THE EFFECT OF GREEN INFRASTRUCTURE ON EQUITABLE ACCESS TO ECOSYSTEM SERVICES

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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ADAPTING URBAN INFRASTRUCTURE FOR CLIMATE CHANGE AND THE EFFECT OF GREEN INFRASTRUCTURE ON EQUITABLE ACCESS TO ECOSYSTEM SERVICES

As of January 2022, the eight previous years of weather have been the eight warmest ever recorded (Borenstein, 2022, para. 10). This pattern of warmer-than-average weather is being spurred on by climate change and humanity's inability to curb greenhouse gas emissions such as carbon dioxide. According to the National Oceanic and Atmospheric Administration, the concentration of atmospheric carbon dioxide has risen to 418 parts-per-million (NASA, 2022). This concentration of atmospheric carbon dioxide reaches a level higher than anything in recorded and understood prehistoric records. As such, current levels of greenhouse gas emissions are doing far more to advance climate change than prevent it. With this inability to stall climate change, it is imperative that society begins the time-consuming and necessary steps to protect the wellbeing of present and future generations. These steps require significant public and private investment in resilient infrastructure that can withstand the effects of future generations of climate.

This STS paper explores the relationship between the infrastructure and built world that provides for the essential needs and services of society. In particular, this analysis explores how different groups of society experience disproportionate levels of access to the ecosystem services provided by infrastructure and environment. This pattern of exclusion is related to the larger trends of environmental injustice that disproportionately affect marginalized communities. To compound on these issues, the same groups experiencing unequal access to ecosystem services are among those most likely to be affected by the climate vulnerabilities exacerbated by climate change. Herreros-Cantis and McPhearson (2021) found such a relationship in their study of New York City where they mapped mismatches in the supply and demand of ecosystem

services. Their research found consistent patterns of environmental injustice within communities of racial minorities and low-income residents (p. 13). This disparity in access and its underlying causes will be modeled and explained through the lens of Actor Network Theory (ANT) as outlined by Michel Callon, Bruno Lator, and John Law (Cressman, 2009). Furthermore, the supply of ecosystem services will be analyzed through the lens of ANT in order to identify the links between network actors that facilitate or prevent access to ecosystem services. These various stakeholders will be modeled in order to pinpoint barriers and solutions to equitable ecosystem service access. Additionally, the ANT lens will be applied to the coupled technical project to examine a proposed development of green infrastructure. This overall analysis is particularly pertinent as society must make considerable haste towards climate-proofing the modern world in a dwindling timeframe. While an immediate response is necessary, it must be stewarded in a thoughtful manner that prevents past patterns of exclusion that have resulted in harm and even loss of life for the less fortunate.

The associated technical paper is a proposed solution to inadequate and outdated stormwater infrastructure that establishes a holistic, multi-use space. This technical element includes the sustainable redevelopment of a failing shopping mall that possesses significant areas of impervious surfaces like asphalt, concrete, and roofing as shown in Figure 1.

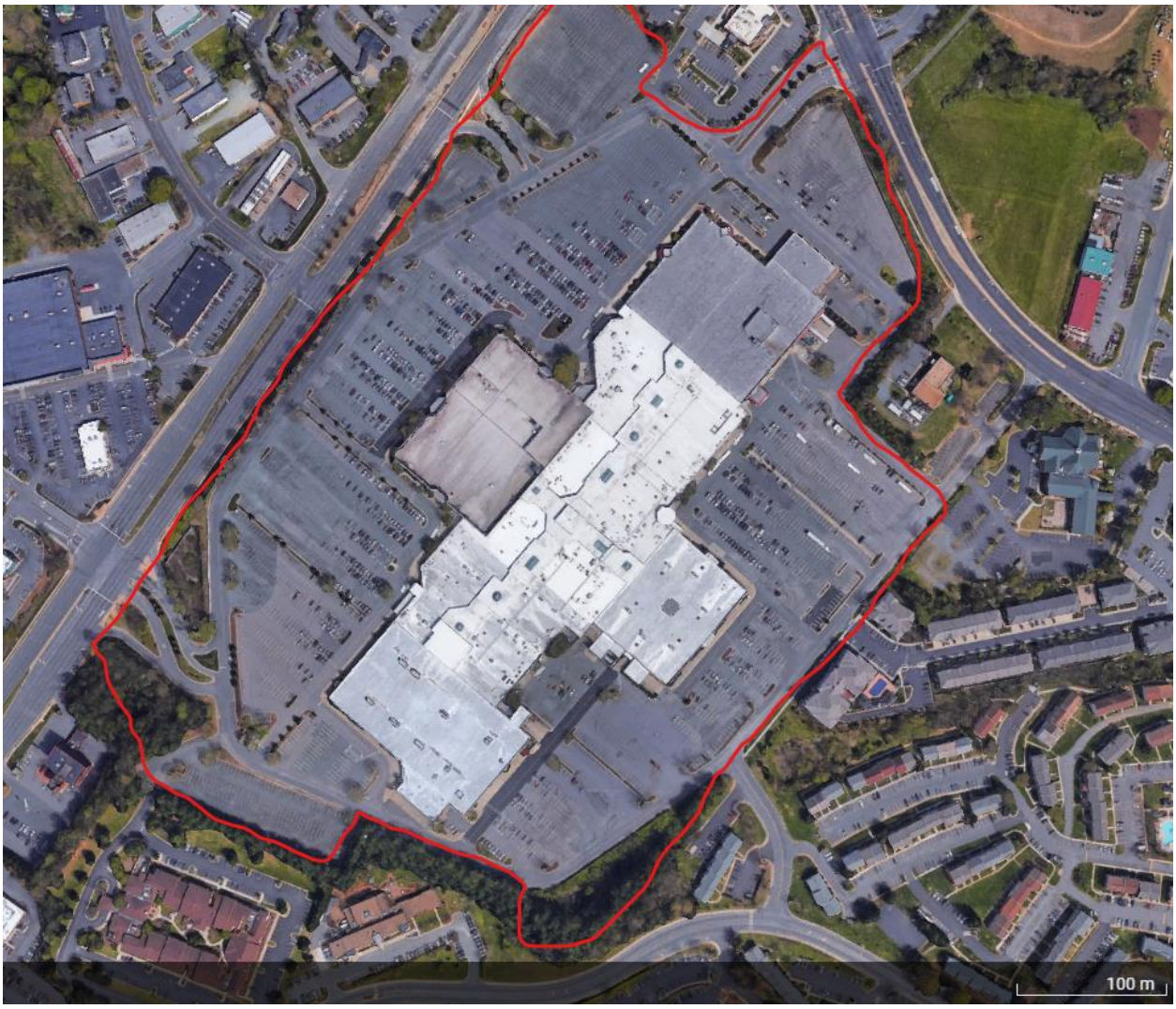

Figure 1: Overhead view of Fashion Square Mall. Outlined in red, is the present conditions for the site of focus in the technical report that are modified with the proposed sustainable redevelopment. (Google Earth, 2022).

The large degree of imperviousness on this site contributes to increased stormwater runoff and subsequent consequences for the immediate and downstream watersheds. In addition to the site's environmental detriments, the commercial decline of the mall has led to disuse and underutilization by the community. This technical work is the product of undergraduate civil engineering students Neha Awasthi, John Gore, Burke Haywood, Shreya Moharir, Annalee Wisecarver, and Rachel Yates. The resulting technical report was produced under the advising of Teresa Culver. As seen in Figure 2, the proposed redevelopment aims to reduce the effects of

stormwater runoff, while also designing a space that promotes public utilization beyond just stormwater management.

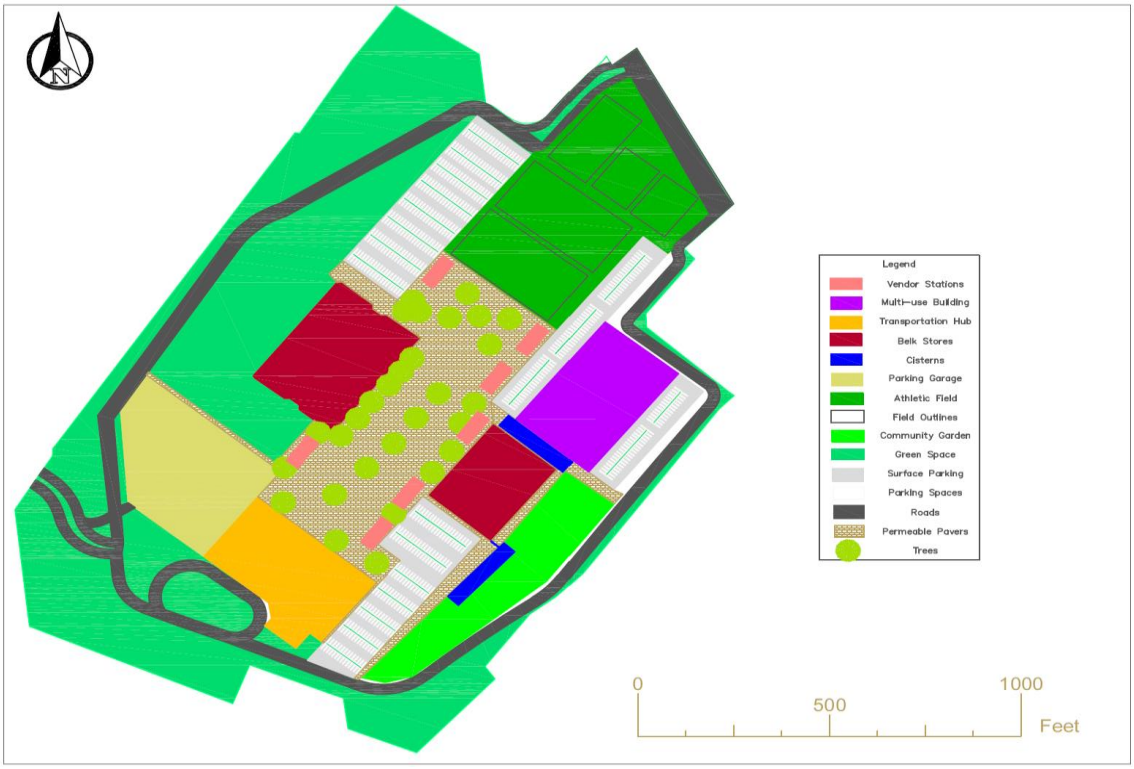

Figure 2: Proposed redevelopment design of Fashion Square Mall. This redevelopment transforms parking lots and vacant stores into green space and other community amenities. (Awasthi, Gore, Haywood, Moharir, Wisecarver, and Yates, 2022).

This work addresses inadequate infrastructure while also being mindful to design for future conditions that will be heavily impacted by climate change. The technical body of work lays the groundwork for redeveloping other failing commercial sites into mixed-use developments that reincorporate the natural environment. Elements of landscape restoration and green infrastructure are prevalent throughout the work as they are integral to harnessing ecosystem services in ways that are environmentally, economically, and socially acceptable. This work aims to satisfy the modern consensus for progress that aligns with the triple bottom line. Therefore, this technical work serves as a framework for similar projects around the globe that are seeking to combine resilient infrastructure investment with community development.

This tightly coupled technical work and STS research highlights the need for communities across the globe to adapt to climate change and implement resilient infrastructure. As established by Kaplan and Ba Tran (2022), 80 percent of communities across the U.S. experienced at least one day of abnormally high temperatures that will only become more common (para. 22). With so many finding themselves impacted by climate change, the work presented by the technical and STS paper will be invaluable to improving the lives impacted by heat waves, flooding, and other extreme weather events. While the technical work provides a framework for developing resilient infrastructure, the STS research demonstrates how that process must be stewarded to ensure that past practices of exclusion don't return and prevent access to the essential ecosystem services resulting from resilient infrastructure development.

CONDITIONS AFFECTING THE URBAN ENVIRONMENT AND SUPPLY OF ECOSYSTEM SERVICES

INTRODUCTION TO THE ROLE AND SUPPLY OF ECOSYSTEM SERVICES

While it has become easier than ever to separate modern life from the natural world surrounding it, it is important to remember that human wellbeing is fundamentally dependent on natural processes and cycles that sustain all life. These processes and cycles can collectively be referred to as ecosystem services or the benefits derived from the natural environment. As defined by the Millennium Ecosystem Assessment (2005), ecosystem services can be divided into provisioning services, supporting services, cultural services, and regulating services (Figure A). With the rise of urbanization, growing numbers of people find themselves disconnected from the natural environment and the services it provides. Moreover, society is encompassed by a built world that often fails to replace what is lost when an environment transitions into heavily managed or developed land.

In the context of ecosystem services, provisioning refers to the capacity for the environment to produce resources such as food, water, and timber. These services are often entirely removed from the urban setting as land is a premium and required for efforts like housing or economic development. As these services become absent in cities, the demand for them shifts to areas outside the city limits and creates a relationship where rural areas provide the needed raw materials to sustain urban development. While this relationship can be mutually beneficial in economic terms, it creates a resource dependence that can be threatened by a future with changing climate. Furthermore, with issues of water and food scarcity becoming a growing concern, it is important for cities to maintain the ability to provide food, water, and shelter from locally available resources. While habitat restoration and expansion can ultimately provide these needs, the population density in urban areas demands a level of land use that is at odds with this

goal. As such, a combination of environmental restoration and technical solutions, such as urban agriculture and rainwater harvesting, will be imperative for many cities' pursuit to sustainably provide for future generations.

In addition to what we extract from the environment, there are a number of constant life-sustaining processes, such as photosynthesis, nutrient cycling, and habitat provisioning, taking place daily. While these processes are indirectly essential for human welfare in the urban context, they are absolutely essential for the native species and fauna present in all cities. The preservation of urban biodiversity has grown increasingly important as growing numbers of species face endangerment and extinction. As Beatley and Brown (2021) explain, the human influenced nature of urban habitat encourages a unique collection of species to make their home within cities (p. 782). Additionally, endangered species are among those taking advantage of the variety of ecosystems present with cities. In fact, a 2016 assessment of threatened species in Australia found that urban habitat supported more threatened species than non-urban areas (Beatley and Brown, 2021, p.777). As self-appointed stewards of the natural world, it is humanity's duty to preserve biodiversity and the variety of species that coexist with society. Therefore, the capacity for urban environments to provide habitat is an essential component of preserving urban biodiversity and fostering human-nature connections within communities.

The environment also plays an essential role in providing public spaces that offer recreation, aesthetic beauty, and numerous health benefits (Beatley and Brown, 2021, p.775). Nature trails, riverwalks, and parks all provide urban communities with space that can be used by residents to exercise, congregate, or simply travel through. Green space also plays an important role in the evaluation of property values. As established by The Nature Conservancy (2016), tree-lined streets and close adjacency to parks with green space can boost property values and

subsequent tax income for the property (p.23). It should be noted however, the relationship between green space and property evaluations is not always as beneficial as it seems to residents. The addition of natural amenities can trigger an increase in housing expense and cost of living that displaces low-income residents in the process known as gentrification (The Nature Conservancy, 2016, p.21). In a more beneficial light, The Nature Conservancy (2016) found that green spaces have tremendous ability to help medical treatment, mental health, and encourage healthy habits through the human-nature connection known as biophilia (p.11). Collectively, urban nature and green space can extensively offset the burden placed on public health systems and maintain the greater overall health of society.

Regulating services make up the category of ecosystem services that are most often addressed with large-scale infrastructure solutions. The ability for the natural environment to regulate conditions like flooding, water quality, and temperature all within the same space is unparalleled by most technological solutions. Thus, in the transition from virgin habitat to city blocks, urban settings have been stripped of their original defense against extreme weather and other environmental impacts. This missing buffer against adverse effects of the environment is increasingly relevant as climate change increases the severity and frequency of weather events like hurricanes, thunderstorms, drought, and heat waves. Without natural landscapes that infiltrate stormwater and dissipate heat, replacement services have to be provided through public infrastructure.

In an effort to replace these missing regulatory services, society employs a full range of man-made solutions such as water treatment, flood barriers, sewers, air conditioning, and landscape architecture (Depietri and McPhearson, 2017, p. 98). However, these solutions are often costly in terms of installation and long-time maintenance. As a result of these expenses,

these essential infrastructure projects can never receive the intended level of maintenance that is essential to their proper functioning. This pattern is evident from the 2017 American Society of Civil Engineer's assessment of overall infrastructure that deemed 12 out of 17 infrastructure categories "poor, at risk" (American Society of Civil Engineers, 2022, Report Card History). Moreover, the American Society of Civil Engineers (2022) estimated that a ten-year investment of $4.59 trillion was necessary to address gaps in infrastructure capacity and service. Therefore, the importance of providing regulatory ecosystem services with cost-effective solutions is increasingly relevant as deferred maintenance and lack of funding are exacerbating problems in infrastructure service.

URBAN DEVELOPMENT PATTERNS AND INFRASTRUCTURTE SUPPLY GAPS

The issue of modern urban infrastructure funding is rooted in 20th century suburban development patterns that have created disproportionate access to public services within cities. With the shift in American population from urban to suburban regions in the later half of the 20th century, tax revenue and subsequent city funding decreased. In conjunction with this, residents leaving urban areas were more likely to be high-income individuals that contribute a significant portion of tax revenue (Wu, 2007, p.564). Due to this loss of tax income, cities lost considerable capacity to fund the public measures and services that heavily influence community welfare. In addition, Wu (2007) states that the process of suburbanization and urban tax loss eventually created a positive feedback loop that further separated funding between cities and suburbs (p.571). Overall, the trends of suburbanization have heavily contributed to a lag in funding for urban infrastructure maintenance and created a multitude of issues related to budget scarcity.

With the introduction of funding scarcity, the issue of preferential treatment begins to creep into the distribution of city services. Without the financial ability to satisfy the needs of all

urban residents, decision-makers are forced to compromise and invest in the projects deemed most critical by those in positions of public authority. While this bureaucratic process has successfully established numerous examples of public investment and benefit, this concentration of decision-making authority introduces the consequences of both conscious and unconscious bias. As a result, the distribution of city services and funding often finds itself directed towards higher-income communities that moved outside the inner urban core (Wu, 2007, p.564). This funneling of investment into less dense, suburban areas decreases the efficiency at which city services can be provided. The resource drain and urban tax loss created by suburbs ultimately directs investment away from urban communities that have higher representation of low-income and minority ethnic groups. This pattern of community disinvestment is seen in modern urban communities and is part of the greater issues of environmental injustice that face marginalized groups of society (Herreros-Cantis and McPhearson, 2021, p.13).

Infrastructure investment is rarely a process that is contained within the structure of a singular institution. As such, these developments are more often the result of partnerships between several public and private organizations. While public and government institutions hold the regulatory authority to approve developments, private groups can contribute towards the funding and public willpower needed to complete projects. However, the introduction of private funding sources contributes to the pattern of community disinvestment within minority and low-income communities. Mandarano and Meenar (2017) examined this trend within Philadelphia, and found that established neighborhoods receive significantly less of the private investment that is concentrated in newer or redeveloped portions of the city (p.1339). Without the land value and economic activity to attract private investment, low-income and minority neighborhoods are forced to rely on government investment that has historically not catered to their needs. Thus,

when investment does find its way into marginalized neighborhoods, the increase in service and amenities can attract wealthier residents that displaces established residents through gentrification (Mandarano and Meenar, 2017, p.1349).

Along with the barriers to accessing services created by community disinvestment, the influence of 20th century financial lending plays a large role. As a result of the immense rate of foreclosure during the Great Depression, the federal government began to distribute insured mortgages that were intended to stabilize homeownership rates (Jackson, 2021, para. 3). Eventually, this aid program evolved to become representative of how financially risky a certain neighborhood was to invest in. This data came to be mapped through the Home Owner's Loan Corporation maps for several hundred cities across the U.S. These maps were generated using neighborhood financial analysis that deemed how hazardous it was to loan mortgages in a given spatial community. This spatial analysis, notoriously referred to as redlining, segregated communities with investment recommendations of "hazardous", "declining", "desirable', and "best". While these assessments were intended to be solely through a financial lens, they disproportionately assessed minority neighborhoods as "hazardous" and undeserving of investment critical to a community's welfare (Badger, 2017, Figure 3).

Although the use of redlining has been relegated due to its capacity to segregate, its lasting effects are part of the underlying barriers preventing marginalized communities from accessing services and amenities. As shown by Herrero-Cantis and McPhearson (2021), an analysis of 108 redlined cities found that segregated neighborhoods possessed elevated surface temperatures and sparse tree canopy coverage (p.13). This prevalence of elevated temperatures and adverse health effects is one example of environmental injustice where marginalized communities face greater risk from environmental conditions. Together, redlining and

community disinvestment have starved many communities of their right to accessing services essential for wellbeing and quality of life. These practices set the foundation for why low-income and minority residents experience climate vulnerabilities resulting from widespread failure to equally provide for all.

PAST PATTERNS, MODERN CONSEQUENCES, AND FUTURE SOLUTIONS

In order to examine the relationships between communities and service access, the use of Actor Network Theory is employed. As described by Cressman (2009), ANT can be used to describe power dynamics that result from the connections within a network of actors (p.4). By modeling the connections and power dynamics of different actors, a holistic approach can be conducted to understanding the underlying causes of an issue and an appropriate solution. As such, Figure 3 models the connections between human and non-human actors that play a role in sustaining a community's access to ecosystem services.

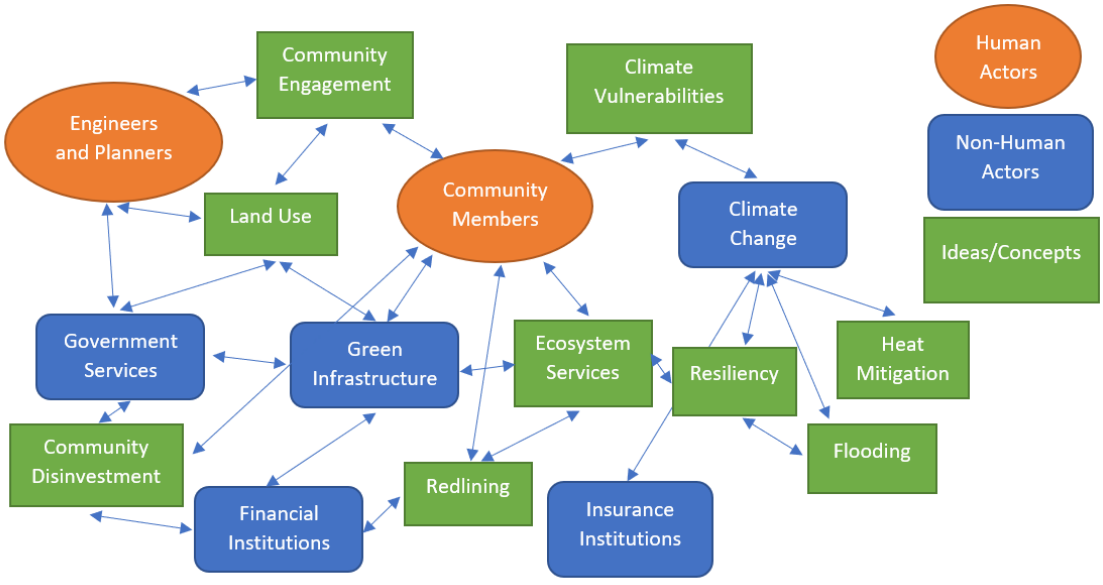

Figure 3: Actor Network diagram of green infrastructure and ecosystem services. This web of relationships between stakeholders is modeled using Actor Network Theory to determine barriers and solutions to ecosystem service supply. (Adapted by John Gore (2022) from Cressman 2009).

With the mapping of actor connectivity, pathways for intervention and key stakeholders become apparent. As established with the discussion centered on community disinvestment, governmental bodies hold significant sway over regulating and distributing public service capacity. Moreover, public servants within government institutions have a powerful role in carrying out the will of the public and meeting their needs. Within this group, engineers and urban planners have the ability, and professional duty, to steward the distribution of public services in equitable ways. As designers of urban land use, this group of actors has particular influence over how a space is used and who benefits from it. Therefore, a connection between facilitator and user is crucial for implementing infrastructure in a manner that restores decision making authority to those directly impacted. This key relationship is shown in Figure 3 as community engagement and is the intersection between public servants, land use, and individual residents.

Figure 3 can also be used as a lens for analysis with respect to the redevelopment proposed in the technical report. The site of Fashion Square Mall is located within a suburbanized offshoot of Charlottesville that has urbanized significantly and disrupted the supply of ecosystem services to the community. With the additional facet regarding the mall's degree of commercial vacancy, the site has not received the investment and maintenance necessary to continue providing an adequate level of benefit to the community. From an environmental standpoint, the site's level of imperviousness amplifies stormwater pollutant and volume issues affecting marine environments in downstream watersheds. This issue of downstream health is particularly relevant as the effects of climate change increase the future frequency and intensity of rainfall events. Therefore, the combination of issues related to ecosystem service supply, disinvestment, and climate change present the opportunity to use green infrastructure solutions.

As shown in Figure 2, the proposed green infrastructure and land use changes restore regulatory ecosystem services like stormwater infiltration and surface temperature regulation. The changes provide other amenities that make the design a provider of environmental, economic, and social benefit to the community. This design aimed to strike a compromise between stormwater management needs exacerbated by climate change, while providing a space that offered community benefits and amenities.

It should be noted, the use of community engagement was extremely limited in the production of the mall's redesign. The diligence and time required for interacting with the public for a project of this scale was beyond the scope of the technical project. As such, needs and wants for the community were assumed instead of surveyed directly from those that would be interacting with the area on a daily basis. Due to the importance of the relationship between designer and user, this is a critical step that was recommended should any future work be pursued on the project. By receiving the input of community members, designers would be able to modify to the unique needs and issues present in the community. This ensures that some level of decision-making power rests with the community and that they have an impact on investment and development that will affect their lives.

Figure 3's network depiction also reviews the relationships that have emerged due to climate change. With the uncertainty surrounding future environmental conditions due to climate change, significant infrastructure investment is needed to adapt the modern world. These adaptation needs garner even more attention when taking into account that large portions of modern infrastructure is decades old and designed for environmental conditions that don't adjust for a changing climate. As discussed by Morrison (2021), rainfall estimates that are used to guide design standards for roads, stormwater management, and dams are not updated annually (para.

8). This timing gap between climate estimation and minimum design standards creates significant risk of failure as infrastructure faces challenges from aging and environmental conditions not considered in design.

With respect to the challenges presented by community disinvestment, redlining, and climate change, no singular solution exists to satisfy all of the issues presented by these factors. However, great success in addressing these issues can be achieved through the thoughtful, guided investment in green infrastructure that addresses existing and future climate vulnerabilities. As shown in Figure 4, green infrastructure provides a multi-objective use of space that distributes the ecosystem services and amenities that marginalized communities face barriers to accessing.

Figure 4: Ecosystem services provided by green infrastructure. The infographic displays the many different services green infrastructure can perform in a community. (EPA, 2017)

Green infrastructure combines the natural environment with engineering design in a manner that facilitates access to ecosystem services and infrastructure needs. Traditional “grey”

infrastructure developments have historically been used to satisfy society's need to regulate stormwater, temperature, and other aspects of the environment. However, grey systems rely on certain expected minimum and maximum environmental conditions. As these conditions fluctuate with climate change, the effectiveness of grey infrastructure wanes and even fails in the face of environmental conditions that exceed design standards. Furthermore, grey infrastructure development has higher associated costs with construction and maintenance than green infrastructure (Dpeitri and McPhearson, 2017, p.97). This higher initial investment also creates a "sunk cost" that forces municipalities to continue investing and maintaining grey infrastructure in order to provide cost-effective environmental hazard mitigation.

While the lack of flexible performance and higher capital costs can make green infrastructure an attractive option for satisfying urban needs, certain settings reduce the feasibility of these solutions. With land usage at a premium within cities, the full extent of space needed for green infrastructure developments can be economically and socially impossible to acquire. Moreover, environmental challenges such as sea level rise and coastal flooding present issues that require solutions on scales impractically addressed by "green" solutions. As such, combinations of grey and green infrastructure development are essential for maintaining community access to ecosystem services and protection from environmental extremes.

EQUITABLE GREEN INFRASTRUCTURE INVESTMENT

With the established need to provide ecosystem services to disadvantaged communities, urban municipalities are taking steps to provide and adapt through green infrastructure. In New York City, the NYC Cool Neighborhoods Program addresses gaps in street tree coverage in neighborhoods that are most susceptible to the health effects of heat (Herrero-Cantis and McPherson, 2021, p.15). This example demonstrates the role and capacity that government has

in implementing green infrastructure in areas historically underserved. Government's role in infrastructure development also manifests through regulatory actions. Within the city of Philadelphia, the public water department instituted green infrastructure mandates for new and redeveloping properties (Mandarano and Meenar, 2017, p.1339). However, this regulatory intervention concentrated green infrastructure investment within emerging, high-value communities that have the capacity to attract private investment. Therefore, with the failure of private investment to address needs in underserved communities, it is critical for municipalities to balance public and private investment in a manner that benefits equitably.

In addition to institutional interventions, designers of green infrastructure have an important role in ensuring that the product of their work addresses a community's needs. The top-down nature of infrastructure development is typically at odds with creating meaningful relationships between designer and user. However, modern emphasis within planning and design has honed in on this relationship. As a result, high-quality community engagement has emerged as the key to connecting communities with services they lack. In Phoenix, this form of effective community engagement has been taken to address resident's experience with the extreme heat now commonplace in the desert city. Known as "Nature's Cooling Systems", this partnership between Arizona State University, The Nature Conservancy, and the Maricopa County Department of Public Health exemplifies the connected, multi-faceted approach needed to address extreme heat (Cornelius, 2019, para. 4). In their search for a solution to extreme urban heat, the Nature's Cooling System program first sought to understand how resident's experienced extreme heat. This process involved significant discussion with residents in at-risk areas and took their input on the aspects of their lives that needed intervention and assistance. By orienting infrastructure solutions around resident input and experience, decision making

authority is restored to communities that are the ultimate end users of infrastructure development.

IMPLICATIONS OF GREEN INFRASTRUCTURE AS A PROVIDER OF ECOSYSTEM SERVICES

With the increased prevalence of urban populations, it is integral that society maintain the provision of ecosystem services in increasingly man-made environments. While engineers and urbanists have conceived numerous solutions for managing and keeping the environment at bay, the growing pressure of climate change demands investment in solutions that are cost-effective, multi-objective, and resilient. As such, this paper has used Actor Network Theory to examine the stakeholders involved with the supply of ecosystem services. In this analysis, it is evident that significant gaps in access to public services exist due to past practices of development and investment. The combination of community disinvestment and redlining has left marginalized communities in positions that put them at greater risk of adverse environmental effects. This pattern of environmental injustice demands attention and solutions from governmental bodies that can influence regulations and funding essential for change.

Furthermore, effective climate change adaptation demands that infrastructure users are included in the decision-making process that guides such developments. Without the knowledge and lived-experience of residents, future adaptation efforts will replicate past exclusions and exacerbate existing inequities in community access to ecosystem services. Ultimately, community interaction is an absolute necessity in the development of green infrastructure. Future research and projects related to green infrastructure and its benefits should hold community interaction as a central tenet to frame solutions through. Together, thoughtful stewardship of

green infrastructure by government and its servants can reverse the inequities in underserved communities while introducing services resilient to climate change.

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