City-Scale Building

# Exploring the Benefits of Green Infrastructure

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# Introduction

Green infrastructure involves integrating natural elements like parks, green spaces, and sustainable water management systems into urban planning to enhance environmental sustainability. This report aims to address the research question:

*"How can major cities be transformed into greener, more sustainable spaces? What are the benefits for humans and wildlife, and why isn't it more widespread?"*

As urban areas expand, the noticeable absence of green public spaces and habitat preservation becomes increasingly apparent. However, with advanced technology, we can address this issue by adopting sustainable practices, including renewable energy, urban cooling, and water management. The U.S. has a plausible opportunity to reenvision major U.S. cities, transforming them into greener and more sustainable environments. Embracing these practices can lead to a number of benefits, such as improved air quality, the creation of wildlife habitats, reduced operating expenses, and heightened public well-being. In the forthcoming sections, this report will delve into the implementation of green infrastructure in other countries, examining the associated benefits and challenges. Additionally, it will explore why these practices haven't been widely adopted in the U.S., breaking down the feasibility of their implementation and the barriers preventing their widespread adoption.

## Background

Green infrastructure encompasses various components aimed at integrating nature into urban spaces, promoting environmental sustainability, and enhancing the overall quality of urban life. One specific element is the green roof, characterized by vegetation and a growing medium covering a building's roof. Green roofs provide habitats for birds, absorb airborne pollutants, reduce sewer overflow by retaining rainwater, and mitigate the urban heat island effect. Cities in the United States, including Washington, D.C., Chicago, Philadelphia, and New York City, incentivize green roof installations, leading to a significant increase in coverage. Additionally, the Nanyang Technological University in Singapore holds an impressive green roof that serves both as a scenic outdoor communal space and an efficient temperature-regulating feature. Comprising grasses, volcanic rocks, pumice, and washed sand, the roof not only enhances aesthetics but also reduces heat and promotes sustainability. Beyond green roofs, planting native trees and plants is a crucial aspect of green infrastructure. Native plants contribute to increased biodiversity, improved air and water quality, and provide aesthetic and recreational benefits. This approach involves adding more trees, grass, vines, succulents, rooftop green spaces, and animal pathways to major cities, creating not only beautification but also improvements in air quality, habitat restoration, temperature reduction, and enhanced mental well-being for urban residents.

## Exploring Environmental Benefits

While the implementation of green infrastructure is versatile, it's important to focus on locations where its success has been demonstrated.

1. *Western Japan*: A study conducted by Xinyu University, China, and Hiroshima University, Japan, explored the sustainable practices of green roofing in West Japan. They focused on rooftop greening soil with a bamboo charcoal sublayer and analyzed its impact on latent heat flux during the summer season - whether green roofs effectively prevented heating. As vegetation developed, the ground heat flux on the greening soil surface exhibited a significant decrease from -400 W/m2 to -100 W/m2 during sunny July days, further reducing to less than -100 W/m2 in August. Despite maintaining a net radiation of around 800 W/m2 throughout the season, the observed evapotranspiration from greening soil averaged at 1.51 mm/day. These observations suggested that the bamboo charcoal-based greening system, even without constant irrigation, not only sustained lawn grass development but also transformed over half of net radiation into latent heat through evapotranspiration. This system demonstrated its capability to insulate most ground heat during midsummer and the success of reducing heat through green roofing.

2. *Singapore:* Famously known for its impressive green infrastructure, Singapore stands as a model for integrating nature into urban landscapes. The "City in a Garden" initiative goes beyond adding parks by integrating greenery into all aspects of urban life. Examples include Gardens by the Bay, a nature park spanning 101 hectares featuring supertrees that act as cooling ducts for conservatories and bio-diverse conservatories. Singapore's commitment encourages green building practices and rooftops which in turn mitigates heat island effects, absorbs carbon emissions, and enhances biodiversity.

3. Bhutan:

"***The Government shall ensure that, in order to conserve the country's natural resources and to prevent degradation of the ecosystem, a minimum of sixty percent of Bhutan's total land shall be maintained under forest cover for all time.***"

**- Article 5:3, The Constitution of the Kingdom of Bhutan**

Bhutan spans 38,394 km2 which encompasses the entirety of the Eastern Himalaya biodiversity hotspot. Despite Bhutan's built infrastructure, the forest still covers over 70% of the country. Bhutan's unwavering commitment to biodiversity preservation is apparent in its five National Parks, four Wildlife Sanctuaries, one Strict Nature Reserve, and Biological Corridors. These protected areas provide sanctuaries for endangered species like the Chinese Pangolin, Great Hornbill, and Red Panda. Despite an annual discharge of approximately 2.2 million tons of CO2 equivalents, Bhutan's forests function as a crucial carbon sink, sequestering a remarkable 6.3 million tons of CO2 equivalents annually. These practices not only contribute significantly to climate change mitigation, but also enhance the overall quality of life for its residents.

## Exploring Social Benefits

In the UK, research conducted by White et al. utilized national representative samples of British residents and discovered that individuals living in urban areas with a higher level of greenery experienced lower average mental stress and higher life satisfaction. The study used panel data from over 10,000 individuals and found that, on average, residents in urban areas with more green space exhibited lower mental distress and higher well-being over time. Despite effects at the individual level being small, the cumulative benefits at the community level highlight the importance of policies promoting and preserving urban green spaces for overall well-being.

Another study, focusing on "The Association between Green Space and Adolescents' Mental Well-Being," conducted a systematic review summarizing and evaluating evidence for associations between green space and adolescents' mental well-being. The review, considering 14 articles meeting the criteria, found beneficial associations between green space exposure and various positive outcomes such as reduced stress, positive mood, fewer depressive symptoms, improved emotional well-being, better mental health, and behavior. While the relationship varied based on demographic and socio-economic factors, the review suggests that improving the availability, accessibility, and quality of green space, particularly in schoolyards, is likely to generate positive impacts on adolescents' mental well-being.

Finally, Chen, Kaili et al. conducted a study correlating green space with mental health, analyzing data from global studies. The ensuing table outlines various types of implemented green spaces along with their key findings:

## Table A1

Main characteristics and results of the studies on green space and mental health.

| No. | Publication Year | Study Location | Sample Characteristics | Green Space Calculation/Measures | Study Design | Key Findings | Potential Mediators |
|---|---|---|---|---|---|---|---|
| [5] | 2013 | England | 5000 households and 10,000 individual adults | The Generalized Land Use Database (GLUD) classifies land use at high geographical resolution across England and has been applied to 32,482 lower-layer super output areas (LSOAs) | Panel data analysis | A greater amount of green space is associated with less mental stress and greater happiness. | Stress and neighborhood satisfaction |
| [10] | 2020 | Singapore | 22 healthy volunteers (13 females; mean age = 32.9, standard deviation = 12.7) | Contemplative landscape score | Electroencephalography (EEG) technology was used to test the changes in a busy urban street, an urban park, and a neighborhood green space to test the mood swings of participants. | In green space, participants' Frontal alpha asymmetry (FFA) is more significant, which means that they have more positive emotions. | Positive emotion |
| [52] | 2008 | Adelaide, Australia | 2194 residents aged between 20 and 65 | Neighborhood environment walkability scale (NEWS–AU) | Principal components analysis with oblique rotation was conducted to identify summary measures of neighborhood satisfaction. | Neighborhood satisfaction may mediate the association between perceived environmental characteristics and measures of mental | Neighborhood satisfaction |
| [24] | 2020 | Hong Kong, China | 608 pedestrians aged 20 years or over | Normalized difference vegetation index (NDVI) | Multinomial logistic regression models were applied to assess the effects of green space on sleep quality and perceived stress. | High levels of stress affect sleep quality, but the effect is relatively small in neighborhoods with a high amount of green space. | Relief of stress |
| [32] | 2020 | European cities | 3947 adults aged 18–75 years | GIS-derived measures and NDVI | A cross-sectional design was used. | Physical activity, a higher frequency of social contact with neighbors, and better mental well-being | Physical activity and communication with the neighborhood |
| [33] | 2013 | New Zealand | 8157 adults aged 15 years or over | Green space quartiles | Cross-sectional analysis of anonymous individual health survey responses was conducted. | Although physical activity is higher in greener neighborhoods, it does not fully explain the relationship between green space and mental health. | Physical activity |
| [28] | 2011 | Ghent, Belgium | Two inner-city neighborhoods that differ objectively in greenery, with 300 residential households per neighborhood | GIS | Ward's method of hierarchical clustering was utilized. | Stress is significantly correlated with community satisfaction and happiness, but there is no significant difference in the perception of stress between two communities with different amounts of green space. | Stress and neighborhood satisfaction |
| [114] | 2004 | Hamilton, Ontario, Canada | 1504 adults aged 18 years and older residing in four contrasting neighborhoods | Subjective experience of residents | Cross-sectional survey data were analyzed in small neighborhoods. | The influence of the physical environment, such as green space, on neighborhood satisfaction is much higher than that of the social environment; people are more satisfied with communities with more green space, and thus are happier. | Neighborhood satisfaction |

## Exploring Economic Benefits

In Copenhagen, Denmark, there was an emphasis placed on green building practices after a severe event in 2011 that resulted in more than $910 million in repairs. The implementation of features such as permeable surfaces, parks, and water-absorbing landscapes not only mitigated stormwater runoff issues, but it also created shade, air circulation, efficient water management, and prevented urban heat islands. Their incorporation of green infrastructure has led to a reduction in operational costs and an estimated overall benefit and savings of $767 million.

Furthermore, Singapore, despite incurring substantial costs for the implementation of green strategies, witnessed notable economic benefits. The extensive adoption of sustainable practices and green infrastructure resulted in a remarkable 11.6% reduction in total operating expenses, concurrently elevating the city's capital value by 2.3% in 2013.

The integration of renewable energy into green infrastructures is also very economically advantageous. On a global scale, a shift from fossil fuels to renewable energy sources by 2050 could yield savings of at least $12 trillion, as highlighted in an analysis by the University of Oxford. More specifically, Kansas City witnessed a $40,000 reduction in electricity costs within the first year of installing solar arrays. Similarly, a pilot project in eThekwini, South Africa, achieved approximately $20,000 in electricity cost savings in its first year following the installation of solar arrays on five municipal rooftops in 2017. Boa Vista, located in the Brazilian Amazon, is heading towards a $1 million annual savings in energy costs after transitioning to 100% clean energy.

Lastly, the ongoing maintenance and management of green infrastructure, including the upkeep of green roofs, monitoring stormwater systems, and ensuring the efficiency of renewable energy sources, present avenues for sustainable job growth. This dual focus on economic benefits, renewable energy savings, and job creation underscores the holistic and long-term advantages associated with the integration of green infrastructure in urban development strategies.

## Challenges, Critical Thinking, and Solutions

When looking at the different cultural and geographical landscapes, questions arise about the benefits associated with green infrastructure and whether they are true for different countries: What if some cities prioritize material possessions over green spaces, impacting their perception of happiness?

We must also realize that it is much easier to implement green infrastructure into smaller countries (the United States is 13,600 times larger than Singapore).

There must be caution when linking green spaces and happiness. 93.6% of the Bhutanese population considers itself happy (Ura et al. 2023), however most people in Bhutan relate happiness to their beliefs of Buddhism, not because they are surrounded by green space.

However, despite these cultural and size differences, there are strategies to bridge the gaps. While the U.S. might be vast, we can tackle one city at a time, first concentrating on the densely populated urban centers with the most concrete infrastructure then a gradual expansion to the less populated areas. Despite cultural differences, adding green infrastructure will still increase neighborhood satisfaction as shown in several countries regardless of size (Table in Exploring Social Benefits). Additionally, the lower income communities will benefit the most.

It seems like green infrastructure has an array of benefits, so why isn't it implemented everywhere? Mostly cost and policy. Here are ways to combat it:

1. Public-Private Partnerships: Collaboration between the public and private sectors for funding.
2. Policy Reforms: Advocating for policy changes at various levels is where it begins, adding incentives for sustainable practices and penalties when not followed.
3. Public Awareness: Raising awareness about green infrastructure benefits can generate grassroots support, urging citizens to advocate for sustainable initiatives.
4. Research Support: Investing in research on the benefits of green infrastructure provides policymakers with evidence as to what practices to implement.

## Implementation Strategies

Acknowledging the challenges and considering potential solutions, let's now explore the hypothetical integration of Green Infrastructure into major cities in the U.S.

*Rooftop Initiatives:*

1. Green Roofs: Encourage property owners to install green roofs to absorb airborne pollutants, retain rainwater, lessen the heat island effect, and create a beautiful aesthetic. Provide financial incentives.
2. Produce Roofs: Promote urban agriculture by facilitating the development of produce roofs, fostering local food production.
3. Solar Panels: Implement policies requiring or incentivizing solar panel installation on rooftops to harness renewable energy.
4. High Reflective Surfaces: Advocate for the incorporation of high-reflective surfaces to mitigate heat absorption, reducing the urban heat island effect.

*Landscaping with Native/Adapted Plants and Trees:*

1. Mandate the incorporation of native or adapted plants and trees in front of all buildings and homes, public spaces, and along streets to improve air quality, provide habitat, and manage stormwater runoff.
2. Establish animal overpasses and wildlife corridors throughout the city to enhance biodiversity and facilitate safe wildlife movement.

*Adopt Sustainable Transportation:*

1. Encourage the use of sustainable transportation modes by building cycling lanes, reliable electric buses, and walking-friendly infrastructure.

*Resource Metering and Certification:*

1. Water and Energy Metering: Require all buildings to have water and energy metering systems, promoting efficient resource use and facilitating data-driven sustainability initiatives.
2. LEED Certification: Pass laws mandating LEED certification for all new buildings, ensuring high environmental performance.

*Building Renovation and Sustainable Materials:*

1. Implement policies to encourage the renovation of existing buildings using sustainable and recycled materials, promoting the reuse of resources and reducing environmental impact.

*Green Spaces:*

1. Gardens and Parks: Identify and repurpose underutilized spaces for the creation of community gardens and parks, enhancing green spaces and fostering community well-being.

## Public Awareness and Engagement

A crucial but often overlooked step in green infrastructure is acknowledging the vital role of community participation in planning and implementation. To instill a sense of ownership and belonging, strategies for raising awareness and securing community backing should be carefully incorporated.

1. *Public Forums:* Organize public forums and town hall meetings to facilitate open discussions about the green infrastructure project for community members, especially those from low/no-income, to voice their opinions, concerns, and ideas.
2. *Community Surveys:* Distribute surveys to gather feedback on green infrastructure preferences and concerns.
3. *Educational Programs:* Implement educational programs in local schools and community centers. Inform the younger generation on sustainable practices.
4. *Demonstration Projects:* Develop small-scale demonstration projects within the community to offer a firsthand experience of the positive impact.
5. *Local Events:* Organize localized events, such as tree-planting days, community clean-ups, or nature walks, to build a sense of pride and connection to the green infrastructure efforts.

By implementing these strategies, the planning and implementation process becomes an inclusive and collaborative effort.

## Conclusion

In urban areas worldwide, the integration of green infrastructure has emerged as a transformative solution for environmental sustainability. Examining successful implementations globally such Western Japan, Singapore, and Bhutan reveals multiple environmental advantages. From reducing heat through green roofing to biodiversity preservation, the adoption of green infrastructure significantly contributes to climate change mitigation.

Internationally, studies in the UK emphasize the positive impact of green spaces on mental well-being, with urban areas featuring higher greenery levels correlating with lower stress and increased life satisfaction. Conenhagen's focus on green building practices resulted in economic benefits, reducing operational costs by 11.6% and increasing the city’s capital value by 2.3% in 2013.

Acknowledging challenges such as cultural variations and monetary needs, the report proposes solutions like public-private partnerships, policy reforms, and public awareness campaigns. The integration of green infrastructure into major U.S. cities is plausible, beginning with rooftop initiatives, landscaping with native plants, sustainable transportation, metering, LEED certification, building renovation, and the creation of green spaces.

In conclusion, this report advocates for the prioritization and investment in green infrastructure in major U.S. cities, highlighting its diverse benefits despite its challenges.

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