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Sustainability in Action: Green Infrastructure as a Marker of Sustainable Urban Development

Brianna Santiago, Florida International University, briisantiago02@gmail.com / bsant089@fiu.edu
Student Editor **Nicholas Cabezas**, Florida International University, ncabe004@fiu.edu
Faculty Mentor **Dr. James R. Riach**, Florida International University, riachj@fiu.edu

The current form and pace of urbanization is an ongoing threat to sustainable urban development. As these problems span social, environmental, and economic realms, it is imperative that any proposed solution is able to address these problems holistically. Although a number of silver-bullet solutions such as electric vehicle adoption have been introduced, they do not respond to the problems with an integrated approach. Tackling this problem will require a solution that can be changed and applied on a case-by-case basis. Therefore, the development of green infrastructure is the most efficient solution when responding to the problems threatening urban sustainability. The purpose of this paper is to argue for the efficacy of green infrastructure methods by analyzing the evidence provided about factors like temperature and pollution levels in green cities as compared to other proposed solutions, and to explore critiques of green infrastructure and discuss their potential improvements. The research provided contains a mixture of case studies, participant surveys, and other scientific findings and has the potential to make green infrastructure a priority in the future planning of cities.

Keywords: *sustainability, green infrastructure, urban development, landscape architecture, sponge city*

As cities expand, there have been particular values and principles that have drawn people to a pattern of urbanization and densification. Under their historial guise, cities are supposed to be seen as hubs of human innovation. Their promises of connection, expansion, and infinite possibility drew me to desire urban living at a young age. More often than not, however, they become case studies of humanity's worst collective issues. Unchecked growth continues to threaten our societies' environmental, social, and economic wellbeing. For this reason, it is imperative that we draw up viable solutions to these problems that would better align our cities with the original vision in mind as communities that will propel us into a brighter future. Green infrastructure has proven to serve as a holistic solution to unsustainable urban development, as it tackles a variety of interconnected problems instead of isolated approaches. Green infrastructure can generally be defined as a system of plants and soils that have a variety of aesthetic and functional purposes, such as rainwater absorption, natural cooling, or general beautification. The network can take many forms such as rain gardens, urban forests, or green roofs. It has been shown to reduce the urban heat island effect as well as a wide variety of pollution and emissions sources, address flood risk, and improve public health and wellness. The Chinese sponge city (SC) initiative is just one example of how green infrastructure can be applied, as it demonstrates how green infrastructure methods are applied on an appropriate scale. The purpose of this paper is to advocate for the use of green infrastructure in cities as the best way to solve problems related to our current systems of unchecked growth and urbanization.

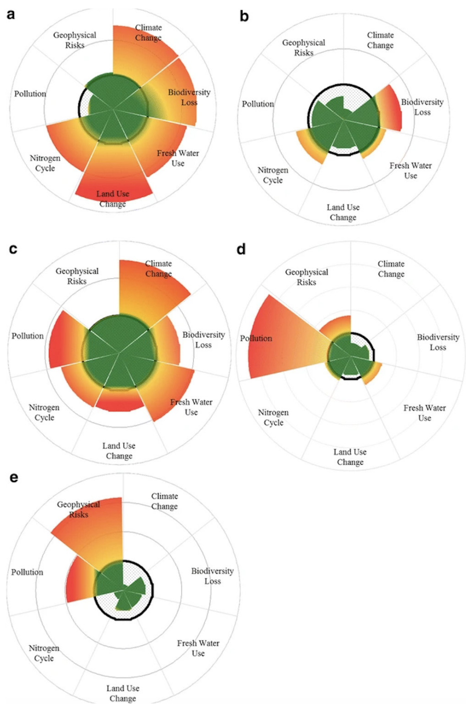
Literature Review

The topic of urban sustainable development connects to both the United Nations Sustainable Development Goals (UNSDGs) and the Planetary Boundaries model. The UNSDGs are a collection of 17 global targets that were introduced by the United Nations in 2015, the main objective of which is to create a system where countries are able to tackle their environmental, social, and economic problems in a checklist form. In relation to the UNSDGs, the topic of urban sustainable development fits into Sustainable Development Goal 11 (Sustainable Cities and Communities), which deals with urban sprawl, land use patterns, and infrastructure development. Additionally, the authors discuss individual 'smart city' initiatives that have been created and evaluate their effectiveness.

The Planetary Boundaries model was created in 2009 and outlines nine environmental thresholds in which humanity must remain within in order to sustain our way of life. Some of these boundaries include factors like ocean acidification and ozone depletion. Hoornweg et al. (2016) have assessed how the issue of unsustainable urban development has a direct impact on certain planetary boundaries including land use change and greenhouse gas (GHG) emissions. This article's perspective is unique because it demonstrates how the planetary boundaries model can be applied to individual cities as well. The authors create a collection of infographics (**Figure 1**) with a planetary boundary chart for global cities such as Toronto and Shanghai. The green shade in **Figure 1** represents our societies functioning within the safe environmental limits; as the colors fade to red, the farther we are crossing the planet's environmental boundaries into dangerous territory. Therefore, the individual impacts of major cities can be directly compared and addressed accordingly.

Figure 1

The Planetary Boundaries Model Used to Compare 5 Global Cities: (a) Toronto; (b) São Paulo; (c) Shanghai; (d) Mumbai; (e) Dakar



Note. Image from Hoornweg et al. (2016)

Many researchers have discussed the numerous causes of unsustainable urban development. For instance, Jartun et al. (2008) discusses how the infiltration of extensive road networks within our cities is causing large swaths of water pollution runoff. Yao et al. (2016) conducts a similar case study with the focus of impervious surfaces such as concrete and asphalt that are prevalent in cities. These materials are known to absorb large amounts of heat, yet cannot absorb water or other fluids, thereby increasing the risks of flooding, chemical runoff, and higher heat levels. Zuniga-Teran et al. (2021) takes a more socially-focused approach to the causes of unsustainable urban development, highlighting colonial histories of environmental injustice in many major cities. An example of this is the lack of green infrastructure in urban areas that are predominantly low-income or communities of color. Although each article addresses different causes of unsustainable urban development, there is a general consensus that the status quo of urban development must drastically change in order to address the consequences.

Moreover, much research has been done concerning the consequences of unsustainable urban development, the majority of which are biophysical in nature. For example, Ren (2021) defines a phenomenon called the urban heat island effect that results from increased temperatures due to rapid urbanization. This occurs when heat is trapped by gray infrastructure such as asphalt and buildings instead of being released into the atmosphere. This phenomenon can be observed using a variety of climatological models such as spatial maps and temperature graphs as tested by Ren (2021). The high temperatures can be traced to large concentrations of carbon dioxide (CO_2) and methane (CH_4) due to a variety of factors such as urban industrial activity and elevated usage of internal combustion (IC) vehicles (Zimnoch et al., 2019).

In response to the causes and consequences of unsustainable urban development, a wide range of solutions have been introduced by researchers. Although there is a general consensus that solving the problem of unsustainable urban development will require high levels of disruptive action, there are disagreements about which type of solution would be the most effective. For instance, Skipper et al. (2023) discusses the idea of widespread electric vehicle adoption, which can easily be seen as a type of silver-bullet or one-size-fits-all solution. Other researchers like Priya et al. (2021) and Wang R. et al. (2022) discuss different types of green infrastructure implementations such as the SC strategy, which would address a multitude of environmental, social, and economic problems instead of just one. Burghardt et al. (2023), Reyes-Riveros et al. (2021), and Wang P. et al. (2022) elaborate on these strategies by adding an emphasis on human health and wellbeing benefits like decreased stress and depression.

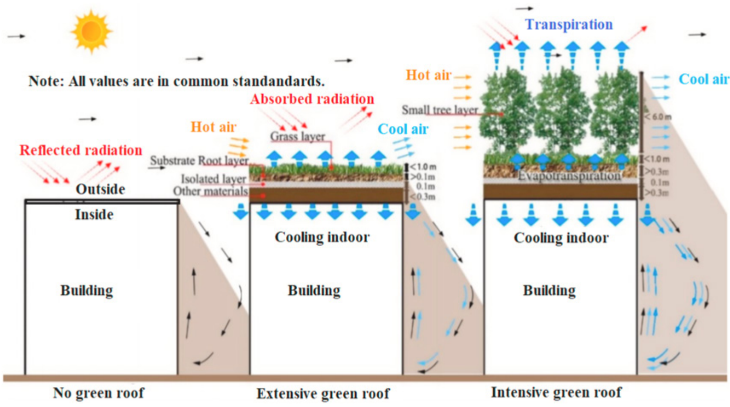
The main critique of the literature reviewed is that solutions have historically ignored the importance of environmental justice and wider social benefits that are needed in order for cities to be considered more sustainable (Zuniga-Teran et al., 2021). In this paper, I would like to present some approaches addressing environmental justice alongside how we can further create a more integrated and inclusive approach to the problem of unsustainable urban development.

Green Infrastructure Impacts on Temperature and Air Pollution

The continuous threat of climate change and the onset of more extreme weather events accentuates the need for a wide range of adaptation and mitigation strategies. Two types of extreme weather events brought on by climate change that directly impact urban areas are increased flooding and extreme heat events. Ren et al. (2021) discusses the dangers of the urban heat island effects that have become more common in dense cities, while Zimnoch et al. (2019) comments on the rising carbon dioxide and methane emissions. For example, emissions from industrial activities contribute to high temperatures. These temperatures can become dangerous to human health by increasing heat-related illnesses like heat stroke. The extremely high density of urban centers as well as the methods of land use are the main contributors to these problems. The implementation of green infrastructure methods has been proven to reduce temperatures (Priya et al., 2021) and overall air pollution (Zimnoch et al., 2019) within urban areas. Priya (2021) highlights how changes to a city's microclimate via green infrastructure strategies such as green roofs and urban parks can drastically reduce temperatures by up to 12°C. This is due to a variety of ecosystem services that plants provide such as shading, carbon dioxide exchange into oxygen, as well as a process called evapotranspiration in which plants transport cool water from the ground into the atmosphere. In particular, the temperature-reducing benefits of green roof infrastructure also extend to the interior of buildings. These landscapes also reflect solar radiation from a building's rooftop, which helps to keep the building cooler inside (Priya et al., 2021). These processes are illustrated in the figures below.

Figure 2

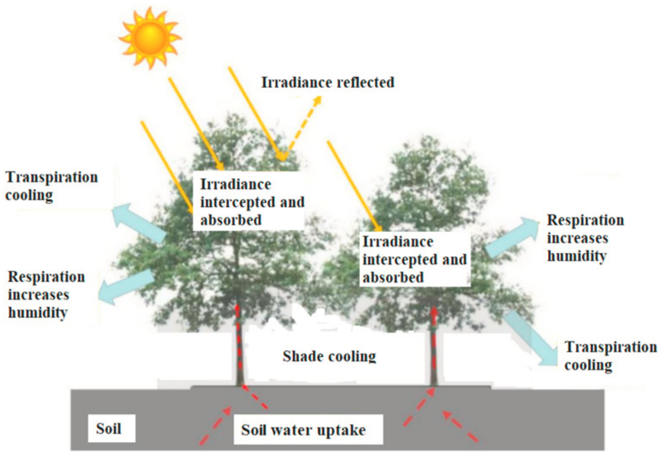
Visual Representation of Green Roof Cooling



Note. Image from Priya et al. (2021)

Figure 3

Process of Evapotranspiration



*Note. I*mage from Priya et al. (2021)

The research conducted by Priya (2021) also finds correlations between the density of a tree's canopy and the amount of sunlight reflected for cooling and shading purposes. For example, a tree with leaf coverage of about 80 percent can reduce air temperature by 2.5°C. Each 10 percent increase in leaf coverage means a temperature reduction of 0.3°C (Priya et al., 2021). Therefore, it can be concluded that adopting a variety of green infrastructure strategies with the prioritization of canopy-dense tree and plant species is a highly effective method of reducing urban temperatures and GHG emission concentrations.

Furthermore, adding green infrastructure such as green roofs and trees to urban areas leads to large reductions in particulate matter (PM) air pollution (Abhijith & Kumar, 2020). As PM moves through the air, large amounts of these substances are deposited on the leaves of urban greenery and removed from the atmosphere. The research conducted by Abhijith and Kumar (2020) concluded that the majority of PM deposited on the leaves of green infrastructure are PM1, which are particles that are about one micron in size. The reduction of PM was found to range from 14% to 21% (p. 4). Utilizing green infrastructure provides a much better solution to urban air pollution than other silver-bullet solutions such as the widespread adoption of electric vehicles (EVs). According to Skipper (2023), switching from IC vehicles to EVs does lead to significant decreases in PM, ozone, and GHG emissions pollution, with a 25% decrease in tailpipe emissions and a reduction of PM by about 0.5 to 2 micrograms per m^3. However, PM is still prevalent as a result of EV usage due to dust creation from tires, brakes, and road wear. Therefore, green infrastructure methods provide a more comprehensive solution to the urban heat island effect and high levels of urban air pollution.

Green Infrastructure Impacts on Flooding and Water Pollution

As explained by Yao (2022), the current infrastructure of urban areas is actually exacerbating urban flood risk through the proliferation of impervious surfaces. This water has to flow as runoff, which can then collect and transport harmful sources of water pollution like heavy metals and polychlorinated biphenyls or PCBs (Jartun et al., 2008). As polluted water eventually makes its way through the water cycle, it has the potential to contaminate drinking water and put human health at risk. Since the issues of flood risk and water pollution are intertwined, it is best to consider them together when trying to identify viable solutions.

The green infrastructure method of SCs is effective in both reducing flood risk and toxicity of urban runoff (Zhou & Penning-Rowsell, 2021 & Anderson et al., 2016). The intention and philosophy behind the SC technique is to mimic nature's methods of controlling rainwater and floods. An SC uses strategic planting methods such as rain gardens or bioswales in order to replace impervious infrastructure such as parking lots or concrete pavement. Elevation and topography are essential elements of planting methods, as it is important to understand how the water flows within a given area. These plants allow for floodwaters to filter through the soil and prevent runoff. Furthermore, Anderson (2016) discusses data that show how bioswales can also filter out chemicals like pesticides from parking lot runoff during a rainfall event. Plants and soils are able to store chemicals in their roots and in the ground which keeps them from reentering the water cycle. By reducing the bio-accumulation of toxic contaminants using bioswales, humans will benefit from decreased exposure to harmful pollutants.

Green Infrastructure Impacts on Human Health and Wellbeing

The benefits of green infrastructure extend to more than just the biophysical sphere. Urban landscaping and forestry are linked to improved human health and wellbeing. By preventing or reducing the negative environmental impacts as stated above, there are a plethora of negative health effects that can be avoided as well. For example, by reducing the likelihood of extreme heat events using green infrastructure, it can be expected that rates of heat-related illnesses like heat stroke would also decrease (Ren et al., 2021). Moreover, Reyes-Riveros (2021) analyzes how proximity to public green spaces (PGS) are linked to human physical health and wellbeing. The authors of this study conducted a literature review that found that 63% of articles on this topic observed correlations between available PGS and decreased stress levels, as well as how PGS encourage individuals to engage in more physical activities such as individual and group sports.

In a specific case study, Pengwei Wang (2022) surveys the impact that small urban parks have on human mental health. Time spent in small urban parks was not only linked to decreased depressive symptoms, but was also linked to stronger social cohesion. Individuals who spend more time in PGS have more positive social interactions with others which also improves mental health. This is in contrast to other types of urban infrastructure such as car-oriented infrastructure, which generally discourages individuals from spending time in nature or outside of a vehicle.

Observing the attitudes of citizens in a community towards green infrastructure is also important as a means of encouraging the adoption of these practices. Rui Wang (2022) organized a case study on the attitudes of Chinese citizens towards SC development. The authors of this survey found that around 70% of survey participants had positive beliefs surrounding SCs in terms of climate solutions, social cohesion, and aesthetic value. For these reasons, shifting to a set of green infrastructure models can have numerous beneficial impacts on human health and wellbeing.

The Environmental Justice and Green Infrastructure Debate

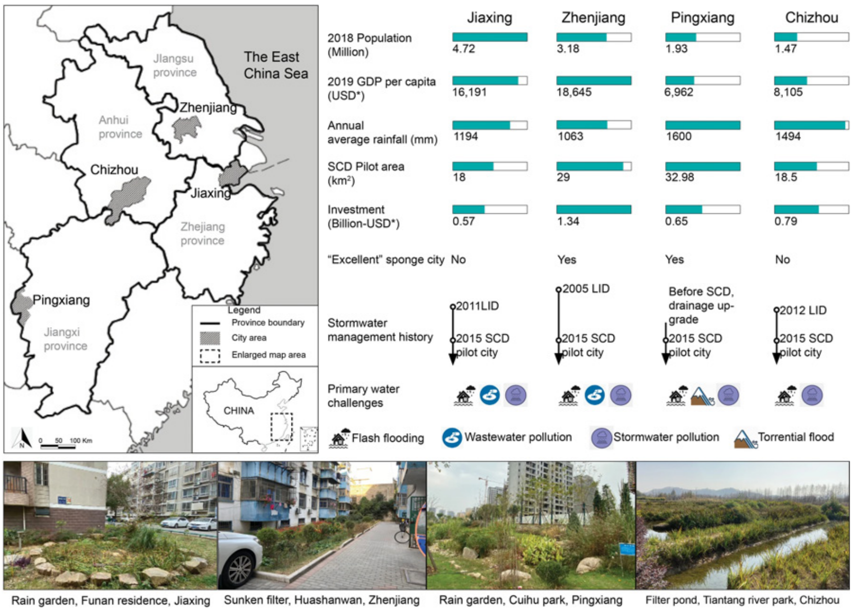
A major critique of the current state of green infrastructure adoption is the dismissal of environmental justice as an important factor to consider. A review of green infrastructure history by Zuniga-Teran (2021) highlights how strategies to implement green infrastructure into urban areas mostly targets predominantly White neighborhoods with higher income levels. Ignoring lower income and minority neighborhoods means that these communities are at increased risk to some of the threats discussed above such as the urban heat island effect and increased flood risk.

Although this critique is valid and has been thoroughly researched, there is current evidence that shows how green infrastructure implementation is moving in the right direction towards environmental justice progress and how we can further its expansion. For example, a case study conducted by Burghardt (2023) shows how knowledge of institutionalized racism is critical for infrastructure projects, and how history can be used to right the wrongs of the past when it comes to greening practices. This case study was conducted in Baltimore, Maryland in the United States, a city with a deep history of race-based community segregation. The study found that there has been a significant increase in investment in these communities as a result of tree-planting efforts conducted by the city (Burghardt et al., 2023).

Furthermore, Rui Wang (2022) demonstrates how green infrastructure projects can be largely community-led, which leads to stronger community engagement amongst a range of income levels. Their case study in China monitors the success of SCs in four cities with differing levels of gross domestic product or GDP. The SC tests were considered the most successful in Zhenjiang, the city with the highest GDP, and Pingxiang, the city with the lowest GDP (Wang R. et al., 2022). This study also shows how the level of monetary investment differed in each city, proving that green infrastructure can be adapted to each city's individual needs (**Figure 4**). Visual examples of these interventions as pictured below demonstrate how green infrastructure projects do not have to remain as costly corporate endeavors.

Figure 4

Results of Sponge City Pilot in China



Note. Image from Wang et al. (2022)

Overall, the main points of this critique will need to be the focus of the conversation around green infrastructure in the coming years; however, all of the previous benefits of green infrastructure mentioned above cannot be taken advantage of if only certain members of our urban societies can experience them. With ongoing discussions of creating more holistic approaches to environmental sustainability, it is clear that these problems are being seen and addressed in some form.

Discussion

As the world continues to urbanize, there are many aspects of our societal norms that make the possibility of sustainable urban development a difficult goal to reach. Therefore, striving to achieve urban sustainability must be done using the most efficient and holistic methods in order to tackle the range of issues. As a response to the threats of water and air pollution (Ren et al., 2021; Anderson et al., 2016), climate change (Zhou & Penning-Rowsell, 2021), and human health risks (Reyes-Riveros et al., 2021), the site-specific implementation of green infrastructure methods provides the most effective solution.

Overall, the sources discussed in this article suggest that a majority of the causes of unsustainable urban development can be tackled all at once. The reduction of urban temperatures by up to 12°C (Priya et al. 2021), as well as the reduction of flood risk from urban runoff (Zhou & Penning-Rowsell, 2021) are excellent for climate change adaptation and mitigation. The deposition of particulate matter onto the leaves of urban plants (Abhijith & Kumar, 2020) and the removal of toxic contaminants from flowing water (Anderson et al., 2016) demonstrates how effectively green infrastructure can handle air and water pollution. The surveys conducted on the relationship between human health and PGS demonstrate how important green infrastructure is to the long-term prosperity of human beings.

The critique of historical environmental injustices in the realm of green infrastructure implementation is an important topic to examine as it holds the key to answering certain questions about the limitations of green infrastructure as a comprehensive solution. As shown in case studies from Baltimore in the United States (Burghardt et al, 2023) and a group of Chinese cities (Wang R. et al., 2022), these injustices are increasingly being taken into consideration and being applied to new initiatives for integrated urban sustainability.

One of the best aspects of green infrastructure is the wide-variety of opportunities for implementation. The emphasis on applying a holistic approach is essential to my analysis—holistic in the sense that a variety of solutions and technologies must be implemented together in order to tackle such wide-ranging issues. There are low-cost options such as community-created rain gardens and bioswales (Wang R. et al., 2022), as well as opportunities for larger government-funded projects like asphalt conversions and city-wide tree planting (Burghardt et al., 2023). I believe that the potential to make positive change in this area has never been greater. Green infrastructure provides the possibility of addressing problems associated with environmental justice, climate change, and human health in synchrony.

Conclusion

The way in which our societies have expanded urban living has created dire environmental, social, and economic consequences. The all-encompassing impervious surfaces and general lack of PGS has largely disconnected us from nature and from each other. If we are to encourage change in order to live more sustainably, we must rethink the historic methods of urban planning and landscape architecture that we have relied upon for decades. Although green infrastructure measures are not intended as a silver-bullet solution, they have proven to be an incredibly valuable tool for an integrated approach to sustainable urban development. After reviewing this research, I would conclude that site-specific strategies for green infrastructure such as community initiatives or neighborhood action are the best way to address the importance of environmental justice (Burghardt et al., 2023). Reducing environmental and health risks for the greatest amount of people will have the greatest benefit to society. These benefits can be enhanced through retrofitting practices for the current urban landscape.

By ignoring the viable solutions provided, our societies will continue to expose millions to the risks of climate change, pollution, and negative health impacts. However, the good news is that there are plenty of viable solutions to work with. Through this research, it is clear that utilizing a range of connected solutions can have a much larger positive impact rather than focusing on the creation of a one-size-fits-all objective. By taking action based on these findings, we can take advantage of a once-in-a-lifetime opportunity to make our urban spaces safer, healthier, and more harmonious places to live.

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