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Kaitlyn G. Mahoney[1], Rory Cavicke[1], Oluwaseun M. Akinola[1], Jacob S. McCormick[1], Abiola S. Lawal[1*]

[1]School of Civil and Environmental Engineering, University of Connecticut, 261 Glenbrook Road, Storrs, CT, 06269, USA.

Email: alawal7@uconn.edu

Reimagining Multifunctional Green Space Design Approaches in Climate Resilient Cities

Abstract: Urban landscapes exacerbate the impacts of extreme temperatures and weather, and are hotspots for air pollution, flooding, and temperature spikes. Natural systems such as multifunctional green spaces can play a key role in protecting vulnerable urban landscapes while also improving urban livability.

Introduction

Climate change is causing more extreme temperatures and weather events that pose a risk to human health, safety, wellbeing, and economic viability. As such, cities around the world are turning to nature-based solutions for protection against worsening climate events. Nature based solutions, such as green infrastructure (GI), are engineered natural systems that are integrated into densely paved environments to reduce local temperatures, capture stormwater runoff, and prevent flooding or pollution, thus enhancing urban resiliency. Urban green space can also improve human health and social wellbeing by offering space to exercise, socialize, relax, and connect with nature and community. Thus, the growing need for urban green infrastructure (UGI) for climate adaptation and resiliency presents an opportunity to tap into the psychological healing effects these nature-based solutions have on humans.

Given that non-nature-based technologies alone cannot address worsening climate conditions, UGI adoption is proving to be an efficient and more importantly inevitable way to address climate resiliency. Furthermore, with 68% of the world's population projected to live in cities by 2050, there is an urgent need to prepare and develop urban areas that are environmentally, economically, and socially sustainable[1] and UGI adoption provides an opportunity to reimagine and design more sustainable, healthy cities (i.e., composition, morphology, and layout). However, addressing the issues of climate change and societal inequities simultaneously through UGI adoption is difficult considering the complex nature and scale of these problems present.

Current designs for optimizing multifunctional green spaces to achieve both engineering and social objectives are complicated. For one, most UGI studies use unreliable and inconsistent measures that make drawing concrete conclusions regarding the wellbeing benefits difficult. These inconsistencies lead to contradictions between designing green space for social and engineering outcomes. The lack of a unified methodology also complicates current UGI research regarding primary or secondary objectives, adoption methods, benefit assessments, and multifunctional integration. Greenspace diversity and characteristics add further complexity due to the support of certain objectives over others and the myriads of differing solutions make the issue even more challenging. Nevertheless, city planners must determine how to incorporate multifunctional green spaces as a mitigation strategy to achieve both social and resiliency objectives.

The process as depicted can certainly prove overwhelming, but to simplify things, we outline a methodology that couples engineering and social objectives through a design criteria framework (Figure 3). The proposed framework outlines the design criteria and features for each primary objective, with the overlapping features used to design efficient multifunctional green spaces. To demonstrate how this framework can be applied, we select a set of climate resiliency objectives whose design criteria can be linked with those needed to meet social objectives, thus demonstrating how both goals can be obtained. We discuss the design criteria needed for both climate resiliency and social economic benefits using the design considerations outlined in the framework.

Framework

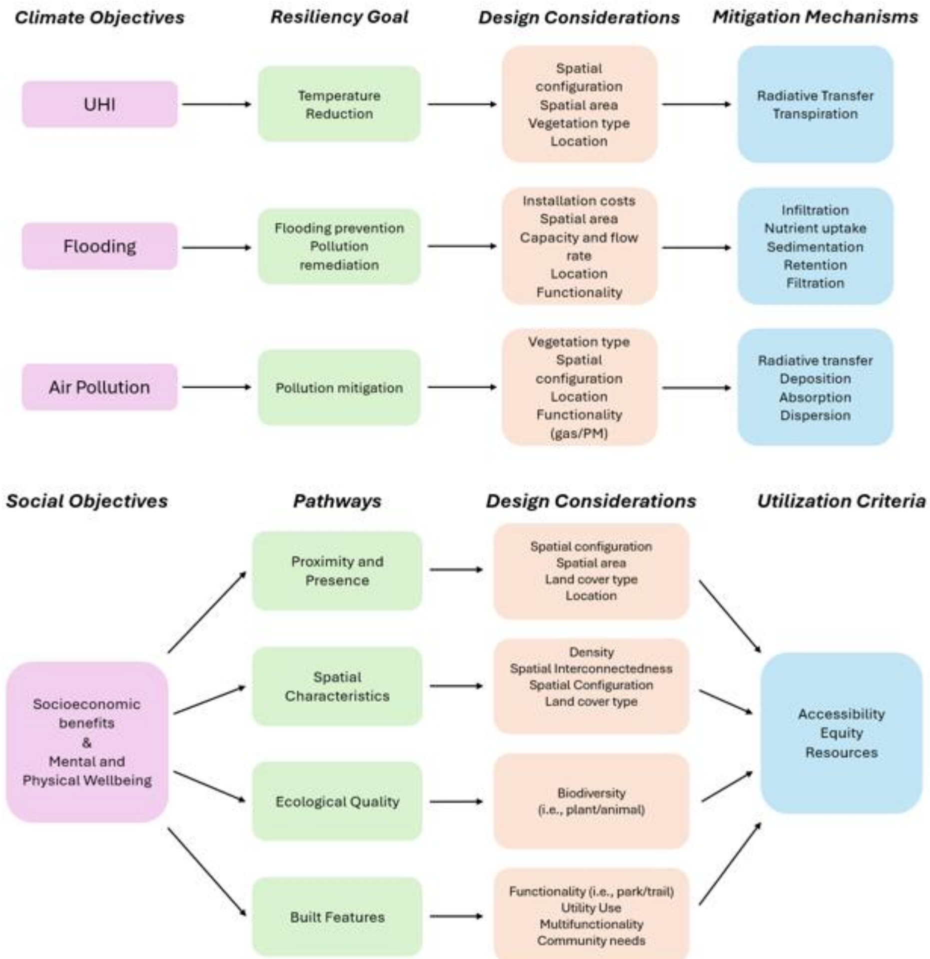

Figure 1: Engineering-Social Design Framework for Multifunctional Greenspace

Climate Design Considerations:

We examine three pressing concerns exacerbated by climate change: extreme temperatures, air pollution, and flooding in urban areas.

Extreme Temperatures: An issue that stems from increasing urbanization and worsening climate change is the intensification of the urban heat island effect (UHI). Urban areas often experience extreme temperatures due to the absorption properties of their built surfaces (i.e. grey infrastructure). These built surfaces readily absorb solar radiation in contrast to natural areas (Figure 1)[2]. The UHI effect is further exacerbated by climate-induced, decadal regional temperature increases (Figure 2)[2]. Increasing the ratio of green infrastructure to grey infrastructure can help reduce ground surface temperatures, cooling requirements, and improve the quality of life for urban residents.

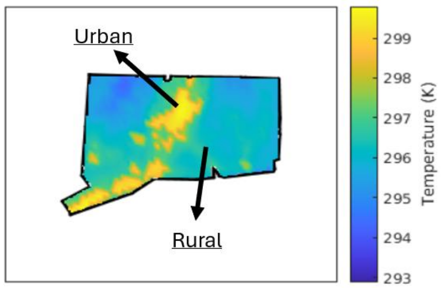

Figure 1: Averaged Urban vs Rural Temperatures (2010-2011) in Connecticut, USA.

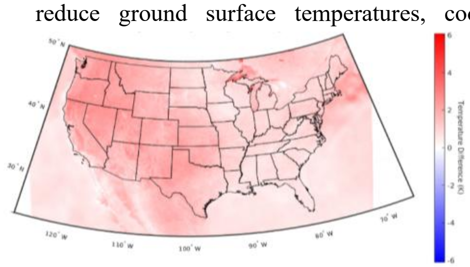

Figure 2: Averaged Noon Decadal Temperature Differences ([1980-1989] – [2010-2011]) across the US.

UHI considerations for engineering green spaces include the degree of cooling, spatial proximity, and range of cooling effects. Design considerations must also include vegetation density and type, which influence the range of cooling effects. However, while dense vegetative canopies prevent solar radiation from reaching surfaces during the day, it can also prevent radiative cooling at night. Planners must balance the space requirements, as large green spaces are scarce in urban areas.

Air Pollution: Air pollution mitigation mechanisms within greenspace include deposition, absorption, dispersion, and reduced solar radiation. Aerosolized particulate matter for example with diameters ranging from 2.5 to 10 µm ($PM_{2.5}$ and PM_{10}) can deposit on plant surfaces. However, this process is very complex, and ambient removal rates can vary greatly based on local climate conditions, leaf size and texture. Besides particulate matter, pollutant removal also encompasses pollutant uptake through absorption[3]. For instance, some species of trees can uptake gaseous pollutants such as NO_2, O_3, and SO_2 through their leaf stomata[4], making it critical to choose the proper species of tree to target site-specific pollutants. Trees also influence pollution exposure through aerodynamic dispersion, although this can be a non-linear relationship as trees can both disperse pollutants or trap them depending on the local aerodynamic phenomena[5]. Tree canopies shade the ground surface, preventing solar rays from intensifying smog formation[6], which can cause symptoms such as chest pain, coughing, irritation, and congestion. Consideration must also be made to choose species that emit low levels of pollen and reactive biogenic volatile organic compounds to ensure minimal air pollution contribution.

Flooding: Flooding has become more frequent in the coastal United States, putting a strain on infrastructure, and posing a risk to human health[7]. Current sustainable stormwater management practices call on green infrastructure and other nature-based solutions to reduce water pollution and flooding from extreme storm events. UGI can reduce peak flows and flooding by retaining stormwater where it lands and slowing the flow as it passes through soil and vegetation. Stormwater GI harnesses natural processes of sorption, filtration, infiltration, and evapotranspiration to direct water away from the existing gray infrastructure[8] and provide water treatment. UGI examples include bioretention basins, tree filters, and green roofs, but design considerations must account for cost and space. The lack of available land can drive up costs significantly. However, promoting multifunctionality can help attain multiple benefits, making the implementation of green infrastructure more worthwhile.

Social Design Considerations:

Greenspace comes in many forms, such as forest, grass, or shrubs, each carrying unique characteristics and optimum arrangement depending on the design goals. The configuration of these greenspace types can yield a myriad of unique settings that can be optimized to improve social wellbeing. However, linking wellbeing to specific green space characteristics is complicated by the reliance, in many cases, on self-assessment to measure wellbeing. Connecting physical and mental wellbeing to measurable characteristics of greenspace can guide planners towards maximizing the positive impact of urban greening. Here, we suggest an approach that focuses on *pathways* through which UGI provides social benefits as depicted in the proposed framework (Figure 3). We identify the accompanying design criteria that can be specifically linked with engineering design considerations.

Proximity and Presence: Proximity can be measured at the individual household level or local level, though the latter does not consider the travel time required to access neighborhood green spaces. Coupled with proximity, green land cover presence is another key factor. This aspect considers both the amount of green space cover in the area and the type of land cover (i.e. shrubs vs trees) for design considerations. Several studies have shown that proximity and presence, as defined here, are positively linked to mental and physical wellbeing. However, presence might be more complicated, as different types may elicit varied responses, and spatial area is not necessarily a proxy for positive connections with green space. For instance, access to a field, meadow, park, or forest could yield very different responses. The variety of UGI types provides a range of multifunctional and social benefits.

Spatial characteristics: Several studies have yielded important findings linking the spatial characteristics of greenspace to wellbeing, shedding light on yet another dimension for greenspace design. The spatial characteristics here capture the type, usability, and category of green space along with its spatial distribution. Some design criteria, such as patch density, indicate whether separate UGI elements are connected, integrated with other infrastructure like roadways or buildings, or exist as individual patches. For instance, a forest that borders a different type of green space, such as a meadow, could be connected by a trail. Spatial configuration such as alignment or shape is a key aspect to consider, while edge density which refers to the length of the vegetative area, is another important metric.

Ecological Quality: Ecological quality is often measured by the level of biodiversity, referring to the range and number of flora and fauna species located within an area. Additional categories associated with ecological quality include ecosystems or habitats. Research suggests that wellbeing is linked to the perception of greenspace quality, which is often associated with high biodiversity. Several studies have linked the mix of different biota to enhanced well-being[9]. As such, the design criteria here must consider the mix of flora, fauna, and habitat.

Built Features: Of all the pathways, there is overwhelming consensus that built-in features in green spaces lead to increased use. Several studies have noted that utilization in green spaces serves as a good predictor for wellbeing. For instance, researchers found positive correlations between greenspace attributes (playgrounds, sports facilities, walkways, etc.) and physical activity levels of nearby residents[10-13], which improved both mental and physical health. This is key, as there is evidence that simply increasing the amount of nearby green space does not correspond to the level of use by nearby residents without added functionality.

Overlapping of Social and Engineering Design Criteria:

Spatial characteristics along with both natural and built features emerged as specific design metrics of greenspace that impact both resiliency, and wellbeing outcomes across studies. However, their implementation and design specifications might hinder maximum benefits for both objectives, as conflicts can arise between engineering design considerations for climate resiliency and social design considerations. The suggested framework as depicted in Figure 1, can assist planners in identifying green space design features that achieve positive outcomes for both climate resilience and human wellbeing in multifunctional green spaces. The framework highlights how considering both engineering and social objectives, identifying strategies and design criteria that promote both resilience and wellbeing, can help planners maximize the positive impact of urban greening projects. Addressing both considerations will serve to strengthen urban resiliency.

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Author Contributions
The manuscript was reviewed by all authors. All authors have given approval to the final version of the manuscript.

Kaitlyn G. Mahoney: Writing - review & editing, Analysis, Visualization (Figure 3). **Rory Cavicke:** Conceptualization, Analysis, Writing - review & editing. **Oluwaseun M. Akinola:** Writing - review & editing, Visualization (Figure 1 and 2). **Jacob S. McCormick:** Writing - review & editing. **Abiola S. Lawal:** Conceptualization, Writing - original draft, review & editing, Analysis, Visualization, Supervision.

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Authors declare no competing interests.

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