the space referred to by the term is, in fact, green space, focused on natural areas.

These spaces are part of "public space" broadly construed, which include meeting or gathering places that exist outside the home and workplace, and which foster resident interaction and opportunities for contact and proximity. This definition implies a higher level of community interaction and places a focus on public involvement rather than public ownership or stewardship.

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Google map