

Community-based Approaches to Creating Adaptive Solutions for Urban Challenges: Two Case Studies

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ABSTRACT: Addressing diverse social, environmental, cultural, and economic urban challenges requires understanding them as dynamic, complex systems. This paper presents ongoing research within the Baltimore Social-Environmental Collaborative (BSEC), a U.S. Department of Energy Urban Integrated Field Laboratory (IFL). Focused on Baltimore as a mid-sized U.S. industrial city grappling with equitable solutions to climate change and social injustice, BSEC involves diverse collaborators. It adopts an iterative collaborative cycle relating regional climate trends and other factors with environmental and social priorities to inform community-guided equitable climate solutions. This paper highlights two projects within BSEC's knowledge co-creation process. The first addresses energy poverty, employing spatial statistical techniques and mapping to investigate the spatial distribution of energy burden and provide insight into the social injustice in energy access. The second uses field surveys, computation, and community engagement to develop a data-driven decision-making approach to integrating Blue-Green Infrastructure (BGI). The paper concludes with an overview of engagement methods important to BSEC and informative for other architectural researchers.

KEYWORDS: climate Crises, blue-green infrastructure, community collaboration, equitable pathways, urban energy poverty

INTRODUCTION

Human activities are the dominant cause of global warming trends (EPA 2017). Since the Industrial Revolution, human activities including electricity generation and commercial and residential building construction, agriculture, manufacturing, land use changes, and transportation, have released greenhouse gases (GHGs) into the atmosphere. GHGs, including carbon dioxide as a primary emission, trap heat and cause increases in the earth's surface temperature (EPA 2017). Moreover, land use changes related to urbanization are associated with the urban heat island (UHI) effect, resulting in warmer environments and increased demand for cooling electricity. "Climate change, desertification, and biodiversity loss are heavily interlinked and pose existential challenges to humanity" (United Nations Climate Promise 2022). "Individuals and whole communities – including those most vulnerable and marginalized – have the opportunity to engage in climate action in sustained and more meaningful ways" (Kizhakkethottan 2024). Although climate change is a global issue, equitable pathways for community climate change resilience require local knowledge and acceptance for successful implementation (IPCC 2023). "As the effects of climate change worsen, the heaviest burdens fall on underinvested urban communities and neighborhoods, which already experience more than their share of environmental challenges, including air and water pollution, flooding, a lack of trees, and excess heat" (BSEC 2024). In September 2022, the U.S. Department of Energy (DOE) pledged \$66 million for three Urban Integrated Field Laboratories (IFLs) in Baltimore, Chicago, and the Texas Gulf Coast. "These IFLs will expand the understanding of climate and weather events and their impact on urban systems, including diverse demographic characteristics; differing climate-induced pressures on people and infrastructure; and varied geographical settings" (DOE 2022). The Baltimore Social-Environmental Collaborative (BSEC) seeks a new paradigm for urban climate research through an iterative collaboration with local communities. BSEC engages collaborators from neighborhood organizations, city government, non-government community development organizations, federal agencies, and several universities. The team is working to establish a people centered, transdisciplinary IFL that begins with community (human health and safety, affordable energy, and others) and city (improved water quality, decarbonization, functioning infrastructure, and addressing heat) priorities, resulting in observation networks that will deliver climate science and design solutions capable of supporting those priorities. The process involves continuously updating observations and modeling to inform community-guided "potential equitable pathways" for climate action. The decision analysis employs an interdisciplinary approach, combining data science and statistics, modeling and simulation, visual analytics, and domain expertise with on-the-ground knowledge and lived experience of local communities to assess and identify resilient paths of action (Hadjimichael 2023).

This paper presents two cases of research conducted within the BSEC project, illustrating the complex interrelations within built environments. The first case uses statistical regression techniques to examine the links between urban energy poverty and determinants, including sociodemographic, architectural, and urban factors (e.g., UHI). We treat census tracts as the unit of analysis and use public data on eight variables as the proxies to capture climate, demography, urban design, architecture quality, and energy poverty in Baltimore. In the second project, we report

ongoing work to identify UHI mitigation solutions using blue-green infrastructure (BGI). We first propose computational methods to investigate the effectiveness of BGI design proposals to reduce Baltimore’s UHI. We will then work with communities in Baltimore to identify their needs, wants, and opinions related to the research questions and simulation results in an iterative decision analysis process. The paper concludes with an overview of engagement methods important to BSEC and informative for other architectural researchers.

1.0 ENERGY JUST CITY – EVALUATION OF BALTIMORE’S URBAN ENERGY POVERTY

Access to clean and affordable energy is crucial to the well-being and development of our society (Bouzarovski and Petrova 2015). Energy poverty is defined as insufficient access to modern energy services for domestic needs (Wang et al. 2021; Bouzarovski and Thomson 2018; Awaworyi Churchill, Smyth, and Trinh 2022). In 2020, more than one in four households in the U.S. were highly burdened with energy poverty, and approximately 50% of those households experienced severe energy poverty (Drehobl, Ross, and Ayala 2020a). Additionally, the sections of society that have undergone marginalization and disinvestment experience energy poverty at disproportionate levels compared to the rest of society (Wang et al. 2021; Bednar, Reames, and Keoleian 2017). It is hypothesized that Urban Energy Poverty (UEP) is a form of social injustice affected by socio-spatial inequalities that prevail in cities. This research aimed to gain an advanced understanding of the social, spatial, and economic determinants of UEP in Baltimore City.

Baltimore has undergone years of racial and economic segregation (Grove et al. 2018). The legacy of these practices has been ingrained in the built environment, which continues to perpetuate unjust living conditions for the marginalized population. For example, 19.6% of the population lives under the Federal Poverty Line, almost double the national average (Shrider and Creamer 2022; U.S. Census Bureau 2022). These conditions have created higher UEP in Baltimore City than at the national level. The average energy expenditure for low-income households, i.e., below 100% of the Federal Poverty Line, was reported to be 16% (Ma et al. 2019). In Baltimore, one in every five low-income households experiences a severe energy burden of 19% (Ma et al. 2019), considerably higher than in other eastern U.S. cities. Energy access is critical for meeting basic needs and improving economic opportunities, especially for women, children, and minority groups. However, climate change exacerbates environmental shocks, affecting vulnerable populations and hindering progress toward poverty reduction. In this case study, we identify the local determinants of UEP in Baltimore City and measure their effects to inform possible city-scale mitigative measures.

1.1 Methods

We used spatial statistical methods at the census tract level to identify the links between UEP and its socioeconomic, environmental, and urban determinants. A review of existing studies helps classify the determinants into four categories: socioeconomic, household demographic, architectural and urban, and environmental. We used exploratory regression to narrow the initial list from twenty to eight determinates (Table 1) to reduce complexity and multicollinearity. We then applied generalized linear regression and spatial regression for the selected features to examine the effects of the UEP determinants. The results are visualized and analyzed through mapping.

Table 1: Determinants of UEP and its sources Source: (Authors 2024)

Determinants	Metric	Source	Acronym
Urban Energy Poverty (UEP)	Energy Burden	Low-Income Energy Affordability Data - LEAD Tool 2018	EB
Socioeconomic determinants	Median household income	ACS 2017-2021	L_INC
Household demographic determinants	Percentage of single-parent households	SVI by CDC 2016-2020	SMH
Urban and architectural determinants	Health status	PLACES by CDC 2021	HLTH
	NDBI value	USGS 2021	NDBI
	Architecture quality	311 data 2018-2020	ARCHQ
	Urban Heat Island effect (Proxy)- Average summer surface temperature	NOAA 2021	UHI
	Percentage of households using alternate (alternate to electricity) fuels as primary heating fuel	ACS 2017-2021	FUEL
Environmental determinants	Diesel particulate matter in the air	EJI 2014-2016	AIRQ

1.2 Results

Statistical analyses confirm that UEP is affected by the determinants of interest. The ordinary linear regression model of the selected features shows that median household income, percentage of single-parent households, health status, diesel particulate matter, primary household heating fuel, and architecture quality have a highly significant effect on UEP, whereas the UHI and Normalized Difference Build-up Index had a small effect on UEP (Table 2).

Table 2: Generalized Linear Regression Results. Source: (Authors 2024)

Variable	Coefficient	Standard Error	t-Statistic	Probability	Robust_SE	Robust_t	Robust_Pr	VIF
Intercept	12.5	2.92	4.3099	0.000030	3.076	4.094596	0.000068	
L_INC	-1.69	0.46	-3.62	0.000389	0.539	-3.146	0.001931	5.99
SMH	0.016	0.006	2.67	0.008136	0.00782	2.160	0.0319	1.77
HLTH	0.083	0.012	6.63	0	0.014168	5.892	0.00000	7.24
UHI	-0.037	0.019	-1.97	0.050093	0.014423	-2.599	0.010082	3.67
NDBI	0.022	0.0112	2.007	0.046	0.010629	2.122	0.035080	4.07
AIRQ	-1.63	0.4917	-3.325	0.001070	0.5431	-3.011	0.002963	3.33
FUEL	0.016	0.00347	4.64	0.000008	0.003394	4.758	0.000050	1.498
ARCHQ	0.014	0.00316	4.61	0.000009	0.004262	3.434	0.000742	1.749

Furthermore, a Multiscale Geographically Weighted Regression (MGWR) Model was created with an R² value of 0.8567 and Akaike information criterion (AIC) value of 197.5. The standardized coefficients from MGWR confirm that socio-spatial variables are significant in describing UEP (Table 3). Health status and income levels have the highest influence, respectively. The racially and economically segregated neighborhoods of Baltimore City have always been victims of respiratory diseases due to poor housing conditions. In 1937, the Baltimore health commissioner highlighted the association between poor housing quality and the inner-city tuberculosis rate (Leclair-Paquet 2017). There have been several reports that cite the relationship between socioeconomic conditions and asthma patients in Baltimore City (Ahluwalia et al. 2013; Grant and Wood 2022; Kimes et al. 2004).

Table 3: Summary statistics for coefficients estimates. Source: (Authors 2024)

Variables	Mean	Standard Deviation	Minimum	Median	Maximum
Intercept	0.0253	0.0374	-0.0404	0.0303	0.0874
L_INC	-0.2469	0.0392	-0.3390	-0.2516	-0.1625
SMH	0.0542	0.0697	-0.0867	0.0346	0.2184
HLTH	0.5501	0.0009	0.5488	0.5502	0.5517
UHI	-0.0940	0.0237	-0.1437	-0.0936	-0.0450
NDBI	0.0836	0.0173	0.0520	0.0827	0.1241
AIRQ	-0.1610	0.0055	-0.1711	-0.1625	-0.1502
FUEL	0.1591	0.0011	0.1572	0.1590	0.1607
ARCHQ	0.1539	0.0583	0.0713	0.1481	0.2457

In line with scholarship, income negatively correlates with UEP (Mashhoodi, Stead, and van Timmeren 2019), while single-parent households (Robinson 2019), health status (Hernández 2016), lack of building quality (Cyrek and Cyrek 2022), and efficiency (Taltavull de La Paz et al. 2022) positively correlates with UEP. Interestingly, UHI aids in lowering UEP due to its influence on building energy consumption (Li et al. 2019). Contrary to the literature, the air pollution proxy, Diesel Particulate Matter (DPM) concentration (Wang, Maruejols, and Yu 2021), has a negative correlation. This could be because DPM is generally high near industrial and urban centers with high vehicular activity and experience higher temperatures.

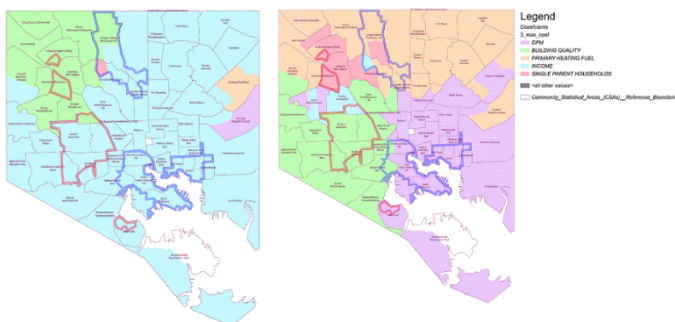


Figure 1: Second (left) and third most influential factor of UEP by census tract. Source: (Authors 2024)

The study confirms that Baltimore City presents a case where building stock quality, income, health, and race are deeply interconnected with energy burden. The western parts of the city (Rosemount and Southwest Baltimore) with the highest energy burden are highly affected by health, status income, and architecture quality (Figure 1). These areas have been historically affected by major blight conditions. Weatherization assistance for low-income populations could be extremely helpful. Spatial injustice without intervention can perpetuate a vicious cycle of energy injustice, widening the gap in energy inequality. Equitable pathways for climate action, such as retrofitting of inefficient housing stock, upgrading to clean energy systems, and addressing UHI can simultaneously address energy, greenhouse gas (GHG) emissions, and the local desire for improved streetscapes and buildings.

2.0 BLUE-GREEN INFRASTRUCTURE TO ADDRESS UHI

Urban development substantially alters natural surfaces, resulting in a range of environmental effects (Girardet 2020). Of them, the UHI effect is an alarming phenomenon where the ambient temperature in cities becomes higher than in the surrounding rural areas (Erell, Pearlmutter, and Williamson 2011). Temperatures in several large U.S. cities, including Baltimore, have increased by about 0.5-3.08 °C over the last 100 years (Akbari, Pomerantz, and Taha 2001). Relatedly, extreme heat and flooding are among Baltimore’s most critical environmental challenges (Baltimore Office of Sustainability 2015). As indicated above, the median energy burden of low-income households in Baltimore is four times higher than that of non-low-income households (Drehobl, Ross, and Ayala 2020b). Therefore, in the interest of equitable solutions, these neighborhoods are a focus for climate action intervention.



Figure 2: Urban context of Baltimore with limited natural elements. Source: (Author 2023)

The European Commission defines Blue-Green Infrastructure (BGI) as “a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services” (European Environment Agency 2013). The term BGI emerged in the context of planning efforts in Sao Paulo, Brazil, specifically aimed at creating a network of “green and blue” infrastructures in response to flood risks (Frischenbruder and Pellegrino 2006). Literature from 1989 to 2015 indicates a shift from earlier concepts like Green Infrastructure (GI) to BGI, reflecting an integrated approach that aims at various ecosystems and associated services (Silva and Wheeler 2017). This shift moves from a simplistic “land use view” toward more adaptable ecosystem service-based solutions (Haase 2015; Haase, Haase, and Rink 2014). BGI incorporates not only green (vegetation) and blue (water) elements and processes but also interventions like permeable pavements, bioswales, retention basins, and constructed wetlands as an integrated whole (Ghofrani, Sposito, and Faggian 2016; Scott et al. 2016). These interventions can create a cooler outdoor microclimate in the city, decreasing the need for indoor cooling and, thus, reducing residents’ energy burden (Drehobl, Ross, and Ayala 2020b).

It is hypothesized that BGI interventions can effectively mitigate the UHI effect (Gonzalez-Meler et al. 2013; Kuller et al. 2018; USEPA 2015). However, little research has investigated the impact of BGI on the UHI effect in Baltimore. Moreover, the lack of data-driven decision-making approaches that help create a comfortable urban microclimate within communities, especially where residents are impacted by UEP, motivated us to develop one for Baltimore by integrating BGI. From this approach, several BGI design and implementation directives can be generated to mitigate climate risks and reduce the energy burden on Baltimore’s residents.

2.1 Project goals

The project goal is to establish a comprehensive framework that facilitates BGI implementation as an equitable climate solution in Baltimore neighborhoods. This framework aims to methodically assess and suggest BGI initiatives to ensure effective implementation, addressing environmental concerns while garnering community support and endorsement. This project is guided by two key objectives: 1) investigating the potential of BGI interventions to improve outdoor environmental conditions in terms of air temperature, relative humidity, and air velocity at the neighborhood scale, and 2) exploring the influences of BGI interventions on outdoor thermal comfort levels, with a focus on community acceptance of widespread adoption. These objectives align with the broader goal of establishing a resilient and sustainable urban environment in Baltimore through strategic BGI implementation. A fundamental goal of the study is to devise decision-making approaches that combine quantitative and qualitative data obtained from computational modeling and community engagement.

Community engagement is a fundamental principle that fosters creating sustainable, inclusive, and livable urban spaces. Inclusivity is a core principle of community engagement. By involving a diverse range of community members, including marginalized groups, in the design process, urban planners and designers can work towards creating equitable spaces that cater to residents’ needs (Gehl 2011). Communities possess invaluable local knowledge and a unique perspective on the urban environment (Moughtin 2003). This knowledge is indispensable in crafting urban design solutions that resonate with the people most impacted. When people are involved in shaping their urban environment, they develop a sense of pride and responsibility (Talen 2000).

2.2 Methodology

This research commenced in January 2023 and spans five years. The methodology involves an iterative approach that builds from a literature review and involves computational modeling of UHI (Tariq, Poerschke, and Lulo 2023) and resident input. Quantitative data from simulation studies and qualitative inputs from the community workshop will be combined using decision science methodologies. The literature review identifies the causes of UHI, scopes of BGI, and critical factors to human outdoor thermal comfort. Vulnerable areas in Baltimore are then selected based

on the literature review and field surveys. Community Workshop 01 involves presenting potential BGIs to stimulate discussions and understand community preferences and expectations. Subsequently, a simulation study using ENVI-met software predicts environmental impacts, comparing existing conditions with modified models incorporating the preferred BGIs. The impact of BGIs will be analyzed based on the impact on outdoor air temperature, relative humidity, air velocity, mean radiant temperature, and outdoor thermal comfort using the Universal Thermal Climate Index (UTCI). During Community Workshop 02, simulation outcomes will be disseminated, reassessing community acceptance. BGI design guidelines will be developed based on effective and socially acceptable BGI interventions, integrating community perspectives and simulation outcomes, utilizing knowledge co-production for inclusive decision-making. An “XLRM” framework, which considers external factors, policy levers, relationships, and performance metrics (Kwakkel 2017), will be utilized to discern the most effective and acceptable BGI intervention for Baltimore. The research intention is to develop a comprehensive BGI intervention design and implementation framework that is applicable in Baltimore and adaptable to similar contexts.

2.3 Study significance

The symbiotic relationship between participation tools and urban interventions is pivotal in urban design practices. Participation tools serve as conduits for gathering data from urban interventions, facilitating the synthesis of the collective knowledge base. Simultaneously, urban interventions can offer context-specific platforms that yield novel perspectives and avenues for study. Despite their complementary nature, the comprehensive conceptualization of urban interventions and participation tools within urban design processes remains a largely disregarded interdisciplinary research domain (Ataman and Tuncer 2022). This project unveils new vistas and themes, each contributing to an enriched understanding of urban design dynamics by generating interdisciplinary and integrated state-of-the-art BGI intervention guidelines for urban planners, policymakers, and community decision-makers.

3.0 DISCUSSION – NEED AND METHODS FOR COMMUNITY ENGAGEMENT TOWARD EQUITABLE PATHWAYS

More than 3.3 billion individuals now reside in regions highly susceptible to the effects of climate change (IPCC 2023). Without adequate support for climate adaptation, they confront an increasing array of hazards. Recent agreements on climate adaptation funding indicate a growing commitment to assisting frontline communities that are socially and institutionally disadvantaged, belong to low-resource groups, and face a disproportionate burden from climate change impacts (Araos et al. 2021; Sanders 2021). We argue that there is a growing need for scholars and practitioners to bring forth the active involvement of local communities for sustainable and inclusive solutions in urban development. Fostering community engagement for climate change adaptation has become a cornerstone for not only acknowledging diverse perspectives but also co-creating interventions that are contextually relevant and socially just (Harrison et al. 2022; Moser 2014; Samaddar et al. 2021).

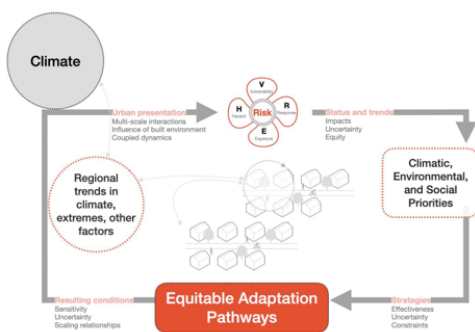


Figure 3: BSEC’s focus on Equitable Adaptation Pathways; Source: (The Baltimore Social-Environmental Collaborative IFL Proposal, Benjamin Zaitchik)

BSEC’s focus on Equitable Adaptation Pathways (Figure 3) reflects a new urban climate research paradigm integrating iterative collaboration with local communities. Through investigating building to metropolitan-scale climate change impacts, climate risks, priorities, and constraints are translated into equitable adaptation pathways to be reviewed and fine-tuned in partnership with community stakeholders. Such an approach helps ensure that future urban development initiatives align with the needs and aspirations of the people they serve, fostering a sense of ownership and resilience.

Achieving effective community engagement involves tailoring strategies to specific community needs and contexts (Samaddar et al. 2021). This includes fostering inclusivity and implementing participatory methods, such as workshops, town hall meetings, and focus groups, to facilitate direct interactions between community members and policymakers. Technology, such as social media and online platforms, enhances outreach and ensures diverse perspectives. Equipping community members with the necessary knowledge and skills for active participation in decision-making is a key aspect of capacity-building that helps sustain engagement. Storytelling and visual communication methods are also beneficial in overcoming language and literacy barriers, making information more accessible to a broader audience (Moser 2014). Addressing urban challenges requires interdisciplinary collaboration among stakeholders, including government agencies, NGOs, and local businesses. Adapted to local contexts, these methods are crucial for genuine community engagement and equitable urban development (Adib,

Wu, and Flohr 2023; Samaddar et al. 2021). Moreover, addressing sustainability challenges like climate change requires new knowledge to tackle their social and ecological complexities and scale. Knowledge co-production fosters actionable and equitable science, bridging academic disciplines and social spheres amidst rapid social and environmental change (Zurba et al. 2022). Equity, commonly understood as the fair and just treatment of individuals, is integral to knowledge co-production. Achieving equity involves intentional efforts throughout project processes, eliminating obstacles to participation. Non-indigenous researchers should practice empathy, strive to understand local perspectives, and identify participation obstacles for indigenous members. Proactive measures are crucial, underscoring the importance of collaborative planning with local partners to recognize and address barriers early (Herman-Mercer et al. 2023).

Community involvement in climate solutions is believed to enhance decision-making quality, trust, democracy, and community satisfaction, fostering ownership over green spaces and longevity of projects. However, these benefits can be compromised by unequal representation and obstacles to sustained participation (O'Donnell et al. 2021), especially when engagement is under-resourced and prioritizes dominant voices over marginalized groups. This issue is exacerbated when local and national governance structures do not support true power-sharing between governmental and non-governmental stakeholders. Effective decision-making requires engagement strategies that genuinely consider, reflect, and respond to community needs and capabilities. This process involves various methods, from informative public relations campaigns and lectures to more interactive approaches such as canvassing, public meetings, surveys, and comments. Additionally, consultative methods like interviews, focus groups, facilitated group discussions, expert workshops, and co-creative methods like learning alliances and living labs are used. Surveys and questionnaires are also commonly utilized, alongside the growing use of social media and GIS-based methods. However, digital approaches can also reinforce exclusion. The choice of engagement methods is influenced by factors including goals and motivations for engagement, resource availability, and timing considerations. Understanding appropriate methods and resources for equitable inclusion is crucial in minimizing negative impacts, requiring exploration of their efficacy across contexts and community groups (Rahtz et al. 2023).

4.0 CONCLUSION

Concerns about Urban Energy Poverty and Urban Heat Island extend beyond rising surface temperatures and into the realms of environmental justice, equity, and public health. These concerns necessitate the development of effective mitigation measures, many of which come in the form of green infrastructure projects and improved housing. We introduced two ongoing architecture and landscape architecture case studies within the BSEC IFL to highlight the need to integrate community-engaged science for developing equitable climate solutions. These projects illustrate the breadth and depth of BSEC's endeavors and exemplify innovative strategies to generate meaningful change. By championing climate and social solutions aligned with community values, BSEC's model of community-oriented interdisciplinary urban science holds immense promise and lays the groundwork for transformative urban interventions. Ultimately, achieving equitable adaptation pathways requires proactive engagement with both professionals and community members to foster collaboration, co-create solutions, and ensure that adaptation strategies are responsive to the diverse needs and perspectives of urban residents. By embracing participatory approaches and prioritizing community input, planners and designers can create more resilient, inclusive, and sustainable cities better equipped to address the challenges of climate change and social equity.

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