Linking GIS, youth environmental literacy, and city government functions to define and catalyze community heat resilience planning in Roanoke, VA

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ABSTRACT

Statistics show that chronic heat exposure and extreme heat waves are the leading cause of death amongst natural disasters in urban spaces across the United States, outpacing the likes of more notable phenomena such as hurricanes, tornadoes, and earthquakes. Heat in urban spaces is not distributed equally due to the urban heat island effect, a phenomenon which significantly elevates temperatures due to the various absorption characteristics of built environment features. Historical discriminatory mortgage lending schemes and planning practices that targeted communities of color have intensified that issue, endangering the health and well-being of marginalized neighborhoods to this day. Although generating feasible design solutions to mitigate the impact of heat in urban spaces represents a substantial challenge, utilizing readily available data sources to garner the social and political support required for actionable change is likely the more complex issue. Because youth are typically less jaded by external social and political influences and will either enjoy the benefits or suffer the consequences related to the built environment for their entire adult life, they possess a unique potential to serve as a vehicle for generating community momentum for the implementation of heat resilience solutions. This thesis explores the spatial distribution of heat throughout neighborhoods in Roanoke, Virginia by exploring both land surface temperature and air temperature discrepancies by Home Owners' Loan Corporation (HOLC) classification and census tract. I find that HOLC polygons not labeled "A" possess a considerably higher average temperature than the most "desirable" classification, and that there is a statistically significant inverse relationship between mean land surface temperature (aggregation of Landsat raster files) and census tract socio demographic characteristics such as median household income and percentage of residents aged 65 and over. This thesis also examines the potential of youth-focused science education programs to catalyze the political will necessary to enact resilience planning efforts that no single governmental agency is responsible for. I analyzed the various impacts that artifacts produced by a 2021 science education program conducted with Roanoke City middle school students inflicted on a 2022 focus group comprised of influential Roanoke public officials. I show the reasoning which supports that four primary opportunity and challenge categories – Breaking Down Silos, Spreading Awareness, Places and Venues, and Resources and Funding – can serve as foundational discussion components for heat resilience planning panels in the future. This thesis advances the awareness of disproportionate exposure to heat in urban spaces and contributes to theories attempting to trigger heat resilience planning efforts.

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GENERAL AUDIENCE ABSTRACT

Extreme heat presents a deadly threat to people, particularly those who live in cities. Heat is not distributed evenly throughout urban areas, with some places being hotter than others. Climate change is a force which will make that problem worse. As a result, it is important for planners and other leaders to implement strategies to solve that issue. Engaging youth in the planning process is one way to speed that process up. This thesis explores whether neighborhoods in Roanoke, Virginia experience different levels of heat stress. I find that areas which have historically been deemed by the government to be "most desirable" are typically cooler than others. This research also examines the ability of youth education programs to compel relevant decision makers to act on an issue. Through an analysis of a focus group discussion, I show that the experiences and ideas of Roanoke City middle school students encouraged Roanoke City public officials to respond to their concerns. Four major themes related to heat resilience opportunity and challenge areas emerged – Breaking Down Silos, Spreading Awareness, Places and Venues, and Resources and Funding.

Dedication

To my family and friends who have helped forge the path of my academic journey

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1 Relevant Literature

1.1 Understanding Heat as an Urban Spatial Issue

Statistics show that extreme heat and corresponding heat waves are the leading cause of death amongst natural disasters per year across the United States, far outpacing phenomena that get significantly more publicity such as hurricanes, tornadoes, and earthquakes (National Weather Service, 2020). During the fourteen-year period from 2004-2018, approximately seven hundred heat-related deaths occurred in the United States each year (Schramm et al., 2021), the majority of which are considered by medical experts to be preventable. As unsettling as this public health crisis appears to be, it is not projected to reverse course at any point in the future without notable intervention (Russell et al., 2020). Worldwide, the issue of increased urban heat is expected to increase in severity with global climate change (Climate Change, 2022). Typical human health reactions to extreme heat certainly include obvious responses such as heat stroke, exhaustion, fainting, and dehydration, but excessive exposure to unusually warm conditions can also exacerbate the effects of chronic conditions like heart disease, obesity, and even mental illness (Center for Disease Control and Prevention, 2020). Different subpopulations are also more susceptible to the impacts of heat. For example, young children and senior citizens are typically more vulnerable to its invasive presence. High nighttime temperatures prevent the human body from routinely cooling down, recovering, and executing standard physical processes (Murage et al., 2017). As the impacts of climate change continue to escalate, the frequency, intensity, and duration of harmful heat waves are increasing, leaving communities not just in the United States, but across the globe, ill-equipped to manage the corresponding consequences (Habeeb et al., 2015).

Although the influence of extreme heat can affect any geographic location, its force is not distributed equally across space. One of the primary explanations for the discrepancy of heat exposure across various locations is known as the urban heat island effect (UHI). At its most basic level, the urban heat island effect is responsible for elevating city temperatures because of the relationship and correlation between air temperature and physical components of the built environment which include building density, impervious surface, color, and presence of vegetation (Oke, 1982). Components of the built environment, such as roads and buildings, first absorb the sun's energy and subsequently radiate it, rendering adjacent places above the earth's surface warmer than other spaces that are characterized by more natural landscapes (U.S. Environmental Protection Agency, 2014). This natural warming effect is significantly exacerbated by the presence of impervious surfaces, such as concrete and asphalt, an environmental factor that is positively correlated with poverty rate and minority status (Wilson, 2020). One of, if not the most significant element in determining the degree to which an area experiences heat stress is the amount of greenery present, or the percentage of land area covered by tree canopy (Hart and Sailor, 2008). Studies conducted in Europe show that dense cities are indeed much warmer than their rural counterparts and that greenspaces (both on the roof of buildings and at the surface level), can ameliorate heat stress by expanding shade coverage and significantly enhancing the local evapotranspiration rate, thus providing a substantially cooler microclimate (Perini and Magliocco, 2014). Given the fundamental importance of plentiful greenery and small allotments of impervious surface to the ability of neighborhoods and individuals to cope with the impact of extreme heat, ensuring equitable access to amenities such as public parks should be a primary objective of planners.

The above factors that are associated with how heat accumulates in urban areas also explain one of the most perilous components of the extreme heat hazard: its heterogeneous distribution throughout space, which correspondingly jeopardizes the health of certain populations more than others. In the United States, the hottest areas of modern cities also tend to be associated with the most vulnerable and historically underserved communities (Uejio et al., 2011). In the first half of the twentieth century, the United States government deployed explicit efforts to preserve the segregation of residential areas throughout cities, and those actions have not only contributed to lasting financial hardships for the demographic groups that were marginalized throughout that time, but also to the intra-urban temperature variation which exists across large metropolitan areas to this day (Hoffman et al, 2020). The Home Owners' Loan Corporation (HOLC), a federally-sponsored program that largely operated in conjunction with the Federal Housing Administration (FHA) embedded the overtly racist attitudes of property developers and mortgage lenders in the wake of the Great Depression by generating a scheme to perpetuate housing segregation. The Home Owners' Loan corporation constructed layered territorial boundaries known as graded polygons which allegedly represented the perceived lending risk of a neighborhood, a process that was largely guided by racial prejudices (Bailey et al, 2017). The color-coded HOLC polygon rating system was as follows: "most desirable" = A (green), "still desirable" = B (blue), "declining" = C (yellow), and "hazardous" = D (red). "Redlining" is a term which stems from that categorization blueprint and describes the discriminatory lending practices which disproportionately prevented people of color from realistically accessing government-backed mortgages which could have allowed them to build wealth through home ownership. The areas which did not qualify for these loans, often characterized by large populations of marginalized individuals, were literally labeled "hazardous" and outlined in red on a map. That mechanism initiated the process of systemic disinvestment in communities of color, perpetuating detrimental socioeconomic outcomes that are still evident in the modern era (Bailey et al, 2017).

As the seminal study linking historical housing policies to residential heat exposure indicates, "LST (land surface temperature differences across the cities - 108 U.S. cities were included in the study) follow a non-uniform distribution of differences, suggesting that historical redlining policies are reflected in present-day intra-urban heat differentially" (Hoffman et al, 2020). Underpinning this claim is the fact that Home Owners' Loan Corporation (HOLC) grade polygons, which were placed in the "D" classification by the Federal Housing Administration, currently experience higher average temperatures than any of the other categories (Hoffman et al, 2020). A similar study found that areas marked with a Home Owners' Loan Corporation classification of "D," in which minority groups are statistically overrepresented, are much hotter and had a lower Normalized Difference Vegetation Index (a measure of the presence of greenery) than other categorized territories that have historically enjoyed more investment in the climatically diverse cities of Baltimore, Dallas, and Kansas City (Wilson, 2020). Given the historical injustices which have repeatedly inflated the vulnerability of minority communities, it is absolutely imperative for planners to prioritize equity, not necessarily equality, in generating spatial responses to extreme heat (Wilson, 2020).

An example which validates the assertion that residential location is a determining factor of heat exposure is the 1995 Chicago Heat Wave in which well over 700 individuals succumbed to the devastating suffocation of extreme heat. Eric Klinenburg, author of *Heat Wave: A Social Autopsy of Disaster in Chicago*, described the tragedy as an "unnatural disaster" in which pre-existing, underlying social implications and segregated urban layouts affected the ability of each individual/neighborhood to cope with the intense heat stress. As the calamity unfolded, public officials realized that the overwhelming majority of victims were members of minority communities who either had pre-existing medical conditions that were triggered by the heat, or an impaired heat-resistance capacity due to factors stemming from poverty (Klinenberg, 1999). One of the dominant components that affected small-scale efforts to withstand extreme heat in Chicago was air conditioner accessibility, a luxury that was simply not available to many of those whose lives were claimed by the disaster. Part of the reason that the issue of extreme heat has been relatively ignored in comparison to other environmental hazards is directly related to a societal overreliance on air conditioning units to mask thermal discomfort, as opposed to emphasizing passive cooling techniques in urban design (O'Lenick et al., 2019). Whether planning responses to extreme heat include an increase in park/greenspace accessibility, ensuring that air conditioning units/energy usage is energy efficient and affordable, or actually modifying existing infrastructure to encapsulate natural cooling, the swift adoption of corresponding plans and programs which are comprehensively endorsed by local demographic and socioeconomic groups is paramount to successfully managing urban heat exposure.

1.2 Planning for Heat Resilience

As the evidence continues to mount confirming that neighborhoods within the same geographic location experience varying levels of susceptibility to environmental hazards (Wilson, 2020), community leaders must develop tangible strategies to combat that discrepancy. Resilience, an emerging component of the planning sector that is rapidly increasing in popularity given the unrelenting nature of evolving societies and the ramifications associated with a changing climate, is a complex concept that encompasses the overarching endurance of a community. More specifically, the U.S. Global Change Research Program (USGCRP) defines resilience as "a capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment" (Bey et al., 2020). That comprehensive conceptualization encapsulates the essence of an effective resilience plan, one that acknowledges the inherent interdepencies of local institutions as well as the impact of underlying societal structures like poverty and food insecurity (Woodruff et al., 2022). While urban planners certainly play a pivotal role in the initiation and fulfillment of resilience efforts, it is imperative for local government interagency collaboration to emerge in order to establish multiple footholds throughout a community which can be utilized to obtain information regarding disproportionate vulnerabilities and advance corresponding corrective measures (Woodruff et al., 2020). Resilience planning must be a multidimensional, dynamic endeavor which attacks environmental stressors from an array of angles, including necessary modifications to both the physical infrastructure of an area and its social service offerings (Keith et al., 2021).

Situated at the intersection of urban planning and public health, heat resilience planning requires a unique combination of problem recognition and proactive intervention. While this issue is framed by many localities across the country as an acute disaster response, approaching heat stress as a chronic problem which affects the critical components of everyday life (the economy, health care system, and housing suitability) is a more accurate conceptualization (Bolitho and Miller, 2017). There is no question that adjustments to the built environment in urban areas are necessary to improve the thermal comfort of proximal human populations, but comprehensive public policy necessary to compel those crucial investments simply does not exist (Dare, 2019), nor does the recognition of the essential role that public alert systems and social programs can play in the prevention of unnecessary heat illness (Berry and Richardson, 2016). Therefore, addressing the issue of heat requires coordination between the planning, education, and public health sectors.

Given the interdisciplinary nature of heat stress and the collaboration between countless stakeholders that is required to generate a successful heat mitigation scheme, designing programs which facilitate harmonious partnerships between urban planners, public health professionals, educational leaders, emergency management personnel, and community members is essential to the operation of a healthy, repeatable planning process. Because the ramifications associated with heat waves are not spatially and temporally uniform, approaches to increasing heat resilience must be neighborhood specific (Perkins-Kirkpatrick and Lewis, 2020) instead of regionally adopted. The unique nature of this enterprise highlights the necessity for urban planners to address this issue with interagency governmental cooperation and resident support, while also moving towards the utilization of innovative, diversified techniques which ensure that their communities are furnished with adequate infrastructure, social programs, and design strategies to successfully mitigate the impact of extreme heat. Projects and policies which provide immediate relief at the expense of long-term benefits, such as the dissemination of energy inefficient appliances, should be de-emphasized if possible, while initiatives which prioritize sustainable progress, like a perpetual effort to expand urban tree canopy and other greenery, must be prioritized and executed.

Regardless of the theoretical rationale that supports a heat resilience intervention scheme, a planning project designed to provide support and assistance to a neighborhood or community will only be successful if it is accepted by that population (van Empel, 2008). To ensure that the future vision compelled by a resilience proposal is shared by both planning professionals and local residents alike, engaging citizens in the construction of that plan is the most ethical and effective option. An exemplary illustration of the type of community engagement model required to effectively combat heat stress can be found in the Nature's Cooling Systems project conducted in Phoenix, Arizona. This four-step, iterative studio process organized to engage community members, design sustainable solutions, plan at a neighborhood-scale for heat resilience, and subsequently implement the ideas of the citizenry required the cultivation of genuine relationships to uncover the unique characteristics of each residential region. Once the participants obtained a baseline level of understanding about the topic, they were able to effectively engage with workshop leaders and community partners to develop ideas ranging from modern infrastructural advancements which offer an increase in shade to more intricate solutions such as the installation of heat advocacy programs and the enhancement of drinking water accessibility for the general public (Guardaro et al, 2020).

Another example of an effective, resident-driven, neighborhood-scale urban heat resilience plan was implemented in the Hunting Park neighborhood of Philadelphia. After a quantitative report identified Hunting Park as one of the most vulnerable residential spaces to extreme heat exposure, the Philadelphia Office of Sustainability established an intervention to identify the root causes of the issue and utilize community input to shape the relevant solutions. Funded by the financial contributions of both local and national non-profit organizations and facilitated by an assortment of partnerships between government departments, community organizations, and residents, the "Beat the Heat Hunting Park Initiative" was formed. Over the course of an eight-month community engagement process, over six hundred residents provided feedback to project organizers through environmentally-themed festival events, surveys, and a design workshop. Environmental advocates and faith leaders joined forces with public officials to process and analyze that feedback, while simultaneously attempting to identify the most beneficial locations for infrastructure adjustments (tree plantings, green roof installations, etc.) and social service offerings (cooling stations, outreach groups, etc.). Ultimately, the robust base of community knowledge and input provided by residents and activists in the Hunting Park area provided planners, other government officials, and community leaders with the tools to successfully develop a package of site-specific heat resilience solutions. That final product included an assortment of interventions such as the procurement of an enhanced educational awareness program concentrating on extreme heat, the expansion of a program devoted to utility subsidization, and the installation of shading structures and street greenery (*Philadelphia Beat the Heat*, 2019).

Both of the examples of community-driven heat resilience project efforts in Phoenix, Arizona, and Philadelphia, Pennsylvania serve as excellent models for similar planning processes in other locations. The presence of a significant campaign designed to improve the local quality of life naturally stimulated community interest and education, and the magnitude of those efforts facilitated the interagency government collaboration necessary to generate a profound impact. By encouraging all residents to provide information and data about their experiences with the issue of extreme heat, the planners were able to equitably tailor the corresponding solutions to those specific needs. Furthermore, because the interventions were designed in accordance with the knowledge contributed by citizens, they are more likely to be accepted, supported, and effective over an extended period of time. Both of these projects were able to successfully strike a healthy balance between elevating community awareness and knowledge, soliciting resident feedback, and designing suitable solutions that embody the characteristics desired by the relevant citizenry.

1.3 Public Participation and Engaging Youth in the Planning Process

The above section illustrates why community involvement in resilience planning is important and it offers some examples of community involvement efforts; however, substantive involvement from communities most vulnerable to the impacts of climate change in resilience planning is far from commonplace (Meerow and Mitchell, 2017). Given the history of racism by the United States government, for example, in relation to the prejudiced construction of the federal highway system (Karas, 2015) and the aforementioned "redlining" initiatives, minority communities are often distrustful of planners and public officials. The assortment of historical, racially charged policies, coupled with the overwhelming homogeneity of the urban planning profession (according to the latest census, eighty-one percent of urban and regional planners are white (Owens, 2015) has cultivated an unstable relationship between planners and a large portion of the constituents who they are tasked to serve.

Shifting the conceptual model of planning from a top-down mechanism to a "grassroots' ' approach which directly involves the citizenry with decisions that ultimately impact their lives can enhance transparency (Thrupp et al., 1994). This notion of genuine public involvement in the planning process is underscored by Arnstein's 1969 illustration of *A Ladder of Citizen Participation*, in which she advocates that "citizen participation is citizen power" which cannot be achieved merely through governmental "manipulation," "therapy," "informing," "consultation," or "placation" (Arnstein, 1969). Instead, she argues for authentic partnerships between planners and citizens, conducive to collaborative efforts which can result in mutually beneficial solutions for all stakeholders involved. The commitment of planners to nurture trustful, symbiotic relationships with members of the community is especially important in the process of building a sense of credibility with formerly marginalized neighborhoods.

In addition, because heat and temperature are such a pervasive component of residents' experiences, many do not recognize it as an issue that can be changed, and it can therefore be difficult to garner political and social support for an initiative that appears to be less time sensitive than other pressing societal issues. In countries across the globe, shifting away from reactionary methods of intervention in order to engage in sustainable, forward-thinking policymaking has been a cumbersome process, even for localities which possess a commitment from governmental leadership to abandon outdated plans in favor of more effective and equitable alternatives (Hess, 2014). This inherent delay, coupled with the notion that an overwhelming majority of individuals, including those who are disproportionately impacted by heat stress, are unaware that it is a dilemma which is directly influenced by planning decisions (Guardaro et al., 2020), renders obtaining the political will and social approval necessary to enact meaningful change quite challenging.

Given the extensive difficulties surrounding the procurement of sufficient funding for the development and enhancement of heat resilience planning, investigating avenues which can provide a spark for political leaders and community members in that capacity is a worthwhile investment. Members of the youth represent a subset of the population that is not typically involved in planning processes, but who should be provided with the opportunity to have an impact on decisions and the development of plans which will affect them (Frank, 2006). The novelty of heat resilience planning provides a fresh gateway for youth to enter the planning realm, and it introduces the critical potential to equip them with the skills and motivation to immerse themselves in civic participation throughout the duration of their life (Frank, 2006).

Still, youth involvement in civic initiatives is an underexplored opportunity capable of initiating both community involvement and political will to proactively address community climate resilience. While socio-economic inclusion is one of the primary priorities of the American Planning Association (APA, 2021), far less consideration is given to the unique contributions that members of the youth can offer to the planning profession. Even though the youth do not typically possess a consistent role in current planning processes, that lack of involvement should not be construed as an indicator of their interest level, but rather a sign that there are not enough routine opportunities which solicit their engagement (Frank, 2006). There is no alternative method to account for the lived experiences of youth, or to gauge their unique perspective on the desired future for their communities, without providing them a seat at the table (Jacquez et al., 2013). To address this incessant issue, the Director of Planning in the City of Hampton, Virginia decided to create a full-time program which allows members of the youth to regularly engage with real-world decisions. That strategy caused participation in planning from that age group to increase substantially, ultimately enhancing the social capital and cohesiveness of that community (Carlson, 2005). Perhaps the most essential component of programs like "The Youth Planner Initiative in Hampton, Virginia" is the ability to engage youth in non-tokenistic planning processes which cultivate intergenerational cohesiveness and allows them to strengthen the bond with the places in which they live (Botchwey et al., 2019). Because youth represent the subset of the human population which will either enjoy the advantages or suffer the ramifications related to the climate resilience planning throughout their adult life, integrating them into the core of that process is vital to planning equity.

1.4 Environmental Literacy and Theories of Change

One way that others have suggested youth involvement can directly contribute to building community resilience is through environmental literacy programs that connect science education with place-based learning and political action. At its core, the primary function of science education is to better equip program participants with the ability to actively engage with others on issues which affect their lives (Rudolph and Horibe, 2016). Making a concerted effort to ensure that students can engage in scientific, "lived" curriculum that directly impacts their community both enhances their ability to contribute to planning decisions and encourages them to continue down a path of public participation throughout their adolescent and adult life (Roth and Lee, 2004). One such example of youth engaging in this particular fashion occurred in "The Mill Creek" project which saw hundreds of children at Sulzberger Middle School in Philadelphia work with college-aged students to learn about the urban watershed issues associated with Mill Creek. After learning about the mismanagement of the nearby floodplain and housing development, the young students were motivated to gather as much information as they possibly could about the topic to develop proposals about how planners could address the issue. The students' efforts garnered a significant level of notoriety from local public officials and also encouraged them to experience landscape legibility by becoming familiar with and invested in the issues which plague their community (Spirn, 2005).

A similar process was conducted with 10–14-year-old children in River City, Iowa, which allowed them to investigate whether their city exhibited characteristics of the urban heat island effect. Throughout the course of this educational process, the students took thermal measurements, conducted interviews with residents which gauged their perspectives, and generated a short documentary to display their results. This science education program allowed the youth to learn about the landscape which surrounds them, engage with other community members to share the information that they were able to digest, and generate products capable of influencing the decisions of local planners (Barton and Tan, 2010).

Designed to educate people to learn about strategies which can improve the resilience of a specific location and recognize the central importance of education in increasing community resilience, the National Oceanic and Atmospheric Administration (NOAA) Environmental Literacy Program Office developed a conceptual framework for "Theories of Change." These hypotheses represent methods by which communities can become more resilient in the face of environmental events (Bey et al., 2020). NOAA's Theories of Change framework directly connects youth learning about environmental topics to increased community resilience through several hypothesized pathways. In this sense, the theories of change provide the foundation for mapping how youth educational activities could lead to greater community involvement in resilience planning. Targeting a comprehensive expansion in environmental awareness and stewardship specifically related to the mitigation of extreme weather events, NOAA infused a combination of scientific information, socioeconomic factors, and social cohesion into pathways which may ultimately enhance the adaptive capacity of an area. At their core, these pathways serve as broad, guiding objectives to be pursued through the implementation of localized initiatives.

Given the above literature review, I determined that two important outstanding gaps in planning for heat resilience in any given city include: (1) establishing the spatial distribution and social vulnerability to extreme heat in neighborhoods within the city and (2) understanding the most salient pathways to adapting cities to extreme heat, especially with respect to youth environmental education programs. In the following two chapters of this thesis, I present mixed methods approaches to exploring these gaps in Roanoke, VA. Chapter 2 describes a GIS analysis of various spatial temperature datasets and their correlations with socio-demographic characteristics. Chapter 3 describes a participatory action research project and subsequent qualitative research to better understand how government officials view potential pathways for improving community heat resilience.

2 Evaluating the Spatial Distribution of Heat - GIS Analysis

2.1 Introduction

Roanoke is a relatively small city nestled in the Appalachian Mountains of Virginia that has approximately one-hundred thousand residents. Recently, the issue of extreme heat has been a focus of its local government. In its 2012 Climate Action Plan, Roanoke identified the threat of extreme heat. In 2020, the City's Sustainability Office partnered with the National Oceanic and Atmospheric Association on a citizen science campaign to measure and map the spatial distribution of air temperature. Like many post-industrial cities in the United States, Roanoke suffered population and economic decline in the post-War period and continues to exhibit evidence of racial segregation caused by discriminatory housing and real estate practices. Although the impact of institutional neglect is undoubtedly a multi-faceted problem which permeates through the various components of typical lifestyles, one of the most prominent consequences associated with neighborhood-level historical disinvestment is the routine intensity of heat experienced by residents in areas of the city that were previously redlined. Others have shown that although redlining is no longer legal in the United States, the legacies of the redlining practices can still be observed in the temperature differences between the areas previously designated in different HOLC classes (Hoffman et al. 2020, and Wilson, 2020). Given the significance of the Home Owners' Loan Corporation (HOLC) polygons in shaping the residential environment within Roanoke, along with the comprehensive boundaries and corresponding socio-demographic data that census tracts offer, those two scales present natural analysis benchmarks for evaluating heat stress within the city. In this chapter, I ask whether there are statistically significant correlations between land surface temperatures/air temperatures and sociodemographic data aggregated by relevant census tracts, and whether areas which were previously designated "Still Desirable" (grade B), "Definitely Declining" (grade C), or "Hazardous" (grade D) by the Home Owners' Loan Corporation suffer a disproportionate degree of heat stress (operationalized by both land surface temperature and air temperature) than their "Best" (grade A) counterparts in the City of Roanoke.

Although others have performed nation-wide or multi-city studies associating areal units with temperature, understanding the specific spatial distribution of heat in Roanoke, VA was an important first step to understanding how heat resilience might be addressed specifically in this city. A single, small area-city study presents challenges. First, unlike a multi-city or a larger city study, which may include dozens, or hundreds of areal units to aggregate by, the City of Roanoke had few polygons in each HOLC class, and only twenty-one census tracts. The small area of the city also means that the remotely sensed data is more susceptible to missing data due to cloud cover and infrequent satellite pass-over. To resolve these issues, I used Python scripting to process multiple data sets to increase the robustness of the analysis. I aggregated by two areal units: HOLC class and census tracts (generally smaller areal units than HOLC class polygons).

In this chapter of my thesis, I use GIS analyses to first illustrate the spatial characteristics of intraurban heat variation within the city of Roanoke sparked by historical redlining practices shown in **Figure 2**, and subsequently evaluate the correlation between heat exposure and socioeconomic characteristics.

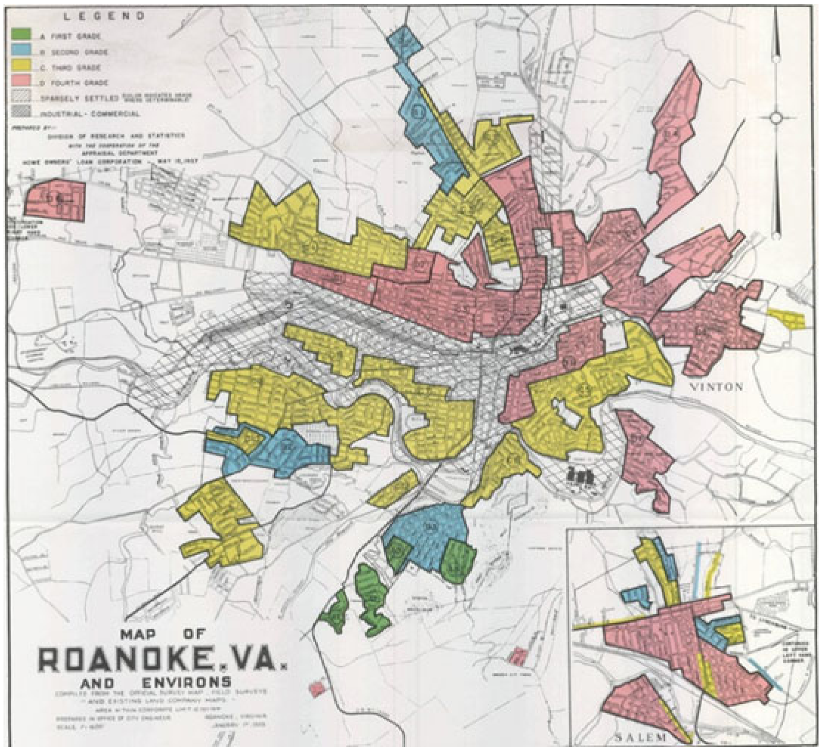

Figure 2 - 20th century map of Home Owners' Loan Corporation designated boundaries in Roanoke, Virginia

2.2 Methods

To address whether statistically significant correlations exist between land surface temperature and socio-demographic data aggregated by twenty-one Roanoke City census tracts, I conducted a bivariate correlation between those two elements. First, I collected land surface temperature from the renowned Landsat 8 program, given its stature as the publicly available thermal imagery source that possesses the highest resolution (Wilson, 2020). That data was retrieved from two separate time periods - the most recent summer dataset and the most recent winter dataset which each encapsulated six to seven individual raster files - and I subsequently calculated the mean "scene temperature" from those rasters. While land surface temperature does not necessarily represent how warm an area feels to the human body, it has been utilized to measure the impact of heat on human health (Harlan et al., 2013). The parameters for the summer dataset included satellite imagery during the July-August 2021 time period with less than fifty percent cloud cover, a criterion that yielded six individual raster files. Each of those files were overlaid with one another to generate a pixel-level average "scene temperature" in an effort to obtain a representative sample of the thermal landscape in Roanoke in the summer of 2021. Once the final "scene temperature" was compiled into a single raster, the mean of the pixels within each census tract was calculated to establish an average temperature for each census tract. That same data collection and analysis process was completed in order to collect land surface temperature for Roanoke's winter season, defined by the December 2020-February 2021 time period. The aforementioned specifications once again generated six raster files, which in turn were processed at the pixel level to produce a mean "scene temperature" and a final land surface temperature average by census tract for the most recently available Roanoke winter data.

Next, I extracted the most recent socio-demographic data available from the United States Census Bureau, 2019 American Community Survey Data, for the relevant twenty-one Roanoke census tracts. Information regarding the variables of "Percent Non-White," "Percent Age 65 & Over," "Median Household Income," and "Percent Bachelor's Degree and Higher" was elicited, providing a framework for understanding the distribution of heat in Roanoke across different populations subsets. The data associated with each of those variables and the corresponding census tract were then matched with the analogous final "scene temperature" to provide the foundation for a statistical analysis.

Finally, to examine the relationship between land surface temperature and socio-demographic characteristics in Roanoke, I deployed a basic bivariate correlation which returns the statistical significance between two variables. In this case, that analysis occurred between the final "scene temperatures" and each of the identified socio-demographic indicators, and Pearson' correlation coefficient was ultimately utilized to identify the strength of the relationship (if any) between land surface temperature and socio-demographic attributes.

I also created a set of boxplots that illustrate the land surface temperature and distribution during both the aforementioned summer and winter time periods throughout the City of Roanoke by Home Owners' Loan Corporation grade polygons. The boxplots display the distribution of pixel values for land surface temperature, by showing the first, second, and third quartile values within the distribution.

Additionally, I constructed a series of boxplots which display air temperature distributions derived from the HOLC classification system. Air temperature is more likely to be reflective of human thermal comfort than land surface temperature, however, the downside of air temperature is its typically low spatial resolution. One city may typically only have a handful of weather sensors, and these are often located at the outskirts of cities. In this study, I use a spatial interpolation of data collected using vehicle-mounted sensors. The sensors collected air temperatures along a set route through the City of Roanoke during a NOAA NIHHIS Urban Heat Campaign (CAPA, 2020). The measurements along the vehicle traverses were then combined with high resolution satellite imagery for land cover to interpolate a continuous air temperature surface for the entire city (Shandas et al., 2019). HOLC grade polygons was obtained from the Mapping Inequality - Redlining in New Deal America campaign.

2.3 Results

Figures 2.1 - 2.4 depict the results of the bivariate correlations conducted between mean land surface temperature averaged both by summer raster files and by pixels within each census tract (hereafter referred to as "aggregated mean") and the corresponding socio-demographic data. The corresponding rho value (placed on a scale of -1 to 1 indicating the positive or negative linearity of the relationship) and the p-value (a value that when less than or equal to 0.05 indicates statistical significance) are also displayed on the following scatterplots. It is important to note that while some trends support findings from the literature, others were not as intuitive.

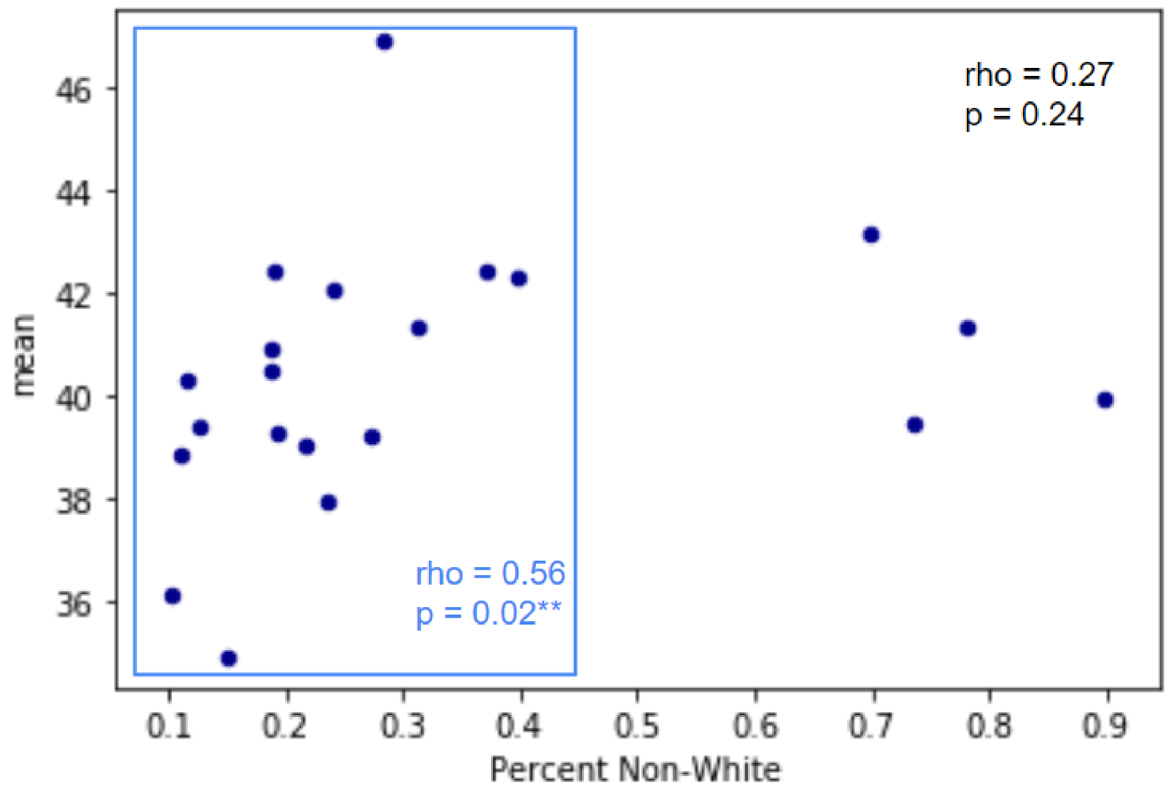

Figure 2.1 - Bivariate correlation between mean land surface temperature (averaged both over summer scenes rasters and by pixels in census tract) and Roanoke census tract percent non-white.

At first glance, the overall relationship between the aggregated mean land surface temperature and percentage of non-white individuals within Roanoke census tracts does not appear to possess an overarching trend. Based on the previous literature, we would expect that census tracts with higher proportions of non-white residents would have higher temperatures. The rho value is 0.27 with a p-value of 0.24, indicating that the comprehensive dynamic is non-linear and not statistically significant. However, after considering that Roanoke census tracts appear to be skewed toward either extreme in the percent non-white category, a distinct trend emerges from the majority of datapoints which range from 0-40% non-white. After removing the four datapoints of census tracts that possess a 70% or greater occurrence of non-white individuals, there is a statistically significant (p-value = 0.02) positive relationship between the aggregated mean surface temperature and the percentage of non-white individuals in the remaining seventeen Roanoke census tracts. Upon further investigation of the four census tracts that possess a non-white percentage of greater than 70%, I found that they are clustered together in the same geographic territory and possess a few unique attributes which are likely responsible for their deviation from the established theme. The presence of Roanoke Country Club, along with the prevalence of a few other parks (CC Williams, Kennedy, etc.) and several large cemeteries (Fair View, Sherwood Burial) likely account for the lower mean land surface temperature of these census tracts compared to the trend found from the majority of the data points. Also, it is important to note that the relationship between racial makeup and temperature is unlikely to be completely linear, as the land surface temperature in an area will begin to plateau based on larger regional meteorological conditions.

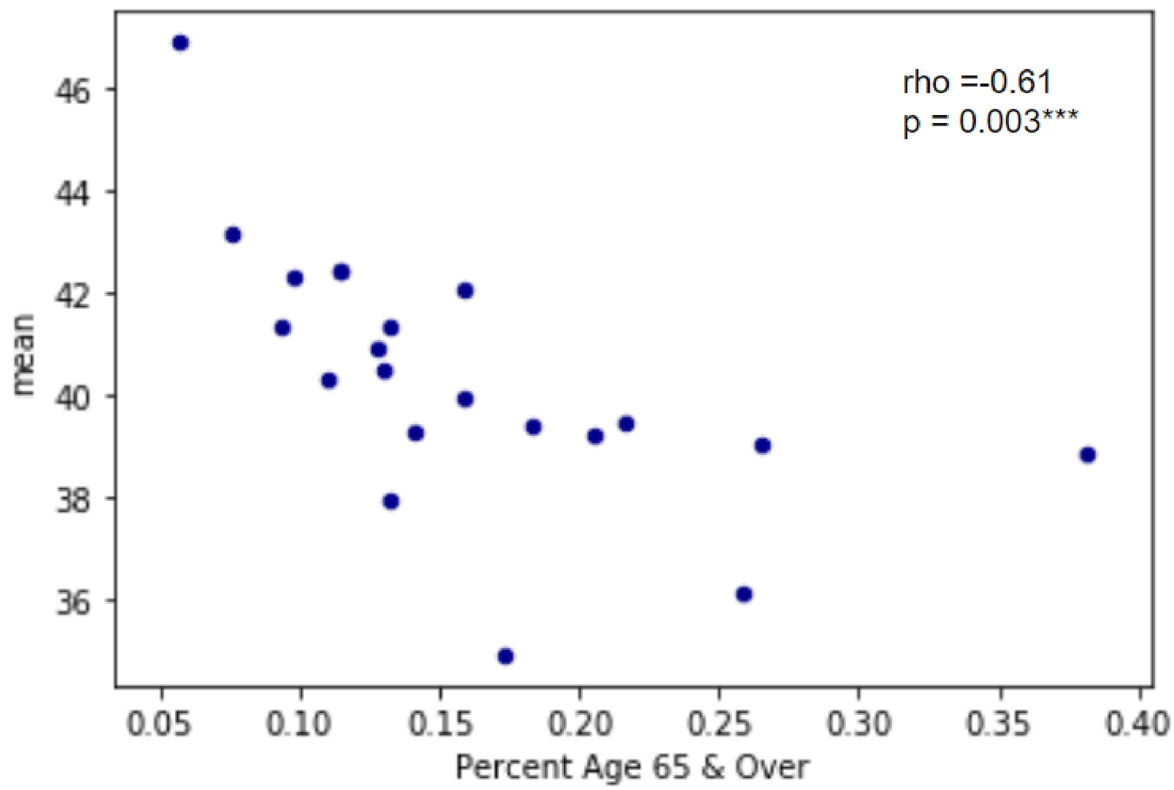

Figure 2.2 - Bivariate correlation between mean land surface temperature (averaged both over summer scenes rasters and by pixels in census tract) and Roanoke census tract percent age 65 & over.

Figure 2.2 illustrates the relationship that exists between aggregated mean surface temperature and the percent age 65 and over characteristic present within Roanoke census tracts. There is a noticeable inverse relationship (rho = -0.61) between these two variables, revealing that as the percentage of a census tract with individuals age 65 and over increases, the mean surface temperature decreases in that area. The p-value of this relationship (p-value = 0.003) signals that this relationship is statistically significant, and renders it a pattern that is applicable to all census tracts within the city of Roanoke. Note that this finding should *not* be interpreted to mean that older residents of Roanoke are not at as much risk from heat exposure as younger residents on an individual scale. Rather, simply that neighborhoods with higher proportions of older residents also tend to be cooler.

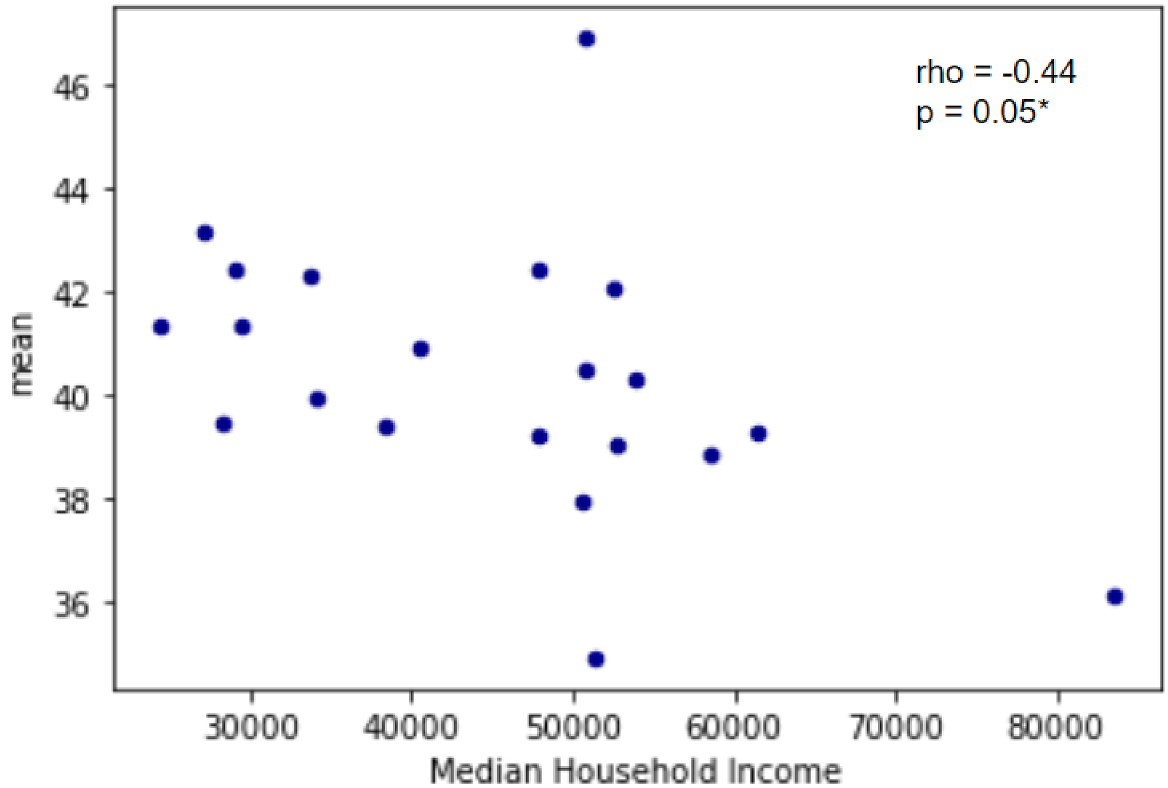

Figure 2.3 - Bivariate correlation between mean land surface temperature (averaged both over summer scenes rasters and by pixels in census tract) and Roanoke census tract median household income.

Perhaps the most intuitive finding of the entire bivariate correlation calculation endeavor is provided by the relationship between aggregated mean land surface temperature and the median household income of each census tract displayed above in **Figure 2.3**. Not surprisingly, there is an inverse relationship between these two variables, showing that as mean household income increases, the mean aggregated land surface temperature decreases. This trend exemplifies the notion that more wealthy individuals inhabit residences that are less vulnerable to heat stress and is evidenced by a rho value of -0.44 and a statistically significant p-value of 0.05.

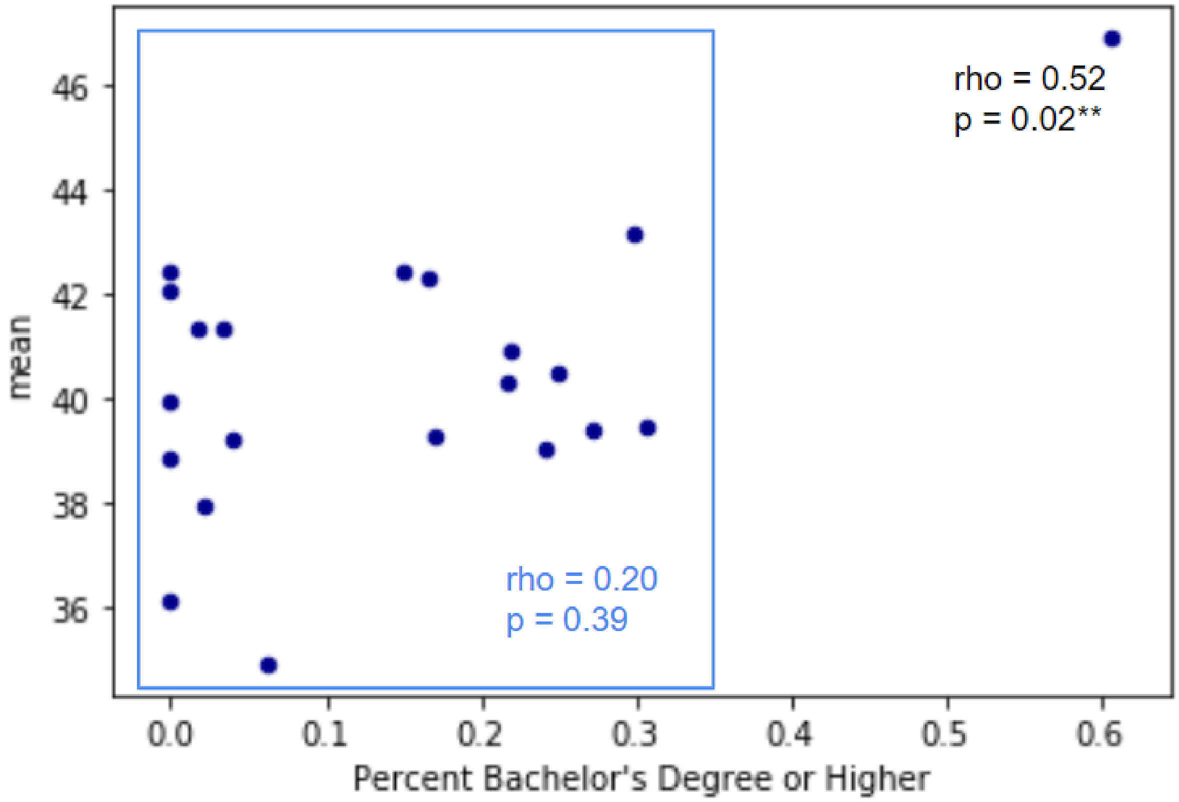

Figure 2.4 - Bivariate correlation between mean land surface temperature (averaged both over summer scenes rasters and by pixels in census tract) and Roanoke census tract percent bachelor's degree or higher.

When assessing the relationship between mean land surface temperature and the percentage of individuals in a census tract that possess at least a bachelor's degree level of education (shown above in **Figure 2.4**), there does appear to be a statistically significant correlation (p-value = 0.02); however, there is a substantial outlier that drastically influences that finding. When removing Census Tract 11 from this analysis (highlighted by the blue box in **Figure 2.4**), there is not a statistically significant relationship between these two variables. Census Tract 11 represents the central hub of Downtown Roanoke, which is the warmest region due to its large proportion of impervious surface and minimal greenery which exacerbate the urban heat island effect. Thanks to the conversion of formerly abandoned industrial buildings into residential apartment units in recent years, that census tract also accommodates a significant number of young professionals who have yet to build the financial capacity necessary to relocate to cooler neighborhoods on the periphery of the city. Removing that anomaly indicates that there is no noticeable relationship between educational attainment and mean land surface temperature within the City of Roanoke.

Land Surface Temperature

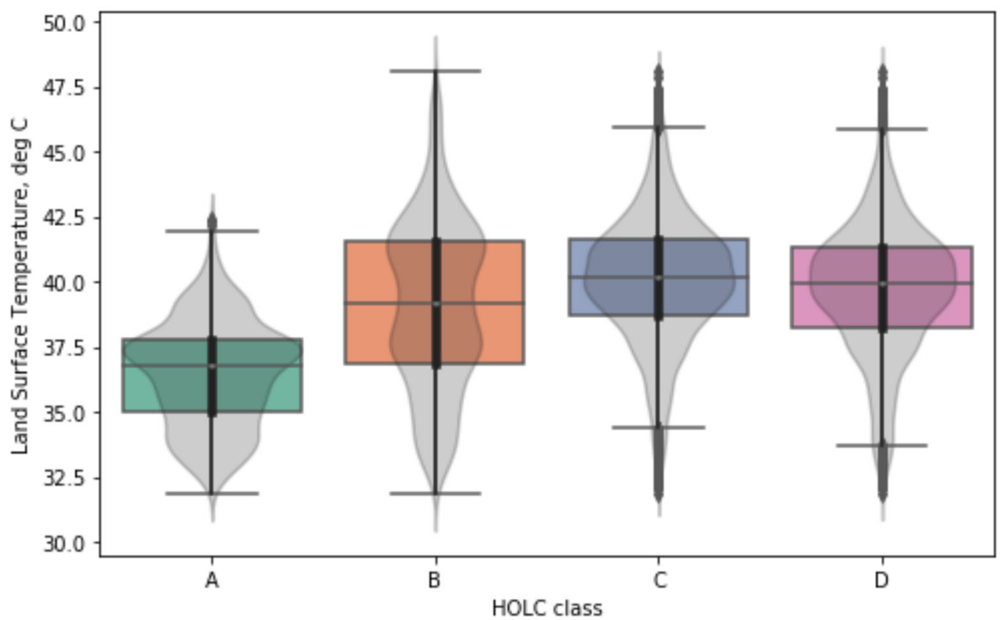

Figure 2.5 - Mean summer land surface temperature (averaged over summer scenes) by HOLC class

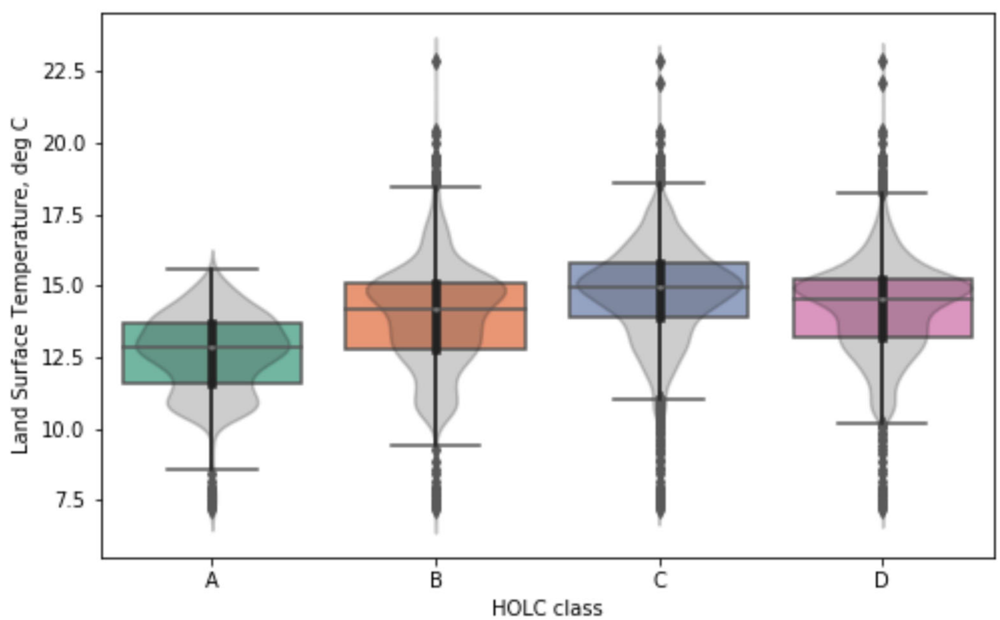

Figure 2.6 - Mean winter land surface temperature (averaged over winter scenes) by HOLC class

Figures 2.5 and **2.6** represent the boxplots constructed by the mean land surface temperature for each Home Owners' Loan Corporation polygon classification averaged over both summer and winter raster scenes. Unlike the findings presented by the Wilson 2020 study which realized considerable variation in land surface temperature across

HOLC polygon classifications in the cities of Baltimore and Dallas, these results mimic Wilson's Kansas City results which offered a more uniform distribution, albeit in an elevated range, of heat across classifications "B," "C," and "D" during both summer and winter time periods.

Air Temperature

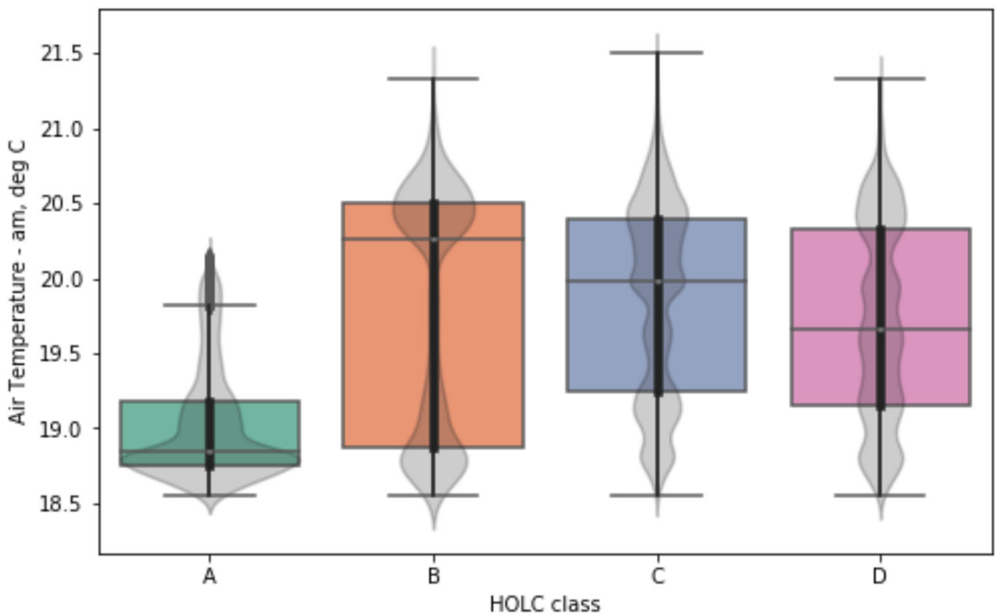

Figure 2.7 - Boxplot of air temperature data collected in the morning by Home Owners' Loan Corporation designation

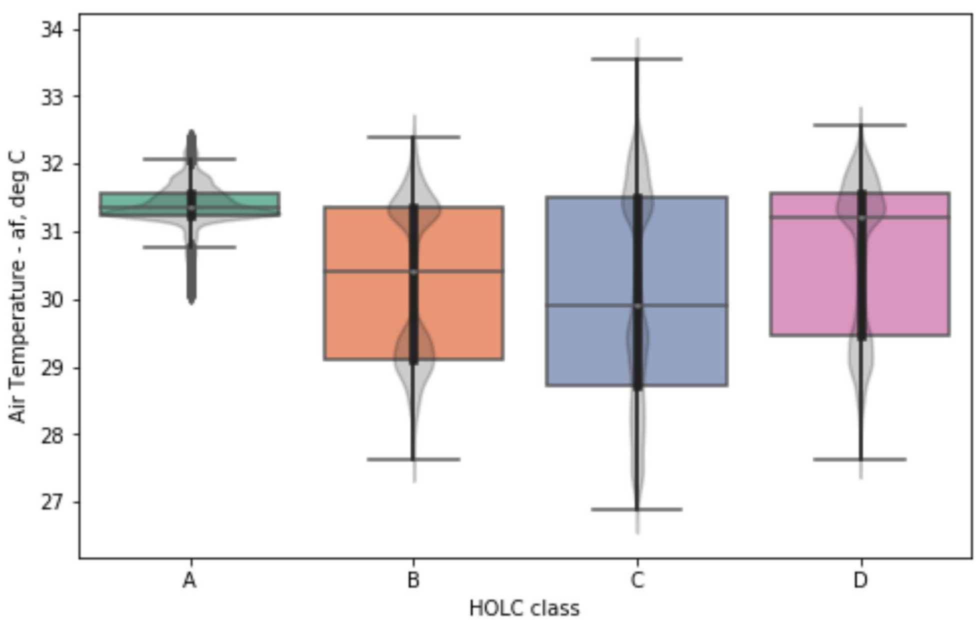

Figure 2.8 - Boxplot of air temperature data collected in the afternoon by Home Owners' Loan Corporation designation

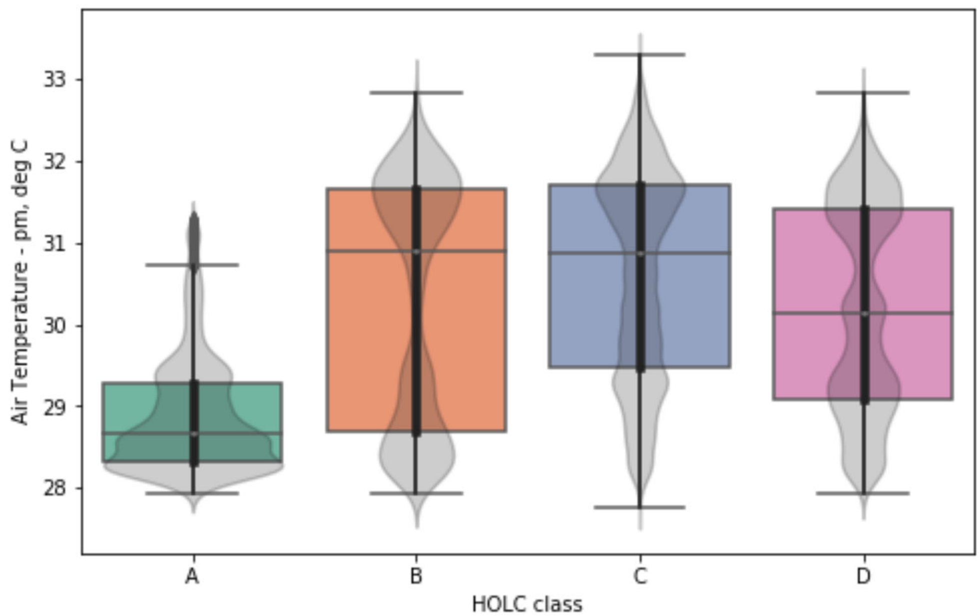

Figure 2.9 - Boxplot of air temperature data collected in the evening by Home Owners' Loan Corporation designation

Figures 2.7, **2.8**, and **2.9** depict graphs illustrating mean air temperature by HOLC class that are developed from the Climate Adaptation Planning Analytics (CAPA) Heat Watch effort which utilized sensors mounted to automobiles and bikes which traversed a scheduled path throughout Roanoke using data from three points in time. **Figure 2.7** displays the air temperatures collected by the CAPA campaign in Roanoke during the morning hours, and it shows that before the sun's radiation has been transferred to the Earth throughout the day, considerable air temperature variation exists between neighborhoods that possess different HOLC grades - most notably between Class A and the remaining designations. **Figure 2.8** exhibits the average air temperature per HOLC classification that was collected during the afternoon, and it shows a quite homogeneous distribution of temperatures across polygon designations. This is to be expected given that almost every urban location will attract and endure a significant amount of heat on a sunny afternoon; however, **Figure 2.9** demonstrates the substantial variation between Class A and the remaining three classifications during the evening hours. This temperature fluctuation is quite significant given the drastic impact that nighttime temperatures can have on the ability of the human body to adequately recover from elevated levels of thermal exposure. It is crucial to realize that the CAPA air temperature data was obtained during a one-day collection process that was influenced in some areas by a localized thunderstorm. While the resulting data can inform conclusions and subsequent decisions, this scenario illustrates a major disadvantage of using data extracted from one point in time: it is subject to anomalies that can blur findings.

2.4 Discussion

The results of the bivariate correlation analysis, along with the mean land surface and air temperature boxplots by Home Owners' Loan Corporation, indicate that heat stress and thermal comfort are not uniformly distributed across the City of Roanoke. Moreover, there appears to be a statistically significant relationship between the aggregated average mean land surface temperature and the socio-demographic characteristics included in this study. The correlation analyses revealed in part that in areas that are primarily white (60% white minimum), census tracts tend to become warmer as they become more diverse. Additionally, the inverse relationship between aggregated mean land surface temperature and median household income suggests that financial status likely plays a major role in the ability of persons to escape heat stress, underscoring the need for planners and public officials to generate community-specific interventions which can mitigate the impact of heat stress for all citizens (Perkins-Kirkpatrick and Lewis, 2020). Still, limitations exist within these findings, particularly when attempting to identify smaller groups that suffer most from heat stress. Because the socio demographic data included in this study is linked to census tract boundaries, there is no direct path to identifying population subsets that may be most vulnerable to extreme heat. The scale of this analysis may even obscure significant patterns of vulnerability. For example, the lower-than-expected land surface temperature of the four census tracts that possess a non-white percentage of greater than 70% in **Figure 2.1** is likely affected by the presence by large cemeteries in that area; however, because residents do not live within the burial ground boundaries, it is unlikely that they are regularly accessing those corresponding benefits.

Although the boxplots demonstrating the mean land surface and air temperature variation which exists between Home Owners' Loan Corporation did not show a sizable discrepancy between classes "B," "C," and "D," the divergence of those classifications from the "A" designation implies that historical, discriminatory actions are still impacting modern communities and neighborhoods (Hoffman et al., 2020). In addition to inferior polygon classifications battling formidable obstacles including lower rates of homeownership, poverty, and higher social vulnerability (Shandas et al., 2019), they are also tasked with managing lifestyle consequences associated with a routine disproportionate exposure to heat. As evidenced by the evening air temperature boxplot in **Figure 2.8**, elevated nighttime temperatures in HOLC classes "B," "C," and "D" can introduce extremely dangerous health consequences to the relevant population as those temperatures prevent the human body from successfully executing standard recovery processes (Murage et al., 2017).

It is important to recognize that due to the inherent heterogeneity associated with the built environment (combined with zoning ordinances), heat will never be distributed uniformly across an urban space. Nonetheless, the disparity in heat exposure across Roanoke which has historically targeted marginalized communities of color is not a natural occurrence. Given the relatively permanent nature of the typical infrastructure components which contribute to the urban heat island effect (Oke, 1982), making swift adjustments in an attempt to quickly solve this issue is an unlikely outcome; however, employing a long-term, community, specific calculated approach to expand the presence of urban greenery in vulnerable communities while also modifying parcels which unnecessarily attract heat is paramount in the quest to foster an urban environment in which heat exposure is distributed equitably.

Lastly, another limitation of this study revolves around the fact that the most significant public health risk associated with extreme heat is elevated indoor temperatures, especially at night. While Landsat land surface temperatures and CAPA air temperatures serve as reliable indicators of that metric, they are imperfect proxies for the actual temperatures experienced by people within their homes. Future efforts should concentrate on better characterizing indoor thermal comfort and its spatial distribution within cities, along with its relationship to housing stock and population distribution.

3 Youth Engagement and Public Officials Theorizing Opportunities for Change

3.1 Introduction

During the summer of 2021, approximately thirty students from Breckenridge Middle School from the Northwest neighborhood of Roanoke, Virginia engaged in a rigorous two-week place-based science education program centered on the topic of the urban heat island effect and urban planning. The ten classroom sessions, directed by Assistant Professor Dr. Theodore Lim from Urban Affairs & Planning Department at Virginia Tech, introduced the youth to the characteristics of the urban heat island effect, as well as the environmental and social consequences associated with its presence. Over the course of the two weeks, students utilized sensors to document the temperatures of different surfaces throughout their schoolyard, while also exploring their own neighborhoods in Google Street View and hypothesizing about the thermal comfort of those locations. Lastly, the students worked in teams to create a "heat resilience network" in the Northwest Roanoke area by linking parks together through the implementation of urban greenery, expansion of pedestrian-friendly infrastructure, and placement of splash pads.

In this chapter, I describe a follow-up study I conducted with government officials from Roanoke, designed to elicit their perspectives of how the preliminary youth engagement activity could lead to other pathways for increasing community resilience to extreme heat. The participants of that focus group formulated their hypothesized solutions within the framework of the National Oceanic and Atmospheric Association Environmental Literacy Program's "Theories for Change," a set of resilience objectives that must be achieved through geographically specific interventions. Specifically, I try to address the following research questions:

1. How do city officials conceptualize where long-term heat resilience outcomes can be achieved?
2. How do city officials conceptualize how long-term outcomes can be achieved?

3.2 Methods

The artifacts produced by the middle school students during that two-week summer education experience included drawings and sketches of potential infrastructural modifications for places that are frequently visited and utilized by those students and their families, interview transcripts detailing the students' perceptions of extreme heat and their corresponding experiences, and ethnographic notes taken by the instructors which highlighted the intellectual progression of students over the course of the program. During the engagement program, the research team also took photographs of the students participating in various activities. After the program, the team transcribed the interviews students conducted of their peers and with the research team and extracted particularly insightful quotations and themes from the data. All of these data components were then used as materials to elicit reflection from a group of government employees from the City of Roanoke.

Throughout the course of the two-week summer education program for middle school students, participants engaged in a variety of activities ranging from exploring temperatures throughout Roanoke by clicking on a tabletop interactive GIS screen to interviewing fellow classmates to gauge their perspectives and personal experiences with heat exposure. Students also measured the temperatures of different surfaces across the school campus using several different sensors, providing them a tangible interaction with the various components of the built environment that typically elevate the temperature of adjacent spaces. Those activities are displayed below in **Figure 3.1**, **Figure 3.2**, and **Figure 3.3**.

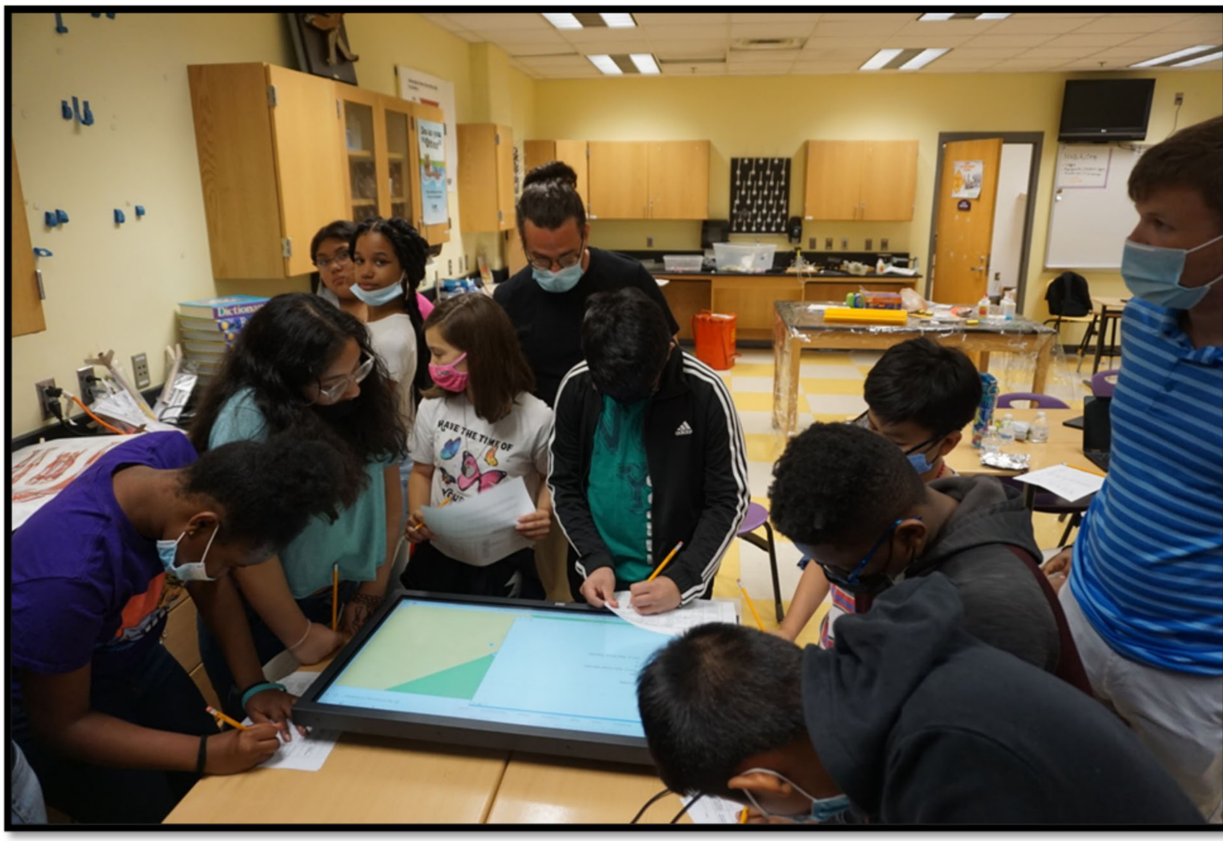

Figure 3.1 - Students exploring temperatures around Roanoke with a tabletop GIS system. Used with permission of Theodore Lim

Figure 3.2 - Students interviewed fellow classmates to learn more about their experiences with heat and thermal comfort. Used with permission of Theodore Lim

Figure 3.3 - Participants measured temperatures of various surfaces located throughout the school property. Used with permission of Theodore Lim

With the help of the City of Roanoke Sustainability Coordinator, Nell Boyle, I organized a focus group of diverse Roanoke City public officials in a discussion of potential pathways forward from the initial student engagement. Participants from the city included representatives from the realm of public education, public services (libraries), parks and recreation, the city manager's office, urban forestry, and building development. I led the virtual meeting conducted via Zoom. First, I provided the group with a brief presentation on the urban heat island effect, heat resilience planning, and explained the science education activities that were conducted with Roanoke middle school students during the Summer of 2021 (described and shown above in **Figure 3.1**, **Figure 3.2**, and **Figure 3.3**). After that brief presentation, I provided the focus group participants with an image displaying the National Oceanic and Atmospheric Administration's long-term "Theories of Change" outcomes, and prompted to respond to the following questions:

> "Given your role in Roanoke and our starting point, which of these long-term outcomes do you see as most relevant to your work?"
>
> "What specific activities can you imagine connecting our youth engagement with the long-term outcomes?"

Images like the one shown in **Figure 3.4** were provided to focus group members throughout the presentation to illustrate the types of cooling solutions that were generated by the students of the summer program. These images served as a reference point for Roanoke public officials to consider how their role could advance these types of heat resilience projects.

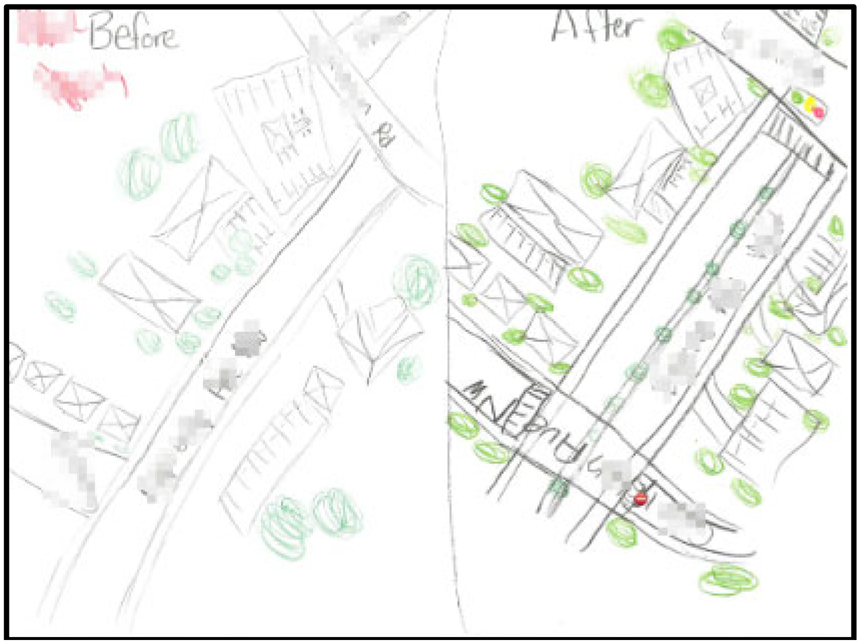

Figure 3.4 - Example of student-produced interventions shown during focus group presentation to explain the Summer 2021 middle school student engagement activities. Source – Theodore Lim

Members of the focus group were subsequently directed to a "Jamboard" page on the internet which allowed each individual to place their response to each question on a "sticky note" adjacent to the long-term outcome that was most applicable to their professional work. Once each person had finished placing their ideas on the collaborative platform, I facilitated a discussion which allowed members of the group to freely share their ideas. Participants were encouraged to expand upon the brief thoughts placed on the screen, while also diagnosing the resources that are available or would be required to fulfill their idea(s). To avoid the potential of inherent power structures or personality traits drastically shaping the structure of the dialogue, I used phrases like "[Would] somebody we haven't heard from yet on any of the topics or any of the long-term outcomes here?" to promote a healthy, inclusive discussion. The focus group lasted for approximately one hour, and after its completion, a comprehensive transcript was manually generated from the video recording. The above research protocol was approved by the Virginia Tech Institutional Review Board (#21-837).

Following the completion of the Roanoke City public official focus group, an in-depth analysis was conducted on the transcript by way of a two-stage coding process (Charmaz, 2014). The first stage consisted of a free coding process. In the second stage, the free-codes were then grouped into larger categories, representing overarching themes and tabulated using Microsoft Excel. The goal of this evaluation was to identify both obvious and subtle patterns which emerged throughout the conversation to unearth potential shared pathways forward across different public sectors in regard to heat resilience planning efforts. This portion of the analysis was conducted by color-coding phrases of text in Microsoft Word, a process which sought to keep complete thoughts intact by creating larger code chunks as opposed to shorter, segmented ideas. In addition to calculating frequencies of each of the categories, I also tabulated frequencies of co-occurrences between categories. This two-stage coding process produced a way to identify the topics that were most salient to the Roanoke City public official focus group, as well as the relationships between those topics.

3.3 Results

Fourteen individuals from the City of Roanoke participated in the focus group conducted in the Spring of 2022, and each member of the panel brought a unique blend of educational background and professional responsibility to the proverbial table (**Table 3.1**).

Table 3.1 Participants' Title, Department, and Number of Years with the City

Title	Department/Agency	Years Experience
Education (Math/Science) Supervisor	Roanoke City Public Schools	35
Land Use and Urban Design Planner	City of Roanoke	10
Urban Forestry Coordinator	City of Roanoke	8
Parks Manager	Parks and Recreation	16
Public Services Coordinator	Libraries	15
Recreation Manager	Parks and Recreation	9
Belmont Branch Manager	Libraries	3
Sustainability Coordinator	Office of Sustainability	10
Assistant City Manager	City Manager's Office	28
Sustainability Program Assistant	Office of Sustainability	Less than 1
Water Quality Administrator	Stormwater Division	7
Stormwater Manager	Stormwater Division	16
Director of Planning, Building, and Development	Planning, Building, and Development	10
Early Literacy Librarian	Libraries	12

Despite what appeared to be some of the participants' first experiences with the subject of how heat resilience could be improved, as the presentation concluded, members of the group seemed quite eager to engage with the following activity. Panelists were prompted to ponder how the opportunities associated with their professional work could relate to the NOAA "Theories of Change" long-term outcomes (**Figure 3.5**), and it was evident that each of the participants put a considerable amount of thought and consideration into their responses (**Figure 3.6**).

Figure 3.5 NOAA "Theories of Change" Long-Term Outcomes

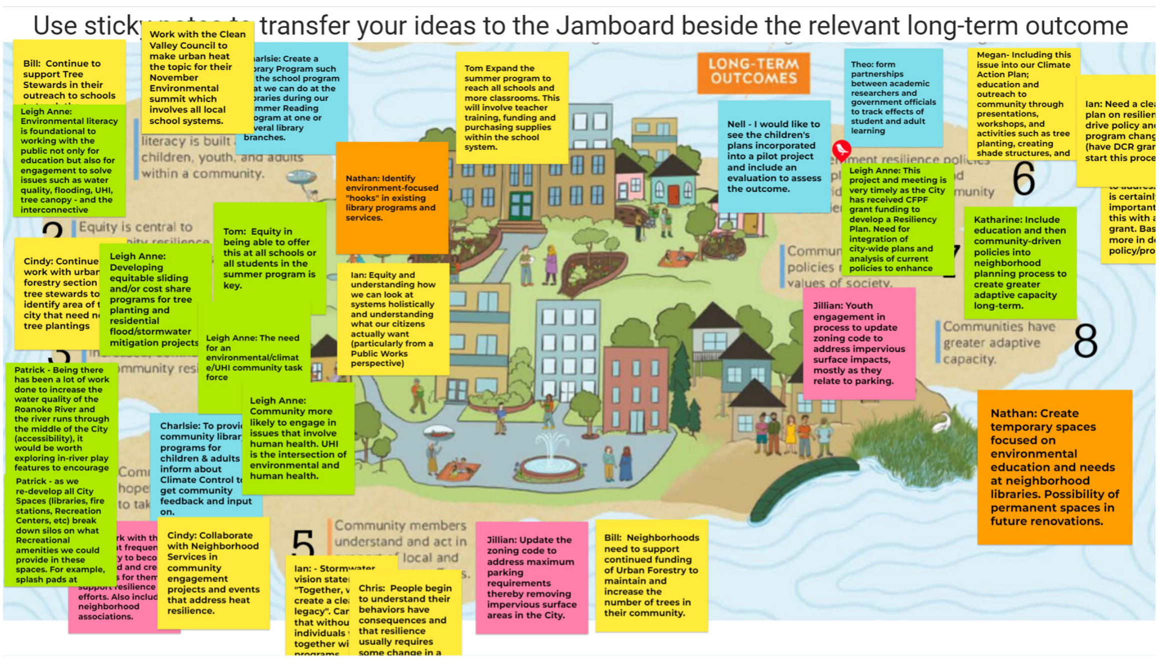

Figure 3.6 Participant-generated Jamboard ideas

Each of the "sticky notes" displayed in **Figure 3.6** represent a specific activity that could be deployed by the City of Roanoke in order to advance heat resilience planning efforts. Those comments substantiate the conceptual framework perpetuated by the NOAA Theories of Change by facilitating a direct relationship between theorized initiatives and "real-world" implementation ideas. NOAA does list six "Causal Pathways" which essentially serve as speculative project-scale benchmarks for communities to achieve the aforementioned long-term goals, parallel in nature to the "sticky notes" that were created by focus group participants. Of those six "Causal Pathways," the avenues which were most profoundly supported by the Roanoke City public officials were Causal Pathway 2 - "Resilience Planning and Policies Integrate Education" and Causal Pathway 3 - "Active Learning Enables Community Engagement in Civic Processes." One of the most ardent examples of Causal Pathway 2 is derived from a plan of action developed by a member of the education system who adamantly supports expanding the Summer 2021 learning program to other classes and youth organizations.

> *"Work with the Clean Valley Council to make urban heat the topic for their November Environmental summit which involves all local school systems; Expand the summer program to reach all schools and more classrooms. This will involve teacher training, funding and purchasing supplies within the school system."*

Enhancing the educational experience of young children who are interested in learning about issues that will have a significant impact on their future is an incredibly important investment for public officials to make, an assertion that is endorsed by both NOAA's guidelines and Roanoke public officials. One of the many examples of Causal Pathway 3 was articulated by a planner who emphasized the relevance of education not only for children, but for community members of all ages as well.

> *"Include education and then community-driven policies into the neighborhood planning process to create greater adaptive capacity long-term."*

This statement introduces a dynamic blend of stimulating societal education/awareness and augmented civic engagement, a relationship which undoubtedly exists but is not always capitalized upon. Perhaps the most crucial component in the successful development of this suggestion is the emphasis placed on neighborhood planning, given that community engagement activities related to resilience are most likely to be successful when deployed on a small-scale thanks to the unique attributes that each community possesses.

Table 3.2 Summary of participant generated Jamboard ideas by long-term outcome and City of Roanoke Affiliation

<u>Long-Term Outcome #1</u> – Collective environmental literacy is built among children, youth, and adults within a community	
Continue to support Tree Stewards in their outreach to schools to teach the importance of our Urban Forest.	Parks and Recreation - Urban Forestry
Environmental literacy is foundational to working with the public not only for education but also for engagement to solve issues such as water quality, flooding, UHI, tree canopy - and the interconnected nature of these issues.	Stormwater Division
Work with the Clean Valley Council to make urban heat the topic for their November Environmental summit which involves all local school systems; Expand the summer program to reach all schools and more classrooms. This will involve teacher training, funding and purchasing supplies within the school system.	Public Schools and Education
Community understanding of the nexus of climate and health. Build out community partners and expand the audience to include all citizens.	Office of Sustainability
Create a Library Program such as the school program that we can do at the Libraries during our Summer Reading Program at one or several library branches.	Libraries
Identify environment-focused "hooks" in existing library programs and services.	Libraries
<u>Long-Term Outcome #2</u> – Equity is central to community resilience education approaches	
Continue work with urban forestry section and tree stewards to identify area of the city that need new tree plantings	Parks and Recreation
Developing equitable sliding and/or cost share programs for tree planting and residential flood/stormwater mitigation projects	Stormwater Division
Equity in being able to offer this at all schools or all students in the summer program is key.	Public Schools and Education
Equity and understanding how we can look at systems holistically and understanding what our citizens actually want (particularly from a Public Works perspective)	Stormwater Division

<u>Long-Term Outcome #3</u> – Social cohesion is increased, contributing to community resilience	
Being there has been a lot of work done to increase the water quality of the Roanoke River and the river runs through the middle of the City (accessibility), it would be worth exploring in-river play features to encourage more use.	Parks and Recreation
The need for an environmental/climate/UHI community task force	Stormwater Division
<u>Long-Term Outcome #4</u> – Community members feel hopeful and are motivated to take action	
As we re-develop all City Spaces (libraries, fire stations, Recreation Centers, etc.) break down silos on what Recreational amenities we could provide in these spaces. For example, splash pads at libraries, rec centers, fire stations, etc.	Parks and Recreation
To provide community library programs for children & adults to inform about Climate [Change] to get community feedback and input on.	Libraries
Community is more likely to engage in issues that involve human health. UHI is the intersection of environmental and human health.	Stormwater Division
Work with the teens that frequent our library to become motivated and create programs for them to support resilience efforts. Also include neighborhood associations.	Libraries
Collaborate with Neighborhood Services in community engagement projects and events that address heat resilience.	Parks and Recreation
<u>Long-Term Outcome #5</u> – Community members understand and act in support of local and state resilience efforts	
Stormwater vision statement - "Together, we can create a clean water legacy." Can't do that without individuals working together with City programs	Stormwater Division
People begin to understand their behaviors have consequences and that resilience usually requires some change in a behavior.	City Manager’s Office
Update the zoning code to address maximum parking requirements thereby removing impervious surface areas in the City.	Planning, Building, and Development
Neighborhoods need to support continued funding of Urban Forestry to maintain and increase the number of trees in their community.	Parks and Recreation - Urban Forestry

<u>Long-Term Outcome #6</u> – Government resilience policies and plans incorporate and provide support for community resilience education	
I would like to see the children's plans incorporated into a pilot project and include an evaluation to assess the outcome.	Office of Sustainability
Including this issue into our Climate Action Plan; education and outreach to community through presentations, workshops, and activities such as tree planting, creating shade structures, and green roofs with youth groups	Office of Sustainability
Need a clear plan on resilience to drive policy and program change (have DCR grant to start this process); Creating formal plans with actions to address resilience is certainly important - starting this with a DCR grant. Basis for more in-depth policy/programs	Stormwater Division
<u>Long-Term Outcome #7</u> – Community resilience policies reflect the values of society	
This project and meeting is very timely as the city has received CFPF (community flood-preparedness) grant funding to develop a Resiliency Plan. [There is a] need for integration of city-wide plans and analysis of current policies to enhance those for climate change.	Stormwater Division
Include education and then community-driven policies into the neighborhood planning process to create greater adaptive capacity long-term.	Land Use and Urban Design
<u>Long-Term Outcome #8</u> – Communities have greater adaptive capacity	
Youth engagement in process to update zoning code to address impervious surface impacts, mostly as they relate to parking.	Planning, Building, and Development
Create temporary spaces focused on environmental education and needs at neighborhood libraries. Possibility of permanent spaces in future renovations.	Libraries

Table 3.2 displays the exhaustive list of participant generated Jamboard ideas as they relate to the NOAA Theories of Change long-term outcomes shown in **Figure 3.5**. By explicitly listing out each thought contribution in relation to the applicable long-term outcome and the City of Roanoke affiliation, both the most targeted objectives and the potential partnerships available to fulfill those ambitions are uncovered. The sheer number of initiatives developed in relation to each long-term outcome serve as an indicator of the scale of opportunity and priority associated with that aspiration. Long-term outcome #1, “Collective environmental literacy is built among children, youth, and adults within a community,” and long-term outcome #4, “Community members feel hopeful and are motivated to take action,” represent the two most popular topics of those

listed in terms of participant interaction. Both of those desires specifically target the involvement of Roanoke residents as opposed to a stricter evolution of abstract planning policies or documents, accentuating the magnitude that focus group participants place on getting people involved and elevating comprehensive societal awareness about the issue of extreme heat exposure and resilience efforts. The actors involved with contributing potential interventions to those outcomes were quite diverse, highlighting the interagency collaboration that is required to facilitate the production of a myriad of strategies which work in tandem to realize that ultimate ambition.

More importantly, each of the ideas contributed to the Jamboard by Roanoke city officials offer specific avenues for resilience efforts to be triggered, intensifying the accountability associated with governmental agencies and community organizations acting in an urgent fashion.

This simple activity provided an effective transition from the presentation to the focus group dialogue session, while also stimulating each of the public officials to recognize how their influence could be applied to the issue of extreme heat and resilience planning. For example, an education supervisor made the following remark early in the ensuing discussion period:

> *"So my thought with this is how do we institutionalize it a little bit more. How do we create a unit that can be taught in the summer to all the middle school kids?"*

Soon thereafter, an individual affiliated with the local libraries commented:

> *"In addition to existing or in addition to new programming, we can look for sort of environmentally focused books that we can put into existing programs and services."*

For these local leaders, it is not necessarily a deficiency in willingness to engage in new initiatives or develop new programs to address complex challenges, but rather a struggle in establishing the development of a coordinated, unified approach which is necessary to tackle wicked issues like extreme heat and the urban heat island effect, particularly when there is no current protocol or directive to do so.

3.3.1 Identifying Primary Trends - Valuable starting points for city officials to formulate "next steps"

The second component of the two-stage coding process (Charmaz, 2014) revealed four distinct, major themes - "Breaking Down Silos" (interagency cooperation), "Spreading Awareness" (to residents), "Places and Venues" (physical and abstract), and "Resources and Funding." In total, there were 38 individual occurrences of these themes materializing throughout the course of the conversation. The emergence of these particular patterns was not surprising given that they are typically an unrelenting component in some form or fashion in the majority of environmental and planning dilemmas; however, the prevalence and dynamic in which these trends emerged provide a glimpse into opportunities and challenges associated with resilience planning.

The first and most significant major theme was that of “Places and Venues.” Accounting for 32% of the initially coded transcript, this result signifies the monumental impact that both physical adjustments (to the built environment) and abstract modifications (in planning documents) play in resilience planning. While several different members of the focus group mentioned the importance of places, an individual from the parks and recreation department proposed an interesting method for reconstructing the conception of summertime play spaces for children.

> *“But we normally think of the indoor spaces, things that we utilize in the winter. But based on those comments that the kids were talking about, it gets too hot outside. I have a five-year-old [and] that's the same thing. [They say:] ‘But I don’t want to go out there. It's too hot.’ So if we had indoor spaces for the extreme heat occasions where people could go recreate and play. There would be potential for that.”*

Planning for the built environment and physical infrastructure is a critical component of elevating an area’s resilience, but several focus group participants acknowledged that the foundation of those initiatives are often developed in grant proposals, neighborhood plans, and comprehensive plans, and reiterated the importance of actively implementing sustainable practices into those documents and pieces of legislation.

> *“One of the ways that I see our role as the planning department is implementing some of these policies through amending our development code. And one of the things that we plan to address is maximum parking which creates a whole lot of impervious surface in the city.”*

The second predominant theme that arose throughout our discussion was the critical nature of spreading awareness throughout the local community. The first step in addressing any problem is actually recognizing that one does indeed exist, and this particular theme accounted for approximately 29% of the code chunks stemming from the focus group discussion. There are certainly varying methods of introducing issues like extreme heat and resilience planning to members of the community, but a local librarian offered a succinct opinion on one the importance of simply starting somewhere.

> *“A lot of people just don't know just the basic definition of climate [change]. So, starting at point 1, just getting the basic information out, and then providing different programs and things and ways that they can help can be a big, big point. So just start at the basics.”*

Starting at the basics, whether it be through an expansion of the environmental section in the local library or a module addition to the K-12 education system, is critical to expanding societal awareness about resilience planning which can in turn play a large role in the successful endorsement and financial support of relevant legislation and plans.

Another major trend produced by the focus group revolved around resources and funding. Acquiring the resources required to fulfill each and every desirable project within a community is often unrealistic, so it comes as no surprise that this primary theme accounted for 24% of the original code chunks. Assessing the lack of resources within a jurisdiction is an important observation to make, while identifying opportunities to access additional funding is an equally critical task. The local urban forester highlighted the former aspect of that dynamic, while an individual working in the water quality department accentuated the latter sentiment.

> *"Part of our issue is the planting budget for trees was removed for 10 consecutive years, starting at the beginning of the recession and moving forward for 10 years."*

> *"The city has recently received grant funding from the Community Flood Preparedness Fund to implement our community resiliency plan, so the timing of this is just really phenomenal, and so we are going to be reaching out and engaging with everyone to make sure we maximize this."*

The final major trend, "Breaking Down Silos," accounted for approximately 16% of the primary trend occurrences and was highlighted by an individual working in the stormwater management division.

> *"How do we multi-purpose spaces to account for these different [functions]? There's just a lot of opportunities for us to break down silos and work together to come up with good policies that we can all work together to implement."*

The phrase "Breaking Down Silos" refers to an enhanced level of collaboration between agencies and organizations to attack a challenge, and while those particular words were specifically stated a few times given the familiarity of these persons with the importance of that concept, it was also suggested in more subtle fashions throughout the meeting as well.

> *"So, I'm a big proponent of the education and expansion of this program… So [to do this we need to], to build partnerships [with each other and] community partners as well."*

3.3.2 Pinpointing overlapping trends and linking to hypothesized resilience pathways

During the first component of the two-stage coding process, code chunks were classified into their primary category; however, the second portion of that endeavor revealed that several thoughts and ideas introduced by focus group participants spanned across those theoretical boundaries. The prevalence of those co-occurrences provides valuable insight on the underlying relationship between these factors involved in resilience planning. The most common overlap of trends in the identified code chunks occurred between "Places and Venues" and "Resources and Funding," an intuitive outcome which represented 36%

of the total pattern intersections. The group members made it well known that updates to existing infrastructure or the creation of new spaces requires significant funding, an aspect that far too often prevents the fruition of innovative ideas.

> *"There has been a lot of work done by the city and departments that are sitting here with the river and increasing the quality of that water. So the Roanoke River is a really nice asset for us here in the city. It runs right through the middle of the city. And so there's an opportunity now, if funding is always the thing, but re-evaluating that as a 'place to play' and if there's opportunities to put in river play parks with that, there could be a lot of potential there."*

Another prominent co-occurrence which emerged from the focus group dialogue, representing 27% of the idea overlap, was between "Spreading Awareness" and "Places and Venues." While not as ostensibly linked as the previous connection, the participants subconsciously emphasized the undeniable potential associated with utilizing community spaces as a vehicle to transmit passive knowledge and correspondingly elevate awareness about the environmental impact of extreme heat and resilience planning. Perhaps the most profound idea situated at the nexus of these two themes was produced by a member of the parks and recreation department who envisioned modified playgrounds as spaces for community members of all ages to both play and learn.

> *"[To increase] heat resilience, [parks should] include education stuff there so people can see it while they're playing and say, 'oh, this is something I never even thought about, but this is part of that campaign.'"*

The final considerable overlap which emerged from the focus group meeting transcript, also accounting for 27% of the total intersection, was between "Breaking Down Silos" and "Spreading Awareness." The connection between these two components underscores the comprehensive, exhaustive effort that is required to effectively improve the informational capacity of an entire community. Collective coordination between governmental departments and agencies to ensure that a unified, accurate message is being delivered to the public in an understandable and engaging fashion is critical to educating and empowering members of the community.

> *"[We need to] make sure that we're educating and empowering the community to understand that something as simple as planting a couple of trees in their front yard or [asking themselves] 'Gee do I really need to make my driveway bigger to handle a third or fourth car.' And just some of those things that are really inexpensive for somebody to do or it could even save them money in the long run. [Things that are] good for the community, good for neighbors, and good for themselves."*

These co-occurrences, which were embedded within the dialogue and corresponding transcript of the Spring 2022 Roanoke City Official Focus Group, exemplify common trends that are ingrained in many planning issues. While those overarching patterns may be helpful in terms of broadly emphasizing categories which are important for planners and other public officials to prioritize, they fail to provide a discrete set of actionable guidelines by which individuals in positions of power should consider and act upon. Similarly, the National Oceanic and Atmospheric Administration's "Theories of Change," published in 2020, provide a generic outline of the limitless possibilities related to effective resilience planning. Each long-term outcome listed represents an end-goal, or a vision for a more sustainable future; however, the concrete causal pathways by which those final outcomes can be successfully conquered have remained relatively theoretical in nature up to this point. The participants of this focus group interacted with the long-term outcomes espoused by NOAA by placing specific activities related to their work that could improve heat resilience planning efforts in Roanoke adjacent to the most applicable overarching theme. That activity, illustrated in **Figure 3.5** and **Figure 3.6**, is site-specific and must be reproduced in other places to formulate specific plans and projects that can advance heat resilience efforts.

After evaluating the identification of primary trends, the overlapping patterns which were embedded within the focus group dialogue, and the ideas displayed on the Jamboard platform which corroborate the intent of the NOAA Theories of Change, there does appear to be a distinct linkage between each of those elements. The four primary themes which were extracted from the focus group discussion also emerged from the original Jamboard activity as seen in **Table 3.3**, an exercise which isolated the primary thoughts of each participant without any influence from other group members. This finding emphasizes the pivotal role that each of these four categories play in each abstract level of the quest to successfully advance heat resilience planning efforts.

Table 3.3 Examples of participant generated Jamboard ideas, grouped by thematic area

Theme	Jamboard post-it notes contents
Breaking Down Silos	*"As we re-develop all City Spaces (libraries, fire stations, Recreation Centers, etc.) break down silos on what Recreational amenities we could provide in these spaces. For example, splash pads at libraries, rec centers, fire stations, etc."* *"Together, we can create a clean water legacy". [We] can't do that without individuals working together with City programs."*
Spreading Awareness	*"Include education and then community-driven policies into the neighborhood planning process to create greater adaptive capacity long-term."* *"Collaborate with Neighborhood Services in community engagement projects and events that address heat resilience."*
Places and Venues	*"Create a Library Program such as the school program that we can do at the Libraries during our Summer Reading Program at one or several library branches."* *"Update the zoning code to address maximum parking requirements thereby removing impervious surface areas in the City."*
Resources and Funding	*"Neighborhoods need to support continued funding of Urban Forestry to maintain and increase the number of trees in their community."* *"This project and meeting is very timely as the city has received CFPF (community flood-preparedness) grant funding to develop a Resiliency Plan. [There is a] need for integration of city-wide plans and analysis of current policies to enhance those for climate change."*

3.4 Discussion

The U.S. Global Change Research Program (USGCRP) defines the planning buzzword "resilience" as "a capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment" (Bey et al., 2020). A complex concept that undoubtedly embodies an optimal attribute for localities seeking to minimize the detrimental ramifications associated with both acute and chronic economic, social, and environmental disasters, resilience planning is a process that is yet to be completely mastered (Woodruff et al, 2022), largely because it is not a ubiquitously required venture and each geographic location possesses a unique collection of vulnerabilities. As a result, uncovering mechanisms which can stimulate interest in resilience initiatives, like injecting youth into planning processes (Frank, 2006), and identifying relevant overarching long-term resilience outcomes, such as those represented by NOAA's Theories of Change, is essential to initiating the resilience planning process. Still, perhaps an even more important endeavor is conceiving and linking actionable proposals to those stable objectives. Working with leaders in government to develop potential projects which serve as pathways to advance resilience planning interests, while also extracting common themes that can serve as a guide for other cities and municipalities is the next logical step in planning for heat resilience.

Not lost in the catalyzation of heat resilience planning efforts is the stimulant required to spark the required political will and governmental desire to begin to do something that no single agency has an existing mandate to be responsible for. The potential for youth to impact the planning process is still relatively unexplored (Frank, 2006) (Jacquez et al., 2013), but can serve as a springboard for innovative decision making when given the chance (Carlson, 2005). By conducting a place-based science education program emphasizing environmental literacy with middle school students in the Roanoke area, those children were not only able to learn about an issue important in their life and to the future of their neighborhoods, but the corresponding perspectives, solutions, and stories which were produced also compelled influential leaders to take a closer look at an important environmental issue that might have otherwise been neglected. The realization of that participatory action research campaign and its results gave credence to the issue of extreme heat within the City of Roanoke for focus group participants, which in turn facilitated the thoughtful discussion of relevant challenges and opportunities. Provided that an extensive amount of effort and dedication is necessary to proactively advance resilience planning efforts, organizing a science education program with young adults can both elevate community awareness and establish momentum.

The four major themes which emerged after analyzing the transcript detailing the conversation of the focus group conducted with fourteen Roanoke city officials ("Breaking Down Silos," "Spreading Awareness," "Places and Venues," and "Resources and Funding") provide a framework for the typical opportunities and challenges associated with heat resilience planning. Evident not only in the dialogue of the group but also in the initial Jamboard artifacts which were generated without any prior discussion amongst participants, these categories represent topics that communities must actively acknowledge and address in order to successfully advance heat resilience efforts. While the specific rate of thematic occurrences and co-occurrences in this study is localized to the City of Roanoke, a similar framework designed to encourage local leaders to theorize the opportunities and challenges associated with those four categories can be utilized in other places to elicit specialized plans for that particular area.

The methodology of this study combined the typical participatory action research process with a more traditional qualitative data collection through the analysis of a focus group transcription and brainstorming exercise. Because the ultimate goal of participatory action research is realized in the knowledge expansion that occurs within its participants (typically students) (Spirn, 2005) (Barton and Tan, 2010), this study elevated the potential tangible impact of that process by documenting its results and directly transferring that information to influential decision makers who are capable acting upon it in a meaningful way. This process can be repeated by academics planners in other locations to bring attention to underserved issues that need to be addressed on a larger scale. Still, because participants were recruited with help from the City Sustainability Director, participation in the Roanoke City focus group was completely voluntary, and the ideas espoused were hypothetical in nature, the group represented a convenience sample. As such, the participants were likely to already have some form of vested interest in pursuing proactive resilience planning, and therefore may not be representative of government officials on the whole. That is not to say that every participant was completely immersed in the need to proactive heat resilience planning, as there were multiple individuals who repeatedly expressed concern about the logistics and feasibility of implementing ideas on a broad scale. For example, one participant reminded the group:

> *"To address [the issue of heat resilience] it requires individual action by everyone. And so, that is just a very, very difficult thing in our society to reverse and it's baked into the DNA.*

Unfortunately, there was not time to delve into the details of these concerns given the scheduling constraints of the focus group, but future studies should set aside time to explore any pushback that is articulated during the presentation or discussion.

Despite the limitations inherently related to a relatively small, voluntary group of community leaders who participated in this open dialogue session, the results of this process do offer meaningful insight into the challenges and opportunities associated with resilience planning. Targeting and actively addressing the broad categories of "Breaking Down Silos," "Spreading Awareness," "Places and Venues," and "Resources and Funding" can expedite the heat resilience planning efforts in other locations. Additional studies should be conducted to continue to refine the best way to catalyze and implement proactive resilience planning. Future work related to this topic should strive to include a larger sample of public officials who possess diverse backgrounds and viewpoints, as well as community leaders and other residents who are willing to volunteer their perspective. Expanding the involvement of focus group participants to more accurately represent the relevant population will only augment the ability of the results that are produced to effectively impact policy and project proposals.

4 Conclusion

As proactive resilience planning, specifically relating to heat resilience, continues to emerge as an increasingly important staple of routine planning efforts given the evolving nature of society and the rapidly changing climate across the globe, examining the methods by which those initiatives can be completed most effectively and efficiently is critical to their comprehensive adoption and genuine success. Currently, outstanding gaps exist for heat resilience planning in establishing the spatial distribution and social vulnerability to extreme heat in neighborhoods within municipalities and understanding the most salient pathways to adapting cities to extreme heat with respect to youth environmental education programs serving as a vehicle for the commencement of heat resilience interventions. By conducting a series of Geographic Information Systems analyses, followed by an assessment of a focus group conducted with Roanoke City officials designed to elicit their feedback on explicit pathways that can advance resilience aspirations, I was able to identify correlations between socio demographic characteristics and heat exposure along with overarching trends that can serve as a foundation for the planning efforts of other communities.

The GIS analysis displayed in Chapter 2 of this thesis illustrates that there are several statistically significant relationships between socio demographic attributes and land surface temperature within the City of Roanoke; however, those relationships are not uniformly intuitive. For example, there is a statistically significant inverse relationship between mean land surface temperature (averaged both over summer scene rasters and by pixels in census tract) and median household income, implying that as individuals accumulate wealth, they typically choose to live in locations that are more thermally comfortable. Not all correlations were straightforward though, as a situation existed where there was a no statistically significant relationship between the percentage of non-white individuals in a census tract and the mean land surface temperature (averaged both over summer scene rasters and by pixels in census tract), but there was a statistically significant correlation between those variables when removing the only four census tracts that possessed a diversity rating of greater than 40%. Upon further examination, it appears that Roanoke Country Club, along with several large cemeteries are located within those census tracts, obscuring an otherwise notable trend. Still, it is important to note that the relationship between socio demographic variables and land surface temperature is not likely to be completely linear given that there is a discrepancy between the scale of those variables. It is also critical to recognize the limitations associated with evaluating socio demographic data at the census tract level given that not all census tracts cover the same geographical area, and there is significant variation within the built environment and zoning characteristics of those abstract boundaries. Perhaps the most prominent example of that individual-level constraint within this study is the propensity of country clubs and cemeteries to lower the mean land surface temperature of a census tract, even though the majority of residents within those abstract boundaries do not necessarily benefit from that passive cooling effect.

The boxplot data illustrating the mean land temperature variation between Home Owners' Loan Corporation polygon grades was not as significant as shown in other studies (Wilson, 2020), but there is a clear distinction between the Class A polygons and the other designations. Similarly, the boxplot figures displaying the fluctuation in mean air temperature between the HOLC classes did not reveal a substantial discrepancy between Class B, C, and D; however, there was a considerable difference between those categories and Class A, especially during the morning and nighttime periods which are the most crucial times for the human body to adequately recover from heat stress. The distribution in data point availability between the four Home Owners' Loan Corporation classes presented an obstacle in comparing a similar number of pixels across classes, as areas designated C and D were substantially more prevalent than those labeled A and B.

Chapter 3 of this thesis briefly describes the science education program that I helped implement, which served as the catalyst for the focus group that I subsequently conducted with government officials from Roanoke during the Spring of 2022. That initial participatory action research experience allowed me to serve as a co-instructor for the youth that engaged with the program and facilitated my development with conveying complex concepts in an understandable fashion - a skill that is imperative for planners to routinely demonstrate when working with other governmental agencies and members of the general public. I believe that the participation of graduate planning students in K-12 student programs could help foster the cultivation of that skill in a relatively low-stakes environment. Additionally, in this situation, the science education program served as an impetus for propelling the discussion of planning for heat resilience amongst influential individuals. Given the aforementioned numerous benefits related to engaging youth in planning, cities and towns across the globe should consider simulating this process as a mechanism to improve the equity of the planning process while also accelerating the timeline on resilience initiatives. The subsequent focus group with City of Roanoke public officials extracted ideas from participants regarding avenues for the advancement of heat resilience initiatives relative to NOAA's overarching hypothesized Theories of Change. Several broad themes emerged from the dialogue and brainstorming exercise of that focus group, including "Breaking Down Silos," "Spreading Awareness," "Places and Venues," and "Resources and Funding." Those categories largely encapsulate the buckets of challenges and opportunities that focus group participants expressed during our meeting and can serve as a framework for the leaders of other municipalities to consider when crafting their own heat resilience plans. Because each individual community presents a unique assortment of assets and vulnerabilities, it is crucial for planners to utilize those broad themes as a structural foundation for discussion while simultaneously exploring the specific proposals and activities that can advance long-term resilience goals within their communities.

Ultimately, planning for heat resilience is a very complex challenge. It requires a comprehensive identification and acknowledgement of the issue, the formulation of a long-term vision with corresponding goals, and the implementation of smaller benchmark activities and projects along the way which promote the interests of the overarching objectives. GIS analyses which display the inequities associated with extreme heat exposure can help generate awareness about that issue, while facilitating the development of science education programs which can elevate community knowledge and shift the onus to governmental and community leaders to take action. Planners must assist those decision makers with understanding the problem, while also serving as intermediaries who can assist in the arrangement of partnerships designed to tackle related economic, environmental, and social projects. Moving forward, expanding science education programs to include all students willing to participate, along with local residents interested in the issue, should be a priority of those conducting the experience. Finally, it is essential to design focus groups which incorporate public officials, community organizations, and civic leaders with the purpose of eliciting collaborative discussions which forge potential pathways to advance heat resilience.

References

APA Policy Guide on Smart Growth. (2021). American Planning Association.

Arnstein, S. R. (1969). A Ladder Of Citizen Participation. Journal of the American Institute of Planners, 35(4), 216–224. https://doi.org/10.1080/01944366908977225

Bailey, Z. D., Krieger, N., Agénor, M., Graves, J., Linos, N., & Bassett, M. T. (2017). Structural racism and health inequities in the USA: Evidence and interventions. The Lancet, 389(10077), 1453–1463. https://doi.org/10.1016/S0140-6736(17)30569-X

Barton, A. C.; Tan, E. We Be Burnin'! Agency, Identity, and Science Learning. Journal of the Learning Sciences (2010), 19 (2), 187–229. https://doi.org/10.1080/10508400903530044.

Berry, P., & Richardson, G. R. A. (2016). Approaches for Building Community Resilience to Extreme Heat. https://doi.org/10.1007/978-3-319-30626-1_15

Bey, G., McDougall, C., & Schoedinger, S. (2020). Report on the NOAA Office of Education Environmental Literacy Program Community Resilience Education Theory of Change. In National Oceanic and Atmospheric Administration. National Oceanic and Atmospheric Administration. https://eric.ed.gov/?id=ED615384

Bolitho, A., & Miller, F. (2017). Heat as emergency, heat as chronic stress: Policy and institutional responses to vulnerability to extreme heat. Local Environment, 22(6), 682–698. https://doi.org/10.1080/13549839.2016.1254169

Botchwey, Nisha D., Nick Johnson, L. Katie O'Connell, and Anna J. Kim. (2019). "Including Youth in the Ladder of Citizen Participation." Journal of the American Planning Association 85 (3): 255–70. https://doi.org/10.1080/01944363.2019.1616319.

CAPA Heat Watch | Heating Climate Zone Map | CAPA Strategies. (2020). https://www.capastrategies.com/capa-heat-watch

Carlson, Cindy. (2005). "Youth with Influence: The Youth Planner Initiative in Hampton, Virginia." Children, Youth and Environments 15 (2): 211–26.

Centers for Disease Control and Prevention. (2020). Temperature extremes. Centers for Disease Control and Prevention.

Charmaz, K. (2014). Constructing Grounded Theory (Second edition). SAGE Publications Ltd.

Chu, E., Anguelovski, I., & Brand, A. (2017). Urban Planning, Community (Re)Development and Environmental Gentrification. Routledge.

Climate Change 2022: Impacts, Adaptation and Vulnerability.
https://www.ipcc.ch/report/ar6/wg2/

Dare, E. A., Ring-Whalen, E. A., & Roehrig, G. H. (2019). Creating a continuum of STEM models: Exploring how K-12 science teachers conceptualize STEM education. International Journal of Science Education, 41(12), 1701–1720. https://doi.org/10.1080/09500693.2019.1638531

Environmental Protection Agency. Reduce Urban Heat Island Effect. EPA.https://www.epa.gov/green-infrastructure/reduce-urban-heatisland-effect.

Elmes, A., Rogan, J., Williams, C., Ratick, S., Nowak, D., & Martin, D. (1970). Effectsof urban tree canopy loss on land surface temperature magnitude and timing. ISPRS Journal of Photogrammetry and Remote Sensing
https://www.fs.usda.gov/treesearch/pubs/54836#:~:text=UTC%20coverage%20is%20asso ciated%20with,reducing%20energy%20use%20in%20cities.

Fishman, R. (2000). The American metropolis at century's end: Past and future influences. Housing Policy Debate, 11(1), 199–213. https://doi.org/10.1080/10511482.2000.9521367

Frank, Kathryn I. (2006). "The Potential of Youth Participation in Planning." Journal of Planning Literature 20 (4): 351–71. https://doi.org/10.1177/0885412205286016.

Guardaro, M., Messerschmidt, M., Hondula, D. M., Grimm, N. B., & Redman, C. L. (2020). Building community heat action plans story by story: A three neighborhood case study. Cities, 107, 102886. https://doi.org/10.1016/j.cities.2020.102886

Hart, M. A., & Sailor, D. J. (2008). Quantifying the influence of land-use and surface characteristics on spatial variability in the urban heat island. Theoretical and AppliedClimatology, 95(3), 397–406. https://doi.org/10.1007/s00704-008-0017-5

Habeeb, D., Vargo, J., & Stone, B. (2015). Rising heat wave trends in large US cities. NaturalHazards, 76(3), 1651–1665. https://doi.org/10.1007/s11069-014-1563-z

Harlan, S. L., Declet, -Barreto Juan H., Stefanov, W. L., & Petitti, D. B. (2013). Neighborhood Effects on Heat Deaths: Social and Environmental Predictors of Vulnerability in Maricopa County, Arizona. Environmental Health Perspectives, 121(2), 197–204. https://doi.org/10.1289/ehp.1104625

Hess, M., Johnson, J., & Reynolds, S. (2014). A Developmental Model for Educational Planning: Democratic Rationalities and Dispositions. International Journal of Educational Leadership Preparation, 9(1). https://eric.ed.gov/?id=EJ1024108

Hoffman, J. S., Shandas, V., & Pendleton, N. (2020). The Effects of Historical Housing Policies on Resident Exposure to Intra-Urban Heat: A Study of 108 US Urban Areas. Climate, 8(1), 12. https://doi.org/10.3390/cli8010012

Jacquez, Farrah, Lisa M. Vaughn, and Erin Wagner. (2013). "Youth as Partners, Participants or Passive Recipients: A Review of Children and Adolescents in Community-Based Participatory Research (CBPR)." American Journal of Community Psychology 51 (1–2): 176–89. https://doi.org/10.1007/s10464-012-9533-7.

Karas, D. (2015). Highway to Inequity: The Disparate Impact of the Interstate Highway System on Poor and Minority Communities in American Cities. 7, 13.

Keith, L., Meerow, S., Hondula, D. M., Turner, V. K., & Arnott, J. C. (2021). Deploy heat officers, policies and metrics. Nature, 598(7879), 29–31. https://doi.org/10.1038/d41586-021-02677-2

Klinenberg, E. (1999). Denaturalizing Disaster: A Social Autopsy of the 1995 Chicago Heat Wave. Theory and Society, 28(2), 239–295.

Leahy, I. (2018). Why we no longer recommend a 40 percent urban tree canopy goal. American Forests. https://www.americanforests.org/blog/no-longer-recommend-40 percent-urban tree-canopy-goal/.

Meerow, S., & Mitchell, C. L. (2017). Weathering the storm: The politics of urban climate change adaptation planning. Environment and Planning A: Economy and Space, 49(11), 2619–2627. https://doi.org/10.1177/0308518X17735225

Murage, P., Hajat, S., & Kovats, R. S. (2017). Effect of night-time temperatures on cause and age-specific mortality in London. Environmental Epidemiology (Philadelphia, Pa.), 1(2), e005. https://doi.org/10.1097/EE9.0000000000000005

Perkins-Kirkpatrick, S. E., & Lewis, S. C. (2020). Increasing trends in regional heatwaves. Nature Communications, 11(1), 3357. https://doi.org/10.1038/s41467-020-16970-7

NOAA's National Weather Service. (2020). Weather Related Fatality and Injury Statistics. National Weather Service. Retrieved from https://www.weather.gov/hazstat/.

Oke, T. (1982). The Energetic Basis of the Urban Heat-Island. Quarterly Journal of the Royal Meteorological Society, 108(455), 1–24. https://doi.org/10.1002/qj.49710845502

O'Lenick, C. R., Wilhelmi, O. V., Michael, R., Hayden, M. H., Baniassadi, A., Wiedinmyer, C., Monaghan, A. J., Crank, P. J., & Sailor, D. J. (2019). Urban heat and air pollution: A framework for integrating population vulnerability and indoor exposure in health risk analyses. Science of The Total Environment, 660, 715–723. https://doi.org/10.1016/j.scitotenv.2019.01.002

Ownes, C. (2015). Urban Planning Faces Possible Diversity Setback. https://nextcity.org/urbanist-news/planning-accreditation-board-diversity-urban-planning

Perini, K., & Magliocco, A. (2014). Effects of vegetation, urban density, building height, and atmospheric conditions on local temperatures and thermal comfort. Urban Forestry & Urban Greening, 13(3), 495–506. https://doi.org/10.1016/j.ufug.2014.03.003

Philadelphia Beat the Heat Toolkit | CAKE: Climate Adaptation Knowledge Exchange. (2019). https://www.cakex.org/tools/philadelphia-beat-heat-toolkit

Pugh, J. (2010). A Report on the City of Roanoke's Existing and Possible Urban Tree Canopy.https://rvarc.org/wpcontent/uploads/2014/01/UTC_Report_RoanokeCity_2010.pdf.

Roth, Wolff-Michael, and Stuart Lee. (2004). "Science Education as/for Participation in the Community." Science Education 88 (2): 263–91. https://doi.org/10.1002/sce.10113.

Rudolph, John L., and Shusaku Horibe. (2016). "What Do We Mean by Science Education for Civic Engagement?" Journal of Research in Science Teaching 53 (6): 805–20. https://doi.org/10.1002/tea.21303.

Russell, D., Gawthrop, E., Penney, V., Raj, A., Hickey, B., & Investigations, C. J. (2020). Deadly heat is killing Americans: Climate death toll rises after a decade of federal inaction. The Guardian. https://www.theguardian.com/us-news/2020/jun/16/climatedeaths-heatcdc

Schramm, P. J., Vaidyanathan, A., Radhakrishnan, L., Gates, A., Hartnett, K., & Breysse, P. (2021). Heat-Related Emergency Department Visits During the Northwestern Heat Wave—United States, June 2021. Morbidity and Mortality Weekly Report, 70(29), 1020–1021.

Shandas, V., Voelkel, J., Williams, J., & Hoffman, J. (2019). Integrating Satellite and Ground Measurements for Predicting Locations of Extreme Urban Heat. Climate, 7(1), 5. https://doi.org/10.3390/cli7010005

Spirn, Anne Whiston. (2005). "Restoring Mill Creek: Landscape Literacy, Environmental Justice and City Planning and Design." Landscape Research 30 (3): 395–413. https://doi.org/10.1080/01426390500171193.

Stone, B., & Rodgers, M. O. (2001). Urban form and thermal efficiency: How the design of cities influences the urban heat island effect. Journal of the American Planning Association, 67(2), 186–198. http://dx.doi.org/10.1080/01944360108976228

Thrupp, L. A., Cabarle, B., & Zazueta, A. (1994). Participatory methods in planning & political processes: Linking the grassroots & policies for sustainable development. Agriculture and Human Values, 11(2), 77–84. https://doi.org/10.1007/BF01530448

Uejio, C. K., Wilhelmi, O. V., Golden, J. S., Mills, D. M., Gulino, S. P., & Samenow, J. P. (2011). Intra-urban societal vulnerability to extreme heat: The role of heat exposure and the built environment, Socioeconomics, and neighborhood stability. Health & Place.https://www.sciencedirect.com/science/article/pii/S1353829210001838.

US Department of Commerce, N. O. A. A. (2021). Excessive heat. Excessive Heat. https://www.weather.gov/phi/heat.

US EPA, O. (2014). Learn About Heat Islands. https://www.epa.gov/heatislands/learn-about-heat-islands

van Empel, C. (2008). The effectiveness of community participation in planning and urban development. 549–556. https://doi.org/10.2495/SC080521

Vogelsong, S. (2020). In Virginia and U.S., urban heat islands and past redlining practices may be linked, study finds. Virginia Mercury. https://www.virginiamercury.com/blog va/there-may-be-a-link-between-urban-heatislands-and-past-redlining-practices-studyfinds/.

Wilson, B. (2020). Urban Heat Management and the Legacy of Redlining. Journal of the American Planning Association, 86(4), 443–457.https://doi.org/10.1080/01944363.2020.1759127

Woodruff, S. C., Meerow, S., Stults, M., & Wilkins, C. (2022). Adaptation to Resilience Planning: Alternative Pathways to Prepare for Climate Change. Journal of Planning Education and Research, 42(1), 64–75. https://doi.org/10.1177/0739456X18801