Redlining's Lasting Impacts and Green Infrastructure in Pittsburgh, Pennsylvania

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The process of redlining, or exclusionary lending practices based on where an applicant lives, is connected by research to lasting disadvantage in urban neighborhoods. Residential Security Maps produced by the Home Owner's Loan Corporation (HOLC) provide a lens of understanding lending bias towards different urban neighborhoods. A body of research finds that the HOLC's system of security grading in these maps coincides with ongoing socio-economic patterns in cities, as well as access to nature. This research based on the city of Pittsburgh uses spatial analysis to examine the relationship between the HOLC's ranking of neighborhoods and current tree canopy, parks, street bike lanes, and greenways to find how green infrastructure varies between neighborhoods of different security grades. In addition, census data is used to provide snapshots of Pittsburgh's demographics at around the time of the HOLC survey and the distribution in 2020. ArcGIS software was used to perform descriptive statistics, buffer analysis, overlay analysis, and geoprocessing. The results of the analysis indicate that the greatest marker of environmental inequality along the lines of HOLC districts in Pittsburgh is the lack of tree coverage in lowly-ranked areas compared to areas deemed more desirable. The research did not find that lower-graded areas suffered in terms of parks or bike lanes, which is probably due to the centrality of these resources and many redlined areas. However, it is concerning that redlined neighborhoods have fewer trees, given that trees have proven benefits to communities with access to them.

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1.0 Literature Review

The city of Pittsburgh today still suffers from the legacies of racist policies which have left black and lower-income families to live in historically disadvantaged neighborhoods (Rutan & Glass, 2018). One lens of understanding historical disinvestment is looking at Residential Security Maps (RSM) drawn by the Home Owner's Loan Corporation (HOLC). These maps, made for over 200 cities across the U.S., illustrate the attitudes and biases of lenders toward different urban communities. On a descending scale of "A" to "D," HOLC surveyors ranked neighborhoods of the city based on their viability for loan repayment for financial institutions. "D" graded urban areas were targeted by banks, making it nearly impossible for households in these typically majority-minority areas to procure a mortgage for decades. Referred to as "redlined," a term stemming from their red symbology on RSMs, "D" graded areas of the city have continued to suffer from biased investment practices even though these policies have been outlawed (Faber, 2017; Hillier, 2003; Lynch et al., 2021; Namin et al., 2022). Moreover, studies connect these areas of the city to lower rates of physical and mental health and a lower quality of life for its residents (Kraus et al., 2024; Lynch et al., 2021; Swope et al., 2022). Additionally, redlining, as a systematic process of investment, has been shown to impact who has access to green space and greenery in the city (Schell et al., 2020). In this context, this work aims to answer how the HOLC's ranking of neighborhoods in its Residential Security maps corresponds with the current spatial distribution of green infrastructure in Pittsburgh, Pennsylvania. Based on a body of research which finds less amenities generally and less greenery more specifically in redlined areas, it is expected that there exists less green infrastructure in "D" graded communities. At the same time, "A" graded areas are expected to enjoy the most green infrastructure.

The presence of trees and vegetation or lack thereof in communities is a significant issue for all users of the city. Not only does urban greenery make neighborhoods more attractive and livable, but it also has positive effects on residents' mental health (Bratman et al., 2015; Li et al., 2018; Turner-Skoff & Cavender, 2019). Trees also have a positive impact on property values, and larger trees have been shown to reduce crime, possibly through indicating social cohesion (Donovan & Prestemon, 2012; Sander et al., 2010). More importantly, urban trees can also benefit urban residents' health through regulation of urban temperatures and air quality (EPA, 2022; Loughner et al., 2012; Nowak, 2013; Rahman, et al., 2020; Tan et al., 2015). A disparity of these resources along the lines of historical investment patterns reflects a systemic issue and inequitable access to the benefits of these features.

1.1 The Home Owner's Loan Corporation

During the Great Depression, millions of Americans lost their income, and many lost their homes. To combat foreclosures, the Home Owners' Loan Act of 1933 was put into effect, creating the HOLC. This New Deal initiative functioned by buying home loans from financial institutions with bonds, and then issuing borrowers long term loans with low interest rates. From 1933 to 1935, the HOLC lent out over one million loans, saving hundreds of thousands of Americans from foreclosure. However, for many, the legacy of the HOLC lies in the "Residential Security" maps created between 1935 and 1940. These maps span 239 U.S. cities and rank neighborhoods from "A" to "D" based on where it was desirable or otherwise considered unsafe for financial institutions to lend. The basis of the grading scale was mainly the age, quality, and value of housing; distance to center city; and the racial and ethnic makeup of an area including immigrant status (Hillier, 2005). On the maps, each grade “A” through “D” was symbolized by a specific color. “A” graded neighborhoods were symbolized in green. These neighborhoods were mainly populated by white, working professionals and contained good quality housing. They were described as the “best” for lending (Nelson et al., 2016). “B” graded neighborhoods were symbolized in blue and were also majority white; however, the housing quality in these neighborhoods did not match that in “A” graded areas. They were nevertheless described as “desirable” for lending (Nelson et al., 2016). Areas with a “C” grade were colored yellow on the maps. These were typically “areas in transition,” meaning they had an increasing non-white population; this transitional status was described as “declining” by the HOLC surveyors (Nelson et al., 2016). Lastly, neighborhoods with the lowest or “D” ranking were described as “hazardous” for lending and had predominantly black or immigrant populations (Nelson et al., 2016). Their red symbology on the maps is where the term “redlining” comes from, referring to the practice of discriminating against borrowers based on where they live. This discrimination happened because of the perceived risk for financial institutions and the long-standing belief that the presence of minorities in a neighborhood diminished property value (Nardone et al., 2021). It is important to take note of the language used in HOLC documents, particularly, “descriptions of the ‘infiltration’ of what were quite often described as ‘subversive,’ ‘undesirable,’ ‘inharmonious,’ or ‘lower grade’ populations” especially in “C” and “D” graded areas, evidencing the racist attitudes driving these neighborhood appraisals (Nelson et al., 2016).

Although the 1968 Fair Housing Act put a legal end to redlining, a body of literature links redlining to ongoing social patterns in cities. An extensive examination of redlining’s continued effects on cities is described by Richard Rothstein in *The Color of Law*. Rothstein argues that redlining is evidence of federal policies that endorsed discriminatory practices based on location.

Moreover, these policies entrenched U.S. cities in inequality into the present da. For instance, lenders continue to show biased lending practices to areas that were redlined by the HOLC (Faber, 2017; Hillier, 2003; Lynch et al., 2021; Namin et al., 2022). Additionally, a majority of redlined neighborhoods continue to be lower income and minority neighborhoods (Mitchel & Franco, 2018). Specifically, decreasing HOLC grades correspond to increasing proportions of Black and Hispanic residents in the current population of a neighborhood (Namin et al., 2022). Moreover, researchers have found associations between redlined areas and negative health (Swope et al., 2022) and even air pollution (Lane, 2022).

1.2 Redlining's Relationship to Green Space

The inequitable distribution of wealth in cities due to systemic financial practices such as redlining has tangible effects on the distribution of nature and greenery in urban ecosystems. Case studies of various U.S. cities show that historically black and redlined neighborhoods have the least abundant tree canopy within the urban region. A study of Durham, North Carolina, found tree canopy to be significantly sparser in "D" and "C" graded neighborhoods compared to "A" and "B" neighborhoods, using Landsat8 image data (Chen, 2022). In Baltimore, Maryland, redlined neighborhoods were found to have "the lowest percentages of canopy cover," and these areas have for the most part remained majority-black to the present day (Grove et al., 2018). A nationwide study using normalized difference vegetation index (NDVI), used to assess the health and density of vegetation, revealed a spatial pattern of decreasing NDVI scores with worsening security grades across the board (Nardone et al., 2021). Moreover, in many cases, redlined communities are typically located in the center of the city, further impeding their residents from accessing nature outside the city limits (Schell et al., 2020).

1.3 The Importance of Urban Greenery

For the purposes of this research, urban greenery generally refers to the network of vegetation within the city, emphasizing trees and urban parks. The importance of urban greenery is intuitive, but also proven in literature. Firstly, trees make spaces more attractive and are a vital "part of the identity and features of a place that invoke pride" (Elmendorf, 2008). Trees and greenery strengthen a "sense of locality" and a "sense of place" for local residents, making them feel more connected to their surroundings (Elmendorf, 2008). There is also a strong association between trees and improved mental health. People who are exposed more frequently and for longer durations to greenery are reported to experience "reduced negative thoughts, reduced symptoms of depression, better reported moods, and increased life satisfaction" (Bratman et al., 2015; Li et al., 2018; Turner-Skoff & Cavender, 2019).

Apart from improving the appearance of local surroundings and residents' moods, trees also have crucial environmental and public health impacts on cities (Wolf et al. 2020). In the context of recent record-breaking heat waves across the world, certain methods of urban tree planting are effective at cooling local temperatures (EPA, 2022; Loughner et al., 2012; Rahman, et al., 2020; Tan et al., 2015). By extension, parks have also been found to have cooler temperatures than the rest of the city (Konijnendijk, et al., 2013: Sadeghian & Vardanyan, 2013). The cooling impacts of greenery are crucial as rising temperatures due to global climate change expose more people to greater heat. Longer and more intense heat waves put populations at risk for heat-based deaths and illnesses, such as heat exhaustion and heat stroke (World Health Organization [WHO], 2018). Additionally, trees filter air and remove air pollutants through leaf stomata (Nowak, 2013). The removal of air pollutants is important because in high concentrations they may cause various illnesses, including heart disease and lung cancer (WHO, 2019). All things considered, trees are a vital metric of green infrastructure, and a lack of trees in an urban locality reflects a gap that should raise concern for urban planners. Determining where within the city there is an abundance or lack of trees can be indicative of ongoing inequality in these city areas.

1.4 Discussion of the HOLC's Impacts

Although literature has established the negative social and environmental outcomes of redlining, some authors emphasize that the HOLC's maps did not necessarily begin these patterns. Researchers in the urban studies field concluded that the HOLC originated redlining following Kenneth Jackson's 1985 publication *Crabgrass Frontier* (Hillier, 2003). Jackson was the first urban historian to claim that the practice of discriminatory investment patterns was connected specifically to the HOLC's RSMs. However, author Amy Hillier argues that the assumption that the HOLC is wholly responsible deserves further questioning. Hillier (2003) highlights that the HOLC did not "initiate" redlining, but the organization's maps constituted more of a "federal endorsement of standards that were already in practice." This qualification is made because lending patterns biased against black and minority neighborhoods were already "common place" in the early 20th century (Hillier, 2003). Moreover, the HOLC had an equitable approach to its own lending practices during the extent of its mortgage refinancing program. In fact, studies on numerous cities found that a majority of the loans the HOLC refinanced during its 1930s mortgage program were to households in “C” and “D” graded neighborhoods (Hillier, 2003; Jackson, 1985). Lastly, the Residential Security Maps were not widely distributed, although they were shared with multiple federal housing programs including the Federal Housing Administration (FHA) (Hillier, 2003). Hillier (2003) and Fishback et al. (2021) both direct more of the blame surrounding redlining to the FHA, which produced similar maps and had more policy influence. However, for Hillier (2003), this “is not to insist that HOLC residential security maps were insignificant.” Although the HOLC’s maps did not “initiate” redlining, their RSMs are great resources which illustrate historical, spatial patterns of biased investment into the city’s built environment (Hiller, 2003; Namin et al., 2022). Lasting patterns along the lines of HOLC-drawn maps show the spatial correlation between its Residential Security Maps and redlining. Assuredly, redlining is anything but a thing of the past and it continues to have a web of impacts on urban residents, including in the city of Pittsburgh.

1.5 Study Area: Pittsburgh

This research focuses on the city of Pittsburgh, Pennsylvania. Pittsburgh is a medium-sized city with a population of approximately 300,000 within the municipality and about 1.2 million within Allegheny County (United States Census Bureau, 2022). Pittsburgh is notably considered a legacy city, referring to the late 20^{th}-century process of deindustrialization in the region. From its origin as a fort and trade outpost in the late 18^{th} century, Pittsburgh developed as an industrial town in the 19^{th} century with the advantage of nearby coal deposits (Byrdsong & Yamatani, 2017). The glass industry took hold at the turn of the 19^{th} century, and came to produce a majority of glass in the U.S. by the end of the century (Pittsburgh Community Broadcasting, 2013). The city’s site at the confluence of three rivers gave it the advantage of regional trade connections, which were later enhanced by rail introduced in the mid-19th century (Byrdsong & Yamatani, 2017; Foster, n.d.). At the same time, Pittsburgh's industry was slowly being taken over by steel from the late 1800s into the 20th century, as industry titans consolidated their holdings.

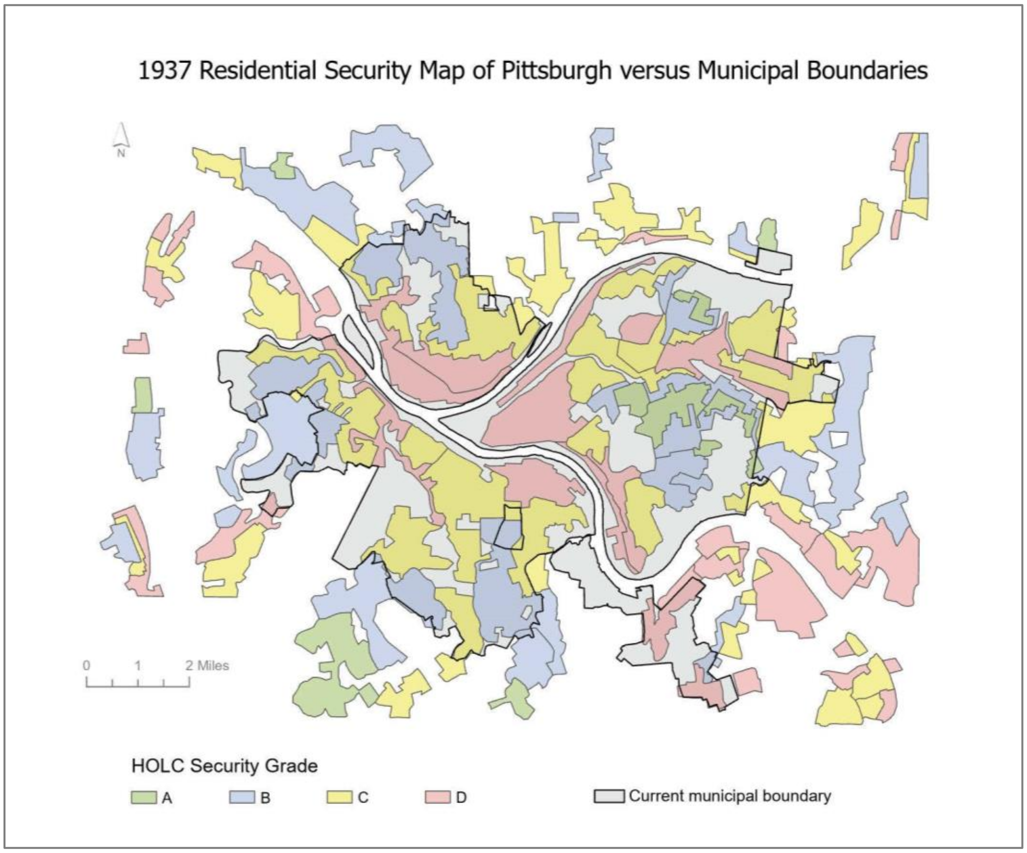


Figure 1: **The 1937 Residential Security Map and Pittsburgh city boundaries.**

The city's population more than quadrupled between 1880 and 1950 as steel continued to expand (Department of the Interior, 1890; Census Bureau, 1950). Economic opportunity attracted many to the city, including a substantial number of black migrants from the Southern U.S. (Byrdsong & Yamatani, 2017). This movement of people increased Pittsburgh's black population and community. Many of these black migrants settled in the Hill District neighborhood, which grew famous for its jazz scene and lively black community in the 1930s. East Liberty, Pittsburgh's "second downtown," was another economically thriving, diverse neighborhood in 1940s, with a substantial black community (HELP Initiative, n.d.). To the east of East Liberty, Homewood, a suburb with black people "among its earliest residents," also grew increasingly diverse as Catholic immigrants and black people moved to the city for industrial jobs (Allegheny County Department of Human Services, 2009; Snyder, 1993). It is important to note that settlement patterns of black people in the early-to-mid-20th century in Pittsburgh were largely decided by segregation and redlining, which kept white neighborhoods white and homogenous and offered few options for black settlers. Nonetheless, these diverse aforementioned neighborhoods became vibrant and generally peaceful communities in the first half of the 20th century.

However, the success of these black and mixed neighborhoods was drastically changed by transitioning demographics and Urban Renewal taking shape through the Renaissance I project in the 1950s and 1960s. These plans led to the demolition in the 1950s of the Lower Hill District to build the Civic Arena and a "phantom cultural center" that was never realized (Snedden, 2019). This move effectively displaced around 8,000, including primarily black families. Many of those displaced relocated to Homewood, one of the only neighborhoods "open to African American [home seekers]" at the time besides the North Side (HELP Initiative, n.d.; Snyder, 1993). Homewood's population became increasingly black as a product of this influx of families from the Hill and subsequent white flight. The loss of Homewood's diversity coupled with an increasing share of renters and the loss of the middle class left the area in decline for many years to come (Allegheny County Department of Human Services, 2009; Snyder, 1993). In East Liberty, almost half the blocks of the neighborhood were razed in the 1970s to install "an outdoor pedestrian mall on Penn Avenue" (Snyder, 1993), effectively destroying most of the businesses in the neighborhood by the end of the decade (Snedden, 2019). Together with this, residential high rises were built in East Liberty to help house the families displaced from the Hill District to Homewood and the North Side (Help Initiative, n.d.). Unfortunately, these planning decisions ultimately undid the upward trajectory of the Hill District and East Liberty by stripping away their businesses and homes and relocating their established community (Snedden, 2019; Snyder, 1993). The Hill, East Liberty, and Homewood entered a period of steep decline in the decades following these projects. In summary, Pittsburgh Urban Renewal projects from the 1950s to 1970s largely disenfranchised a once bustling black community in the city of Pittsburgh. Moreover, redevelopment in these neighborhoods involved clearing trees in the area, especially in the case of the Hill District, which had dozens of blocks razed. It is unclear how to what extent the canopy of these areas has recovered.

In addition to these social changes affecting Pittsburgh's black community, the city's economy also nosedived in the 1970s. While the economy of Pittsburgh had been largely sustained by steel for decades, the 1970s saw a sharp downturn in steel jobs, due in part to new foreign competition, inefficiency in industry methods, and a global energy crisis. This dramatic downturn led to significant depopulation from the city, and Pittsburgh's population decreased by half from about 675,000 in 1950 to about 300,000 in 2020 (Briem, 2017). These changes initiated a transition of Pittsburgh's economy from manufacturing-based to a service- and knowledge-based economy from the 1970s onward. The city of Pittsburgh today is a product of its industrial background and subsequent social and economic transformations.

1.6 Redlining in Pittsburgh

While there is not much Pittsburgh-specific research on redlining, one study evaluated the impacts of redlining on the city (Rutan & Glass, 2017). The study focused on the period from 1970 to 2000, which marked the height of deindustrialization and depopulation in the city (Rutan & Glass, 2017). Spatial analysis revealed that the black population of Pittsburgh for the most part remained concentrated in the same historically black, redlined neighborhoods throughout this time period. At the same time, from 1970 to 2000, "C" and "D" graded neighborhoods were "persistently high poverty" while "A" and "B" graded neighborhoods were "persistently high income" (Rutan & Glass, 2017). Lastly, redlined areas have continued to see a lack of investment in their built environment. In recent decades, over one quarter of the housing stock of redlined areas was demolished, but not replaced. New development has not kept up with this change. In addition, the housing stock of redlined areas remained "composed of a greater portion of old units" (Rutan & Glass, 2017). This research affirms that the investment practices "codified" by the HOLC had continuous impacts on the city of Pittsburgh, physically, socially, and economically; furthermore, these impacts are still observable (Rutan & Glass, 2017). In this framework, it follows that one may expect to find other social problems observed in redlined communities throughout literature specifically in Pittsburgh.

2.0 Methodology

This research employs a literature review as well as geo-spatial analysis through Geographic Information Systems (GIS) software, specifically using ArcGIS Pro version 3.0.1 by Esri. The goal of the literature review is to provide vital background information on the HOLC, whose maps were used in the spatial analysis, and the ongoing impacts of redlining which are associated with these maps. Additionally, the connection of redlining to access to urban greenery is established, along with the importance of urban greenery for urban dwellers. Lastly, the review briefly examines the context of Pittsburgh and how it intersects with redlining. The spatial analyses involved include overlay analysis, buffer analysis, and calculating descriptive statistics. A series of maps was created in order to find the spatial relationship between redlining and green infrastructure in Pittsburgh. Another component of this analysis uses historical census data to provide a demographic context and comparison. Following Rutan & Glass (2017), historic Census data from 1940 are used to find the normalized distribution of the non-white population of Pittsburgh. The grouping of non-white races is used because this is level of detail recorded in the 1940 Census. This data is used to identify black and diverse areas in Pittsburgh and determine the racial composition of redlined areas at the time of the HOLC surveying in 1937. In addition, data from the latest Census in 2020 is used to compare the distribution of demographics in the present day to the snapshot provided by the RSM to identify any lasting patterns.

2.1 Data

The Mapping Inequality project (Nelson et al., 2016), now in its third version, made this digital analysis possible by scanning and georeferencing the original maps printed by the HOLC. The project made a shapefile of the 1937 Pittsburgh RSM available, used in this analysis. Historical census race data and census tract shapefiles for 1940 and 2020 are sourced from National Historical Geographic Information System (NHGIS) (Manson, et al., 2023). This analysis also employs the Tree Equity Score (TES) developed by the American Forests foundation, measuring priority for tree planting based on the gap between expected and actual tree coverage (American Forests, n.d.). This calculation is then combined with social factors including income, employment, race, age, climate, and health (American Forests, n.d.). A shapefile of TES scores across different Pittsburgh neighborhoods was taken from American Forests for the analysis.

Another valuable dataset used in this research was the 2014 Pittsburgh Street Tree Inventory, which includes over 33,000 trees. The data include accurate coordinates of trees, as well as important information on tree size, including tree height, width, and diameter at breast height, also known as the diameter of a tree at around 4.5 feet from the ground. It is important to note some limitations of this particular dataset. For instance, the dataset only includes trees in the city right-of-way, so these data only account for trees in publicly owned areas, excluding, for example, trees in yard sparces. Because the data was taken from a subset of the city's entire canopy, the data is also vulnerable to sampling bias effects, and may not provide a complete depiction of the extent of tree canopy. Additionally, the dataset is confined to the municipal boundaries, while the Residential Security Map of Pittsburgh sprawls outside of this area. Therefore, the data does not cover the entire study area. However, this dataset is also comprehensive, including every tree in right-of-way, and provides a very useful picture of individual tree characteristics. Lastly, shapefiles of parks, bike lanes, greenways, and city boundaries of Pittsburgh were taken from the Western Pennsylvania Regional Data Center.

2.2 Measurements of Green Infrastructure

There are many ways to define green infrastructure; for example, many organizations specifically view it as a way to manage stormwater. In this research, the term "green infrastructure" is defined as the ways in which the city incorporates nature into its built environment to benefit the health of its residents and ecosystem. The definition used in this research is largely based on the definition provided by the European Commission of the European Union (EU). The EU defines green infrastructure as a "planned network of natural and semi-natural areas," and focuses on its capability to improve the "quality of the environment," biodiversity, as well as "citizens' health and quality of life" (European Commission, n.d.). The overarching ethos drives improvements in a range of services for the city, including air quality and recreation. The amenities this research focuses on in order to measure green infrastructure are tree canopy, tree measurements, tree equity score, parks, greenways, and bike lanes.

Tree canopy and tree measurements are used in order to understand the abundance of trees and shade across the study area. Tree measurements are included as a measurement of green infrastructure by further illustrating the quality of individual trees present in different neighborhoods. When trees are larger, their canopy takes up more space, and they can pull more pollutants from the air and have a greater cooling effect (Stephenson et al., 2014; Steppe et al., 2011). Larger trees are also considered more important units of the ecosystem because they provide shelter and habitat for other species, and are associated with greater biodiversity (Stagoll et al., 2012). Moreover, large trees may also be considered an interesting metric of economic status, as they may be correlated with higher property values (Anderson & Cordell, 1988; Sadeghian & Vardanyan, 2013). These factors make larger trees in particular are more effective units of green infrastructure.

In another map, the Tree Equity Score (TES) index is used. This index was developed by the American Forests foundation as a way of measuring the gap of expected tree coverage versus actual tree coverage in an area based on an area's land type (woodland, grassland, desert) and population density (American Forests, n.d.). The tree coverage gap is then combined with social statistics, including income, employment, race, age, climate, and health (American Forests, n.d.). Thus, the priority of "closing the tree canopy gap" is a social priority that considers an area's level of disadvantage or advantage (American Forests, n.d.). Understanding how present-day tree equity aligns with HOLC districts adds another dimension to its tree coverage map counterpart. The social statistics incorporated into the TES of a neighborhood add depth to the analysis and furthermore shows where there are not only fewer trees but also a higher priority to rebuild an urban canopy.

Parks are used in this analysis as green spaces dedicated to trees and vegetation. Similarly, greenways, defined by the Pittsburgh City Council as being "permanent, passive open space that serves to benefit adjacent neighborhoods and the general public," are also assessed (City Planning, n.d.). The Pittsburgh Greenway program was specifically founded to protect steep hillsides that can't be built on; most greenways in the city include a wooded area and can be accessed by hiking trail (Pittsburgh City Planning, 2017). The inclusion of greenways in this analysis acts as an additional measure of green space.

The connections between green infrastructure and bike lanes are less intuitive. Bike lanes are incorporated in the analysis because the infrastructure makes bike travel safer. When people feel safe biking, they are encouraged to swap their car for their bike when travelling shorter distances. Therefore, bike lanes are an instrument in reducing emissions that would typically have been expelled when driving. Biking as a form of exercise is also linked to better health outcomes (Götschi et al., 2015), which aligns with the definition of green infrastructure as a network that benefits the health of urban residents.

2.3 Spatial Analysis Methods

2.3.1 Historical Race Census Data

Historic 1940 census data and shapefiles were acquired from NHGIS. The 1940 Census data was then overlayed with the Pittsburgh RSM. However, the jurisdictions outlined in the 1937 RSM do not line up with any existing political boundaries, including census tracts. This is because the RSM were "intended to incorporate homogeneous groups and types of housing rather than coincide with political or administrative units" (Hillier, 2005). Therefore, following Rutan & Glass (2017) and Nardone et al. (2021), an intersection was performed between the RSM and the historic census tract shapefile, which divided tracts to fit within the HOLC-defined areas after finding the area of census tracts using the Calculate Geometry tool. Lastly, the area of the intersection layer was calculated. These steps made it possible to create population weights dependent on the area of a census tract splintered by the RSM, given the simplifying assumption that population within the Census tracts and HOLC-defined areas were uniformly spread out. These methods were also applied to 2020 Census data. A map was created showing the weighted distribution of the non-white population across the security map of Pittsburgh for both 1940 and 2020.

2.3.2 Map of Tree Coverage

Tree canopy is mapped using remote sensing techniques that create a county-wide land-use raster file with 1m resolution. This raster image was created in 2010 by University of Vermont Spatial Analysis Laboratory with funding from the USDA Forest Service. The image contains land use classifications including tree canopy, shrubbery and grass, dirt, water, rooftops, and pavement. The first step of the analysis was converting the raster file into a vector file type. Then an intersection with the polygonised version of the canopy layer and the HOLC districts was performed in order to overlay the two features. Then, the Dissolve tool created an output layer with an attribute table that showed the sum of the tree canopy area in each HOLC district. Because the shapefile of the RSM did not include spatial geometry, the area of each district was calculated in square meters. Next, the units of the area of tree canopy were converted because the original unit of the canopy file was Survey Feet, equal to 0.30480061 meters. Lastly, the ratio of the area of tree canopy over the district area and is calculated to find the percentage of canopy. This percentage figure is used to make a choropleth map of current tree coverage in formerly redlined areas, with increasingly saturated hues of green used to indicate fuller tree coverage.

2.3.3 Map of Tree Equity Score

The Tree Equity Score organization provides maps of urban areas divided into neighborhood units, which include data on their assigned TES. A geo-referenced map of tree equity scores was obtained from the organization's website. To assess the spatial relationship between contemporary TES across HOLC districts, a union with the HOLC districts layer and the TES layer was created. Next, the output attribute table from the union was exported into Excel in order to calculate some descriptive statistics. The average, median, and minimum TES within HOLC graded districts were found.

2.3.4 Map of Tree Measurements

The map of tree measurements was created by obtaining data from an inventory of 33,498 “street trees” in the City of Pittsburgh created in 2014. This extensive dataset specifically includes all trees lining the streets in Pittsburgh. The data also has crucial information on tree measurements, such as tree heigh, crown width, and diameter at breast heigh (DBH). It is important to mention, however, that the dataset is limited because to the municipal boundaries of the City of Pittsburgh, while the span of the residential security map sprawls outside of these boundaries. Although the data does not cover the entirety of the study area, it is included to further show differences in tree quality. The analysis of tree measurements is conducted by creating a union between the tree point data layer and the RSM. This step creates a table showing the average of the selected tree measurements in each HOLC-defined district. Then, the averages of these are calculated in order to find the mean tree measurements from each HOLC district.

2.3.5 Maps of Parks, Bike Lanes, and Greenways

The map of parks in Pittsburgh in redlined areas was created by performing a quarter-mile buffer around parks. This buffer is meant to represent the threshold of distance that people are generally willing to walk to these resources that delineates to whom they are accessible. The buffer feature layer was overlayed with the digitized RSM. The data from this overlay was then entered into Excel to find some basic descriptive statistics, including the area of park space per district in acreage, the total number of parks within walking distance per district, and the number of parks per district. Another map of parks was created to visualize where parks were concentrated in the city. This map is produced by selecting RSM neighborhoods which contained five or less parks and neighborhoods with more than five parks and creating new layers from the selection. The symbology of color was then changed so that neighborhoods with five or less parks were in muted color and neighborhoods with more than five parks were in bold color. A final map of the distribution of parks was produced in order to establish the "mean center" of parks. This step created a point by calculating the average location of all parks in Pittsburgh. The same steps of creating a buffer and extracting spatial analysis were used in the creation of the maps of bike lanes and greenways. The map of bike lanes shows the total and average number of buffers around bike lanes within districts of different HOLC rankings. Additionally, the map of greenways shows the total area and total number of greenways in different neighborhoods as well as the number of greenways per neighborhood.

3.0 Results and Analysis

Aligning with results of Rutan & Glass (2017), the intersection of the RSM and the 1940 Census data finds that the non-white population of Pittsburgh was primarily confined to areas that were graded "C" or "D" in the security maps at the time of the HOLC survey. As shown by the comparison between the 2020 census map and the map of 1940 data, the distribution of minorities in the city of Pittsburgh today is quite different than from 1940. For one, minorities are no longer confined to a just a few neighborhoods, and the non-white population is now spread out across the city more evenly. However, the lasting minority-majority by a large share in historically black, redlined neighborhoods like the Hill District, East Liberty, and Homewood may reflect a lasting lack of social mobility for those neighborhoods.

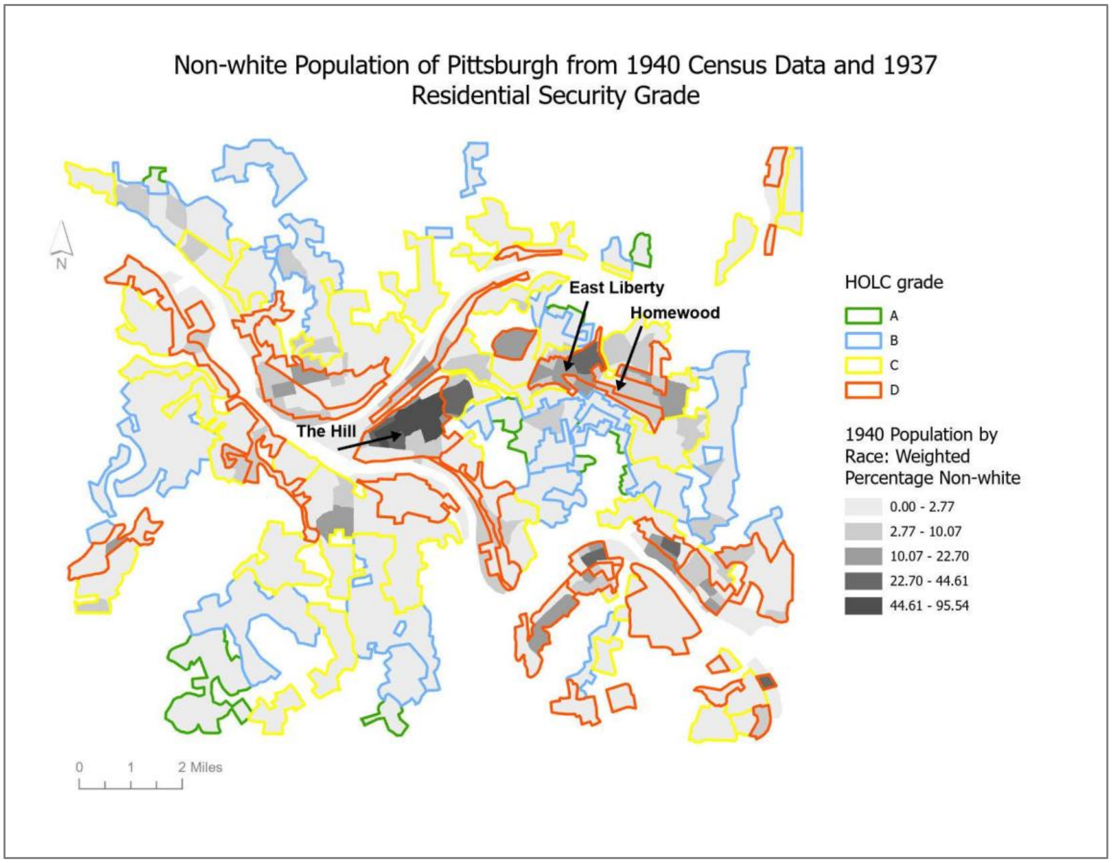


Figure 2: **Map of residential security grade of 1940 census tracts (Manson et al., 2023).**

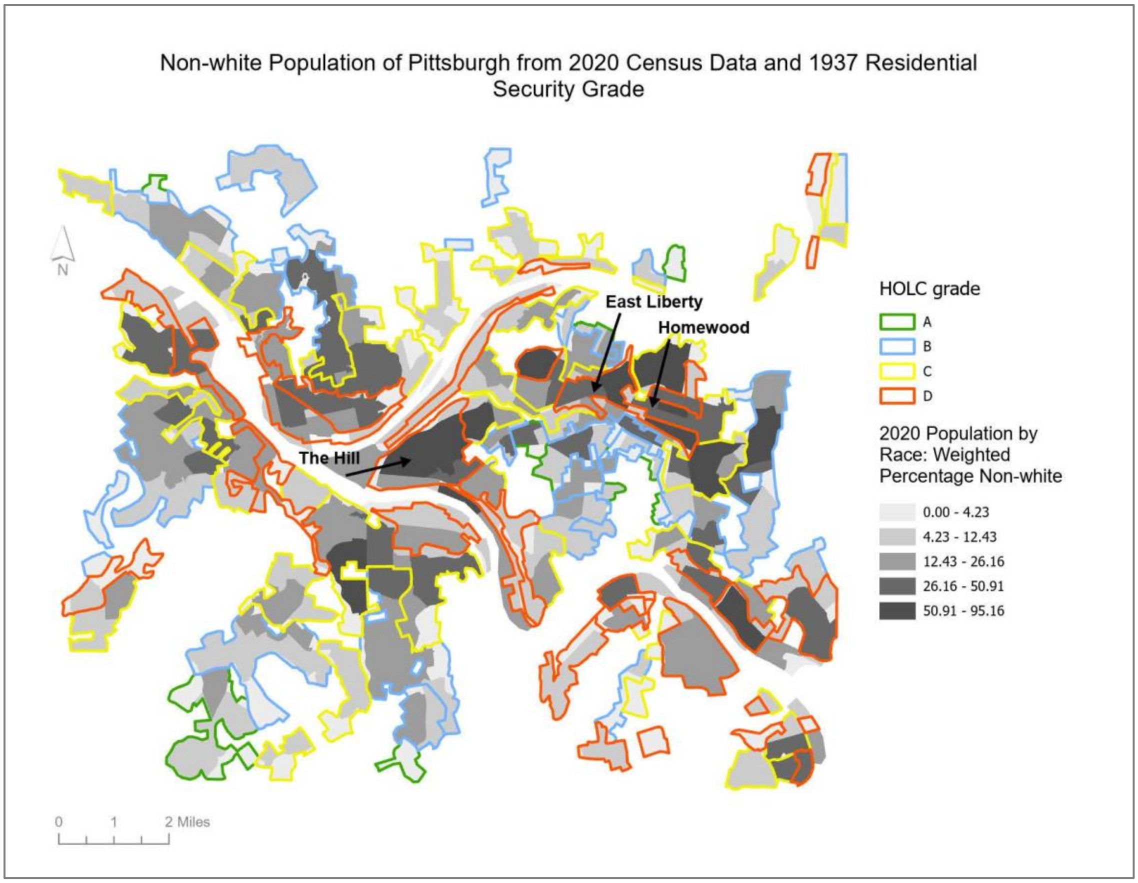
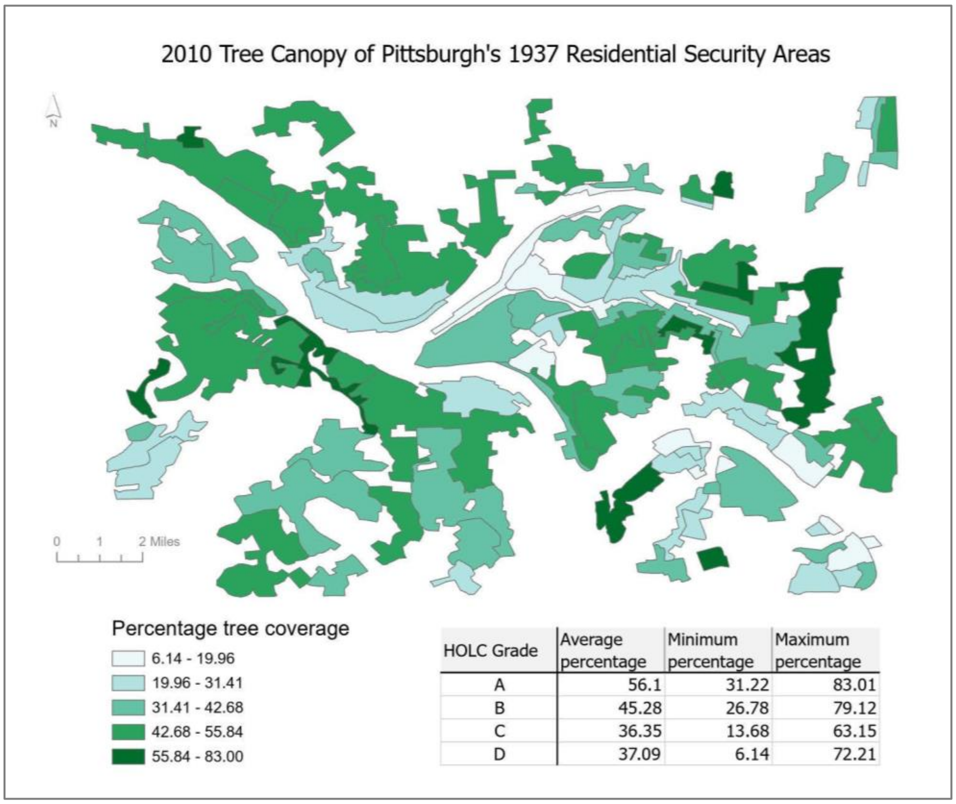


Figure 3: **Map of residential security grade of 2020 census tracts (Manson et al., 2023).**

The analysis of tree coverage revealed that neighborhoods with a higher security ranking enjoy more abundant tree coverage than redlined neighborhoods. Specifically, the percentage of average tree coverage increases as the ranking increases. Also, the jurisdiction with the sparsest tree coverage, at 6.14% coverage, was a redlined neighborhood, while the jurisdiction with the greatest tree coverage, at 83.01% coverage, was an "A" graded neighborhood. This is partially related to the distribution of neighborhoods of different rankings; redlined neighborhoods are more likely to be centrally located, while "A" graded neighborhoods are typically suburbs. To be sure, many individuals formerly redlined areas had relatively higher tree coverage. However, Pittsburgh's hilly topography makes for suburbs with plenty of forested slopes, which could have impacted this distribution. Analyzing topography in another study could clarify these results.

Next, the analysis of tree equity showed that TES generally lowered with declining security grade. Average TES are lower for each descending HOLC grade. In addition, the lowest TES, 37.3%, was attributed to a redlined community. These findings indicate that redlined areas generally had a higher priority for tree planting than other neighborhoods.



HOLC Grade	Average percentage	Minimum percentage	Maximum percentage
A	56.1	31.22	83.01
B	45.28	26.78	79.12
C	36.35	13.68	63.15
D	37.09	6.14	72.21

Figure 4: **Map of 2010 tree coverage of residential security areas.**

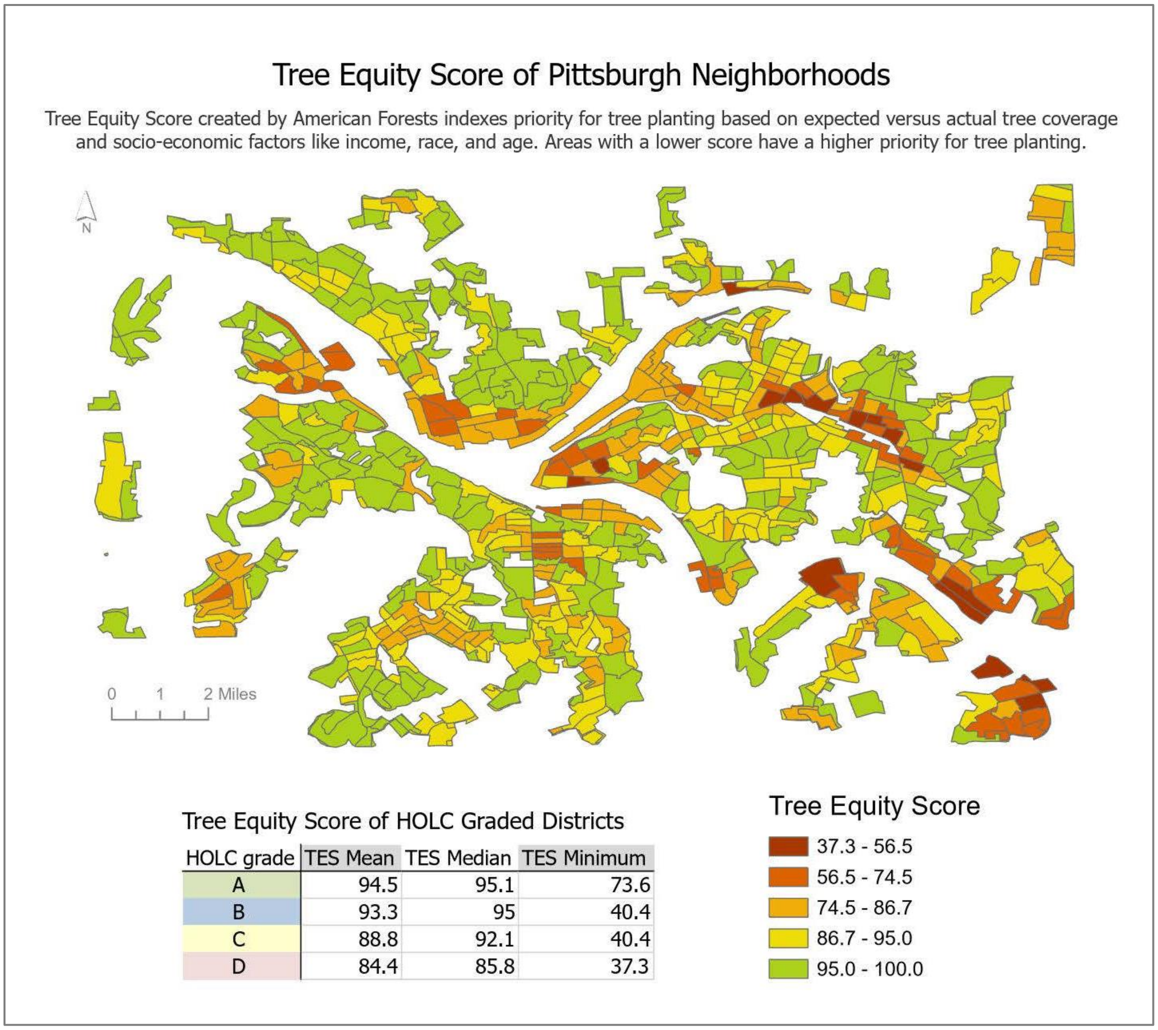


Figure 5: **Map of Tree Equity Score areas in residential security areas (American Forests, n.d.)**

The descriptive statistics derived from mapping tree characteristics also illustrated that as HOLC ranking descends, so declines the average size of trees. Each measurement of trees considered, heigh, spread/width, and diameter at base height, was smaller in redlined areas. Trees in redlined areas were found to be thinner, shorter, and have less canopy spread than their counterparts in more “desirable” neighborhoods.

Table 1: **Average tree size characteristics in different residential security areas**

HOLC Grade	Average base diameter of trees (in inches)	Average height of trees (in feet)	Average width of trees (in inches)
A	16.96	30.80	9.48
B	13.51	28.65	8.54
C	11.96	26.20	7.84
D	10.68	22.84	7.71

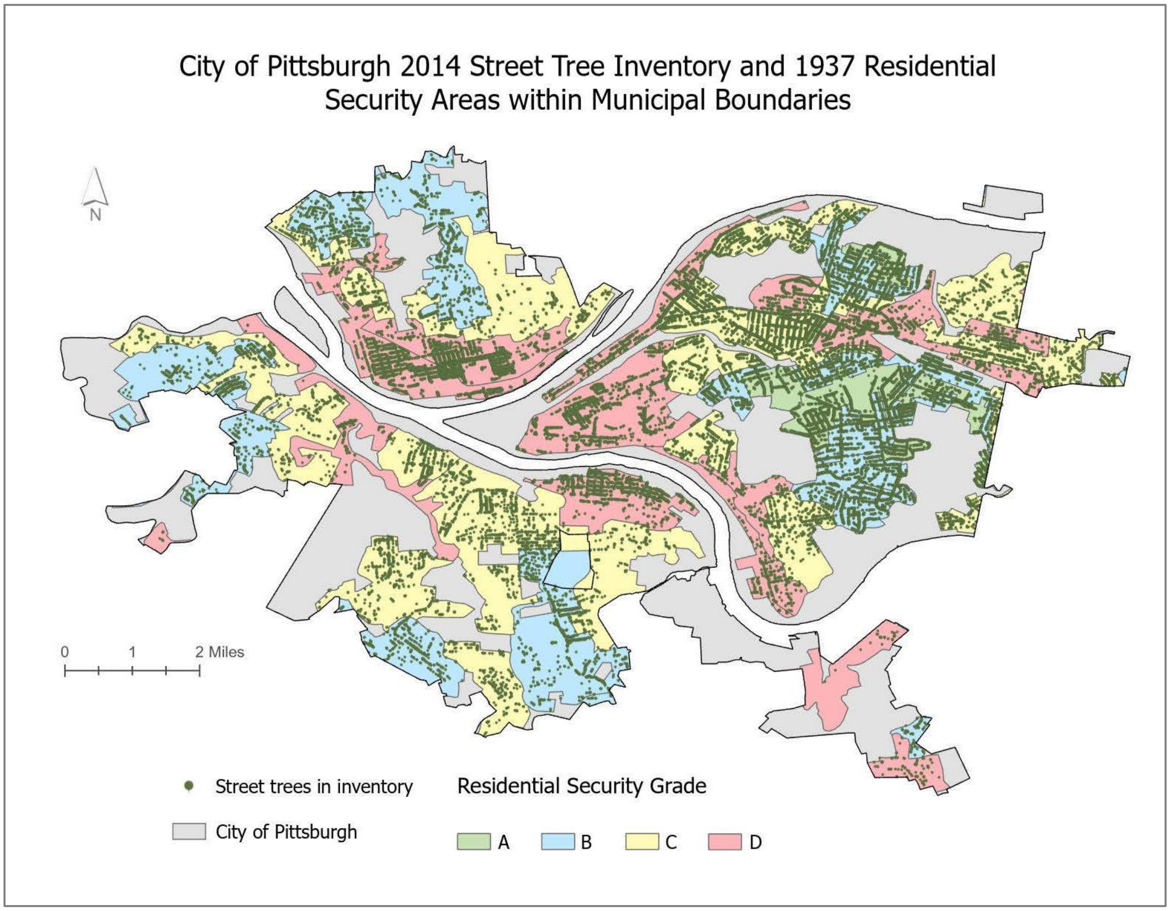


Figure 6: **Map of Pittsburgh's street trees within residential security areas**

Table 2: **Park amenities in different residential security grades.**

HOLC grade	Total acreage of park space	Total square footage of park space	Total number of parks within walking distance (0.25 mi)	Mean number of parks within walking distance (0.25 miles) per neighborhood
A	210.99	9,190,473.23	33	3
B	637.39	27,764,693.60	108	4
C	860.51	37,483,555.59	202	4.8
D	1,081.75	47,121,038.78	196	5.8

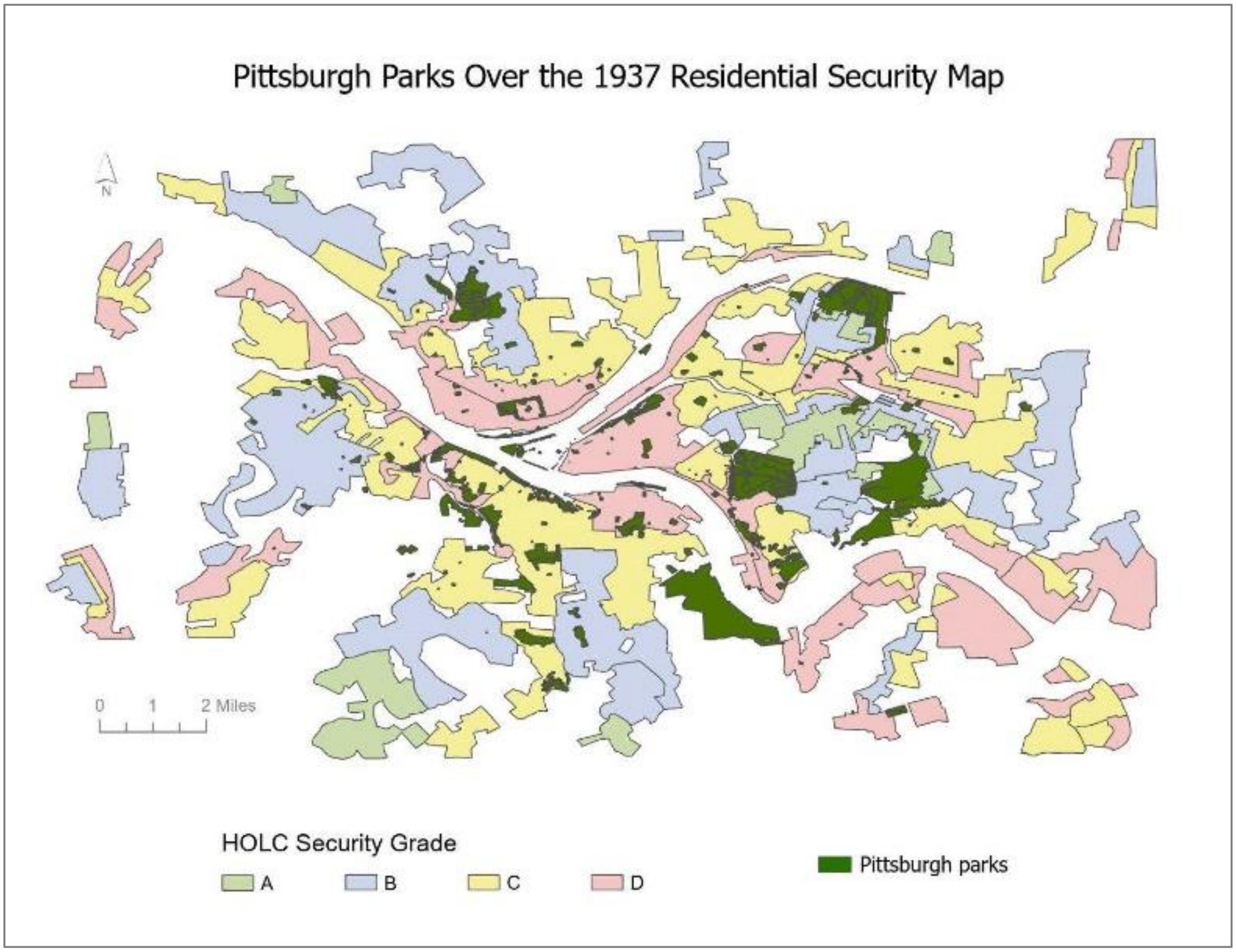


Figure 7: **Map of Pittsburgh parks over residential security areas.**

Analysis of park distribution showed that the majority of square acreage and square footage of parks in Pittsburgh were actually concentrated in areas given “C” and “D” grades. There was an ascending scale, whereby the area of park space in walking distance increased with a descending ranking by the HOLC. This pattern continued for the total and average number of parks within walking distance to each neighborhood. The researcher speculates that this pattern was a result of the central quality of redlined neighborhoods and parks: Neighborhoods at the

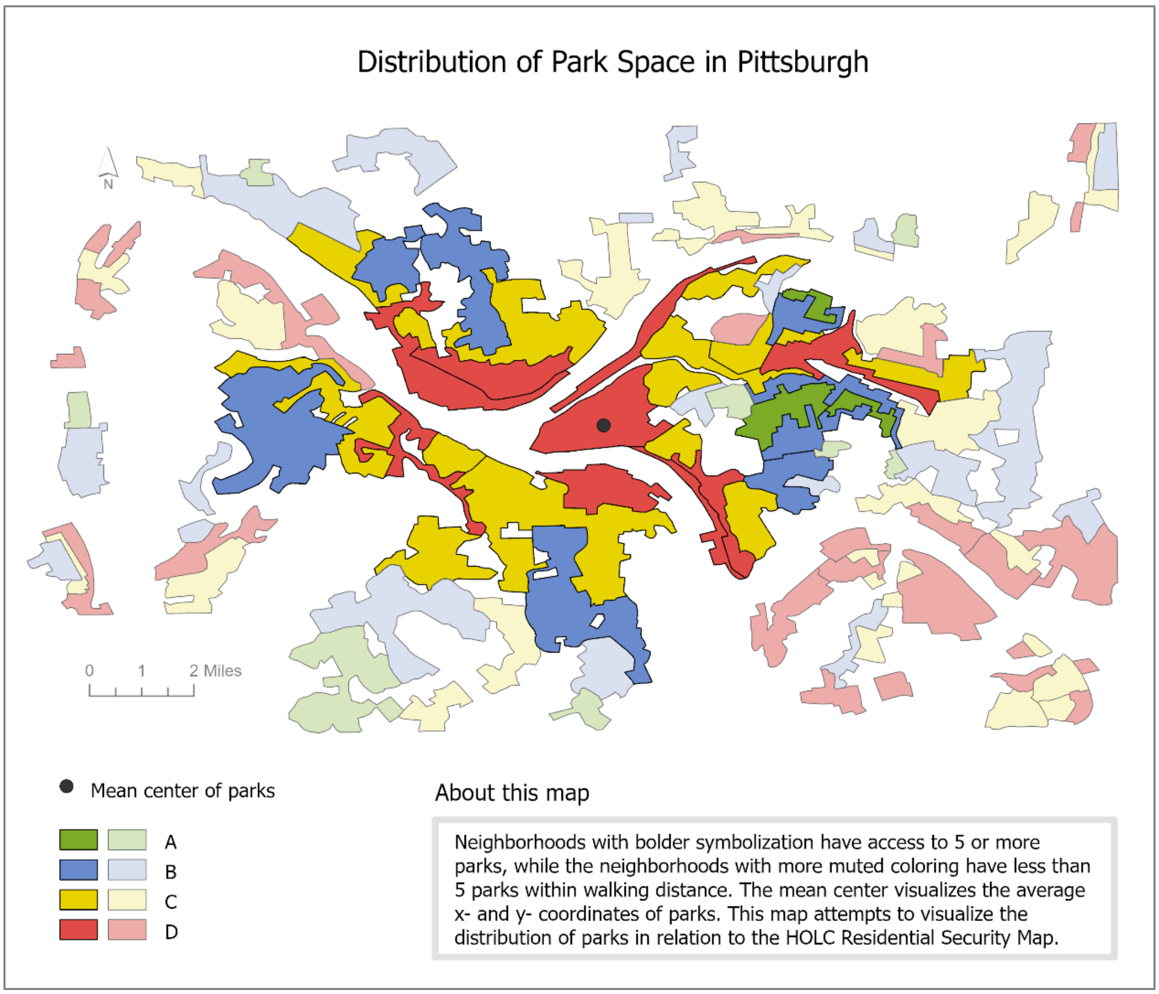


Figure 8: **Map of concentration of park space in different residential security areas.**

very center of the city were all “C” and “D” neighborhoods excluding historically industrial and commercial zones. Another parks map was created to better understand the spatial distribution of parks in Pittsburgh. This map showed that almost all neighborhoods with more than five parks were continuously touching each other, and all of these neighborhoods were concentrated in the center of Pittsburgh. These findings may indicate that the concentration of parks in Pittsburgh is actually best described as being concentrated in the center, rather than concentrated in “A” and “B” neighborhoods of the RSM.

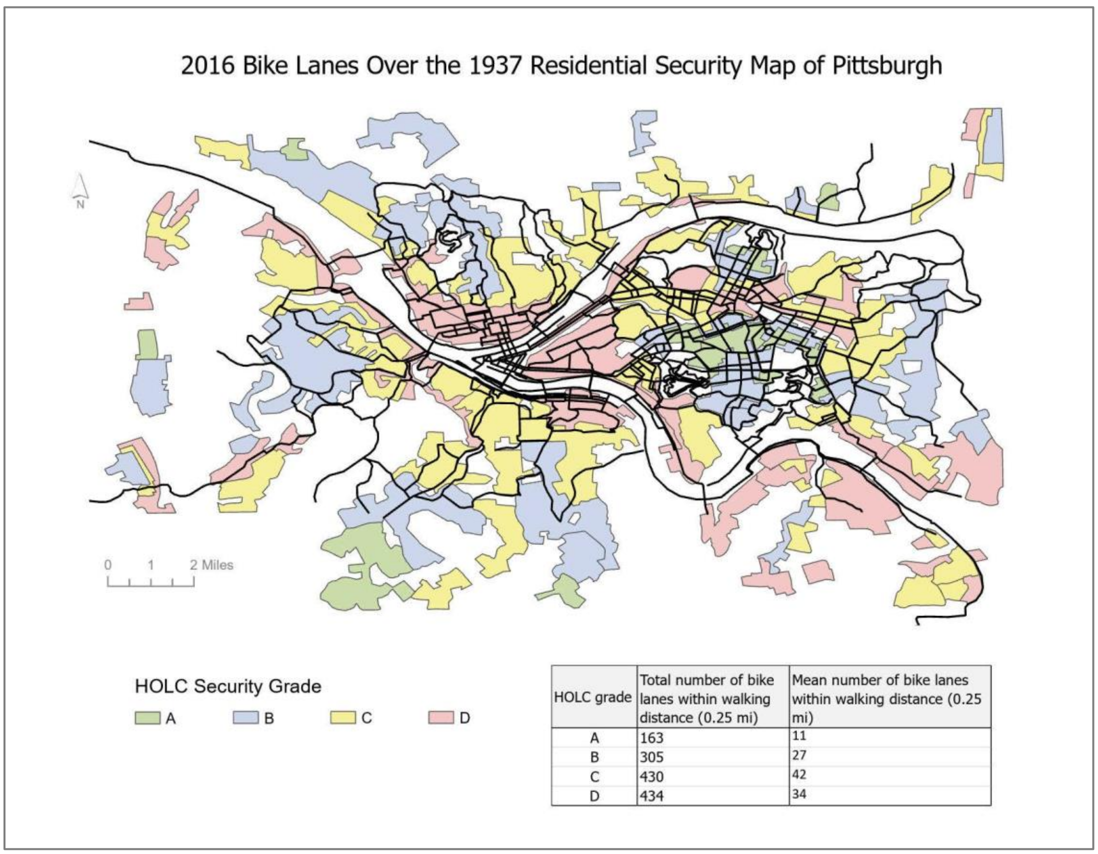
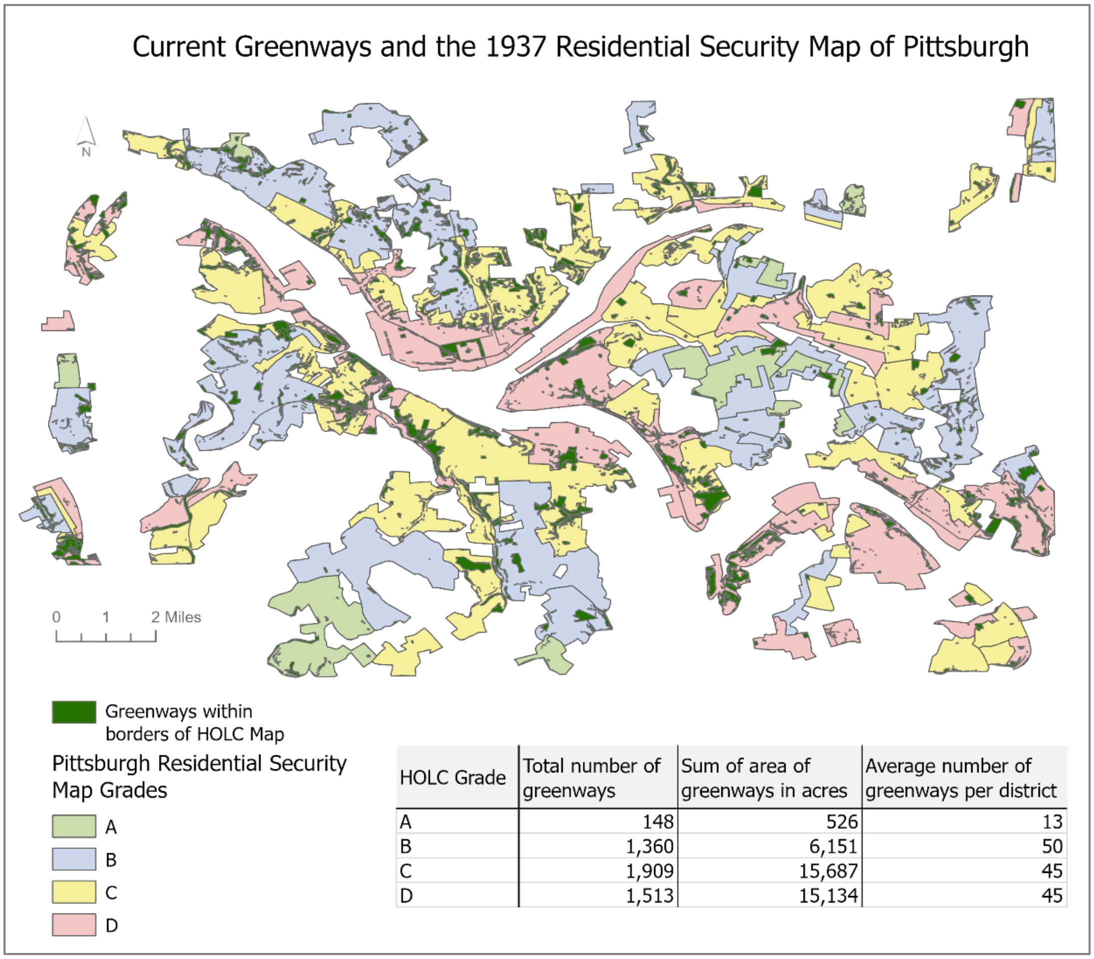


Figure 9: **Map of bike lanes over residential security areas.**



HOLC Grade	Total number of greenways	Sum of area of greenways in acres	Average number of greenways per district
A	148	526	13
B	1,360	6,151	50
C	1,909	15,687	45
D	1,513	15,134	45

Figure 10: Map of greenways within residential security areas.

Secondly, mapping bike lanes and greenways revealed similar results to mapping parks. Bike lanes were also more concentrated in neighborhoods with a “C” or “D” ranking. However, in the case of greenways, there seemed to be no correlation between the distribution of greenways and a neighborhood’s ranking. For example, there was an average of 13 greenways in “A” areas, 50 in “B,” and 45 in both “C” and “D” areas. It is more likely that the distribution of greenways had more to do with the locations of natural features than disinvestment practices.

At the beginning of the research, it was expected that “A” and “B” graded areas would have higher access to parks and greenways. This was presumed because of a list of other negative effects associated with “C” and “D” graded areas uncovered in the literature review. However, there appeared to be little correlation between the distribution of parks, bike lanes, greenways, and the HOLC grading system. The distribution of parks is probably best described by centrality instead of its relationship to the RSM. In addition, the distribution of greenways was generally spread out throughout the city, and there was no pattern based on neighborhood grade.

Nevertheless, the results from the analyses on tree distribution do pose interest. As established by Rutan and Glass (2017), Pittsburgh’s formerly redlined neighborhoods have remained majority-black communities, and have continued to suffer from higher rates of poverty and an aging built environment. Therefore, Pittsburgh’s formerly redlined neighborhoods have been historically economically disadvantaged. A lack of tree coverage and inequitable share of urban greenery for these neighborhoods reflects the invasive impacts of disinvestment. Not only is the canopy of trees sparser in redlined communities, but the trees that are present there are unequal to trees elsewhere. These trees are on average the smallest of all neighborhood types. The variety of improvements that trees provide to mental health, urban temperatures, and air reflect the importance of closing this gap in tree coverage for redlined neighborhoods.

4.0 Conclusions

At the time of the creation of Pittsburgh's RSM, the city's non-white population was living in neighborhoods graded "C" or "D" in the security maps. However, the current distribution of the non-white population in the city of Pittsburgh today has changed, reflecting wider settlement patterns for minorities and a changing economic landscape. However, major historically black neighborhoods like the Hill District, East Liberty, and Homewood remain minority-majority by a high majority, which may reflect a lasting lack of social mobility for those neighborhoods.

The results of this study show that there was not significant variation in park amenities, bike paths, and greenways across neighborhoods graded "A" through "D." In fact, redlined communities accounted for the most area and number of parks and greenways in Pittsburgh. It is inferred that this is because parks and bike lanes are distributed in a relatively centralized dispersal across Pittsburgh, and this was supported by the park distribution map. In addition, it is inferred that the location of greenways is simply more related to the existing locations of natural features the city wants to preserve, rather than to the RSM.

However, the results of the analysis show that tree canopy, individual tree measurements, and tree equity are the most significant markers of environmental inequality in redlined communities. The tree canopy and tree equity maps showed that "C" and "D" communities had less tree coverage than "A" and "B" communities, which aligns with studies by Chen (2022) and Schell et al. (2020). Moreover, the trees in redlined neighborhoods were found to be significantly smaller than trees in more desirable communities. Because it is difficult to know what tree coverage of redlined neighborhoods was like at the time of HOLC surveying, it is also difficult to pinpoint if the canopy in these areas has always suffered as a result of segregationist policies and lack of investment, or if it declined over time. However, it is important to acknowledge that non-white residents have been typically lower-income and renters, which affected their ability to maintain landscaping including trees. These factors compounded by a lack of attention from the city may have made these patterns long-standing.

These gaps in tree coverage in Pittsburgh's formerly redlined communities should raise concern for urban planners. Given the established benefits of urban trees, including but not limited to benefiting mental health of residents, cooling nearby temperatures, and extracting air pollutants, a shortage of trees in disadvantaged areas is something that should be taken seriously. Urban planners should take into account these disadvantages and work to build and preserve the current tree canopy in public spaces of formerly redlined communities. This means that not only should new trees be added, but also that the existing trees on the streets should be maintained so that they can grow healthily and reach maturation. Keeping existing trees in good condition is equally important, given that larger, more mature trees come with their own host of benefits. Additionally, a range of ages of trees is also key to ensuring that older trees will be succeeded and that the urban canopy is reliant on multiple generations of trees.

4.1 Limitations and Future Work

Unfortunately, time constraints limited the extensiveness of this work. This research could be improved with a more extensive analysis of census data covering the period of time between the 1940 Census and 2020. Including more censuses would better illustrate the progression of settlement shift in Pittsburgh and may help illustrate temporal patterns. Additionally, including more population attributes such as income, poverty level, and home value could provide more in-depth characterization of different areas of the city.

Secondly, while this research did not find that parks were geographically separated from redlined communities, archival research that focused on the history of Pittsburgh parks and greenways more in-depth could reveal inequalities that are not captured by GIS. Local stories of Urban Renewal practices illustrate that oftentimes when urban resources are created, they are created at the cost of the communities in which they are constructed. For example, the construction of the Civic Arena in 1961 demolished dozens of blocks of the Lower Hill District. Though the arena was an attraction for the city, its construction displaced thousands of people and also cleared much of the city's existing canopy in that neighborhood. It would be valuable to learn how parks in Pittsburgh were established, and if their creation was at times problematic for local communities. Additionally, an assessment of the quality of the amenities could reveal any variation across different neighborhoods. Lastly, although parks may be within a quarter mile, this study did not assess any factors that could still potentially hinder walkability, such as topography. Steep slopes between point of departure and destination could inhibit or prevent people from accessing park resources, even if they are close by. A topographic analysis using a digital elevation model could provide more insights.

Other potential confounding factors of this work may include the limitations of the tree sample survey, which only accounts for public tree canopy and does not cover the entire study area. In addition, trees in redlined areas were found to be on average the smallest in all of the residential security grade types; however, it would be important to disentangle how the species and age of the trees play a role in this size. The history of settlement patterns in proximity to the downtown core as well as suburbanization and white flight are also factors of demographic patterns revealed in this study that are worth mentioning. All of these concepts are worth exploring in another research.

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