REGULATING HEAT ISLANDS: IDENTIFYING LAND DEVELOPMENT REGULATIONS AS MITIGATION TECHNIQUES

By

CARSON JOHN CROCKETT

A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To the challenge of making this world a better place to be

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LIST OF ABBREVIATIONS

DUA	dwelling units per acre
EPDM	ethylene propylene diene terpolymer
FAR	floor area ratio
ISR	impervious surface ratio
NS-1	Neighborhood Suburban 1 Zone
NS-2	Neighborhood Suburban 2 Zone
NSM-1	Neighborhood Suburban Multifamily 1 Zone
NT-1	Neighborhood Traditional 1 Zone
NT-2	Neighborhood Traditional 2 Zone
NT-3	Neighborhood Traditional 3 Zone
SR	solar reflectivity

Abstract of Thesis Presented to the Graduate School
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Cochair: Kathryn Frank
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Urban heat islands are sections of larger urban areas that experience higher than normal temperatures. Heat islands negatively impact public health, outdoor utility, the built environment, and more. Mitigating heat islands has traditionally occurred using piecemeal techniques, increasing the presence of vegetation and the reflectivity of surfaces while lowering the amount of impervious surface. I propose a more comprehensive action of mitigation using land development regulations. I focus on establishing a correlation between these two variables, but do not propose individual policy action or implementation.

Using solar reflectivity as an approximation of the urban heat island effect, I sampled 30 residential parcels from St. Petersburg, Fl, measuring and categorizing surfaces from each. The resulting data was a reflectivity score for each parcel. I used a correlation model to understand how land development regulations and the solar reflectivity scores from the sample were connected. The resulting model exhibited a clear and significant correlation between zoning and solar reflectivity and less clear, but still significant, correlations between parcel size, floor area ratio, and setback regulations with solar reflectivity.

The results suggest that land development regulations could exist as a mitigating factor of urban heat islands. Clear enough results to suggest policy implementation were not exhibited. Identifying the relationship between land development regulations and urban heat islands is the key value of this study. Future research on this topic is worth completing to gain a better understanding of the relationships exhibited between land development regulations, solar reflectivity, and the urban heat island effect.

CHAPTER 1
INTRODUCTION

Urban heat islands are sections of larger urban areas that experience higher than normal temperatures, creating disastrous consequences for how we operate in everyday life. Impervious surfaces that collect and retain heat are a primary source of urban heat islands, causing harm to individuals and physical damage to the built environment. Researchers and experts have studied the urban heat island effect for decades with countless studies dating back to the early 19th century (Stewart, 2019). These studies established that urban heat islands are a matter of environmental well-being and public health to extreme extents, with an ability to cause injury, hospitalization, and even death (Stone, 2012).

In 2003, a heatwave occurred across Europe, showcasing the impact of extreme temperatures on the built environment. "[O]ver a threshold temperature, asphalt can literally melt, while concrete ruptures, rendering streets impassable" (Stone, 2012). These are risks of long-term heat island impacts. Everyday consequences of the urban heat island effect can cause changes in how people use urban spaces, utilizing the built environment differently. There are many known mitigation strategies concerning construction materials, vegetation, and more.

Less details are known about mitigation strategies that deal directly with land development regulations. Land development regulation "refers to a broad range of governmental controls that affect one's ability to use or develop land" (Morris, 2009). Understanding the relationship between urban heat islands and how urban spaces are designed through land development regulations could be a new link in mitigating the impacts of urban heat islands. I analyzed residential zoned sites across St. Petersburg, Florida. Using solar reflectivity, I compared these sites to land development regulations (parcel size, floor area ratio, and setback regulations). I was able to run a correlation model from this comparison, establishing a connection between the urban heat island effect and land development regulations.

The results suggest that land development regulations could exist as a mitigating factor of urban heat islands; however, clear enough results to suggest policy implementation were not exhibited. Identifying the relationship between land development regulations and urban heat islands is the key value of this study. Future research on this topic is worth completing to gain a better understanding of how we might take advantage of land development regulations to mitigate urban heat islands.

CHAPTER 2
LITERATURE REVIEW

Understanding Urban Heat Islands

Urban heat islands are “urban areas that experience higher temperatures than outlying areas” (EPA, 2022). Surface temperatures nor atmospheric temperatures truly encapsulate the effects of urban heat islands. “While many heat island studies use land surface temperature to estimate exposure, air temperatures are more relevant to human health and comfort” (Stone, 2012). Urban heat islands generally have the greatest impact on temperatures approximately 1.5 meters above the ground (Zhixin Liu, 2021). At their simplest form, urban heat islands are caused by excess absorption of solar radiation by hard surfaces before remitting solar radiation back into the atmosphere as dissipated heat (EPA, 2022). That dissipated heat directly affects the local air around the surface, but not necessarily the surface itself (L Doulos, 2004). Figure 2-1 outlines this relationship. Natural vegetation also absorbs solar radiation, but it dissipates heat differently than man-made structures (EPA, 2022) (Betts & Ball, 1997).

Reducing the amount of solar radiation absorbed by hard surfaces can limit excess dissipated heat being released into the atmosphere. Doulos investigated the performance of 93 different surface types to establish this strategy and compare what surfaces would perform the best in reducing the amount of energy a building needs to operate (L Doulos, 2004). Lighter, more reflective surfaces proved to perform better. Not all materials are created equal, and some absorb more radiation than others while many reflect that solar radiation before ever being absorbed, reducing the amount of excess dissipated heat (USGBC, 2015). Comparing the surfaces in the Doulos study – and in similar studies – opened the door to a new understanding of solar reflectivity.

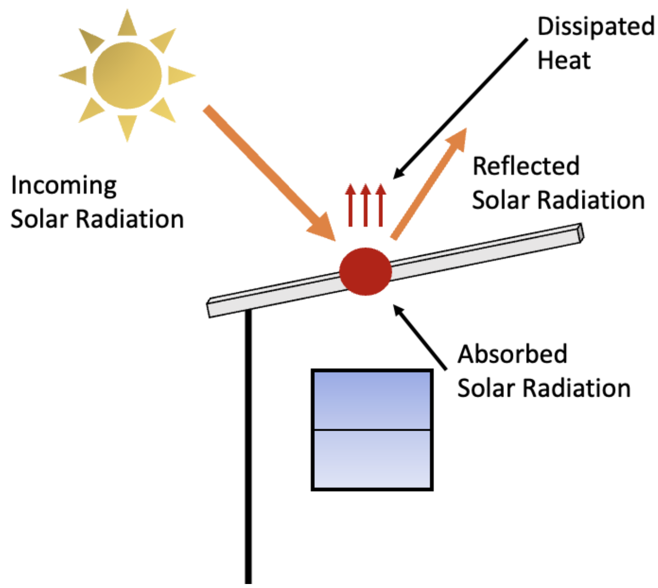

Figure 2-1. Diagram of absorbed solar radiation and excess dissipated heat by impervious surfaces.

Data Source: (EPA, 2022) (Cool Roof Rating Council, 2022)

Solar Reflectivity

Solar reflectivity is a measure of how much solar radiation a surface reflects. Solar reflectivity is displayed as a decimal or percentage that represents the amount of solar radiation that is reflected off the surface versus how much is absorbed (USGBC, 2015). Solar reflectivity values vary by surface material. For example, the solar reflectivity of a new sidewalk, which is generally composed of light concrete, is approximately 0.70 (70%) while the solar reflectivity of a new asphalt road, which is generally composed of a dark material, is approximately 0.05 (5%) (USGBC, 2015). The higher the solar reflectivity, the more reflective the surface and the better the surface is at mitigating or preventing urban heat islands. This correlation between solar reflectivity and the urban heat island effect allows solar reflectivity to act as a proxy for measuring the urban heat island effect.

Natural surfaces, such as grass and vegetation, handle reflectivity differently. Vegetation can reduce impacts of urban heat islands despite not being very reflective. Evapotranspiration lowers the amount of heat radiated from vegetation back into the local atmosphere (Loughner, et al., 2012) (EPA, 2022). Studies have seen differences in air temperatures of up to 3.7 degrees Celsius between highly vegetated, tree canopy areas and open spaces (Mallen, Bakin, Stone, Sivakumar, & Lanza, 2020). Despite solar reflectivity being a leading factor of the urban heat island effect, there are additional influences on urban heat islands.

Climate Change

Climate change is a growing concern. "The impacts of climate change at the urban scale are profoundly greater than the impacts of climate change at the global scale" according to Brian Stone, an expert in environmental planning (Stone, 2012). Surfaces cool overnight, letting out excess heat and solar radiation absorbed during the day, but they must accomplish this in a set amount of time (The Surface Temperature Record and the Urban Heat Island, 2004). Longer periods of daylight with less cooling time overnight can cause urban heat islands to worsen in summer months.

If a surface does not reach low enough temperatures at night, the surface will begin the next day hotter than the day before and it will continue a self-re-enforcing cycle (The Surface Temperature Record and the Urban Heat Island, 2004). The hotter temperatures and increased solar radiation that climate change generates places an even greater importance on nighttime cooling periods. As such, climate change exaggerates the urban heat island effect. This is true of any urban, exurban, rural, or suburban space; however, cities have additional variables that can have greater influence on the urban heat island effect.

Urban Spaces

Buildings and development patterns can impact urban heat islands in both positive and negative ways. Theoretical convention states that highly urban areas contain dense structures and tall buildings that block wind and absorb heat that then act as insulation for hard surfaces, making it more difficult for surfaces to cool; yet this is not necessarily the case according to a study carried out in 2003 by Thomas Peterson. Peterson concluded that "no statistically significant impact of urbanization could be found in annual temperatures" (2003).

Peterson acknowledges many issues with his conclusion, including the fact that most atmospheric temperatures are taken at parks or open spaces away from the densest and most representative blocks in cities. The main limitation, however, is that surface and atmospheric temperatures – especially annual averages – do not accurately interpret the true impacts of urban heat islands as previously discussed (Zhixin Liu, 2021). This study is not evidence that the urban heat island effect does not exist. Rather, this study shows how localized the urban heat island effect can be and often is. Localized solutions are required to address the issues that hard surfaces, density, and lack of vegetation can cause.

Using Urban Design to Mitigate Urban Heat Islands

The Role of Urban Design

Addressing the localized issues of urban heat islands is impossible to accomplish in its entirety but mitigating the magnitude of urban heat islands is possible. Mitigation can employ various urban design strategies, one of which deals with hard surfaces. Alex Wilson suggests a focus on hard surfaces to combat both solar radiation and storm water runoff. In 2004, the total surface area of pavements in the United States could fill the state of Indiana, and that does not account for nearly two decades of new construction projects and building footprints (Wilson A. , 2004). Commonly, urban areas see 75% of their land engulfed by impervious surfaces (Wilson A. , 2004).

In addressing pavements specifically, one mitigation strategy is porous pavements. Implementing porous pavements serves two purposes. Porous pavement systems (asphalt, concrete, pavers, or otherwise) consist of multi-layered surfaces that allow water to filter through the pavement, reducing floods and improving stormwater management (Wilson A. , 2004). Wilson describes the added benefit for urban heat islands in two parts:

> First, turf-based porous pavements cool the air through evapotranspiration. Second, because urban trees shade paved areas, reducing heat buildup, porous pavement reduces urban heat islands by improving the longevity of those trees. The differences in solar reflectivity of porous and impervious pavement is usually fairly minimal, though light-colored aggregate can increase reflectivity slightly with either porous or nonporous pavement. (2004)

This does not include other positive impacts these porous pavements can have in an urban environment.

Several mitigation strategies address other impervious surfaces such as roofs and buildings. Green roofs are part of a concept known as “Pervasive Greenery” (Uli, 2014). Cities do not always have the space for large urban parks, which help fight the urban heat island effect when placed and sized optimally at approximately 1.08 ha according to a study carried out in Fuzhou, China (Xiong Yao, 2022). Dense cities like Singapore that do not have the space to devote towards these parks and conservation lands have identified pervasive greenery strategies such as green roofs, facade vegetation, and street trees (Uli, 2014).

Cool roofs are a less nuanced strategy of decreasing the amount of solar radiation that a building absorbs. “Cool roofs traditionally use natural white materials” such as a highly reflective rubber material known as ethylene propylene diene terpolymer (EPDM) “or second-generation materials like artificial white paint” that are highly reflective (Junjing Yang, 2018).

These materials increase the reflectivity of the roof surface, reducing the amount of solar radiation absorbed by the building. These mitigation strategies generally focus on adding additional landscaping and reducing impervious surfaces. This can be explained by the proven impacts of evapotranspiration (Loughner, et al., 2012). Regardless, each of these strategies are matters of land development regulations and urban design.

The Role of Land Development Regulations

Land development regulations are a typical set of “governmental controls that affect one’s ability to use or develop land” (Morris, 2009). A subset of land development regulations are intensity and dimensional standards such as density, floor area ratio (FAR), impervious surface ratio (ISR), minimum lot dimensions, and site setbacks. The American Planning Association compiled a list of generally accepted definitions for these standards in 2004 (Davidson & Dolnick):

- Density is a measure of the number of allowed residential units over a determined area of land, usually described as dwelling units per acre (DUA).
- Floor area ratio (FAR) is a measurement of land use intensity, calculated by taking the total floor area of all structures on a lot and dividing it by the area of the lot.
- Impervious surface ratio (ISR) is the percentage of a site covered by impervious objects, including concrete, asphalt, and building footprints.
- Minimum lot dimensions are requirements that a lot be of certain width, length, and area for development to occur.
- Setbacks are the required distance between a structure and a defined property line.

Development standards are another subset of land development regulations but tend to apply to specific sites less broadly. Green infrastructure requirements, such as landscaping requirements, subdivision design, and more can also be forms of land use regulations (Rouse & Bunster-Ossa, 2013). Land development regulations directly impact how a site or project is developed, including the amount of impervious surface allowed in a set area with dimensional regulations (Morris, 2009).

The power of regulations cannot be understated. Historic exclusionary zoning practices have left low-income and minority populations in areas of cities that disproportionally experience larger impacts of urban heat islands (Wilson B. , 2020). These historic practices were focused around community disinvestment and redlining, a practice used by banks and lenders to discriminate against minority populations (Wilson B. , 2020). Addressing urban heat islands in these communities today can look at urban design and land development regulations as a tool to use positively. The history of inequity is greater evidence of dimensional standards, development standards, and other land use regulations working together to form the built environment, for better or worse. As more modern land development regulations began forming in the 1990s, newer types of regulations centered around urban design emerged (Grant, 2006)

Form-based codes are regulations centered around concepts of urban design. Form-based codes are used around the world to achieve all kinds of new developments like those discussed in Jill Grant's book, *Planning the Good Community* (2006). Grant's book explores New Urbanist design principles across various developments. Street trees and facade foliage are urban design initiatives and can be part of form-based codes. Standards and building codes that require reflective/cool roofs can be part of urban design. The pavements that are chosen to be used for roadways and pathways could be regulated by urban design guidelines. Incentives to use best practices could exist even if a direct regulation is not implemented.

Community goals determine which regulations or incentives are implemented. As discussed in the book *Community Planning: An Introduction to the Comprehensive Plan*, when planning a community and considering possible regulations, the process is about setting a baseline, creating a vision, and deciding how to get there (Kelly, 2010). The basis of urban planning and urban design already allows for urban heat island mitigation strategies to be regulated; the regulations are just not widely used, if at all. Despite knowing the influence of land development regulations on site design, it is seemingly unknown how this influence contributes positively or negatively to urban heat islands.

The Research Gap of Land Development Regulations and Urban Design

Reducing the area of impervious surfaces in our cities could be the most efficient way to mitigate the impact of urban heat islands. This could be accomplished through land development regulations in the future, or existing regulations could already be accomplishing this goal; however, not enough is known about the relationship between these regulations and urban heat islands. Even experts who have been studying the field of urban heat islands for years have focused more on individual elements of mitigation strategies rather than the overarching question of what shapes urban spaces. Stone, for example, published the article "Urban Heat Management in Louisville, Kentucky: A Framework for Climate Adaptation Planning Land Use Regulations," yet the focus of this study was on individual mitigation strategies and adaptation plans rather than building a comprehensive solution directly into land development regulations (Brian Stone, 2019).

Land use and urban heat islands have been investigated, but not to a site-specific extent. A study completed in 2014 explored the relationship between land uses, neighboring land uses, and Landsat temperature data (Jun-Pill Kim). The 2014 study did determine a significant correlation between land use and differing Landsat temperatures; however, it did not address the impact of individual regulations associated with those land uses and site layouts. What is still unknown is how our urban design and form can be regulated in a positive way to impact the urban heat island effect. Rather than looking at land use broadly, the focus of future research should be shifted to more specific impacts of land development regulations on individual site design that contribute to city wide urban heat islands and microclimates.

Cities actively regulate land uses, impervious surface areas, density, and vegetation within city codes and land development regulations across the country to address impacts like stormwater management, compatible land uses, and public health. Stone has clearly established that urban heat islands are a matter of public health and welfare, bringing the issue into the planning realm (Stone, 2012). Urban heat islands could be part of these similar city regulations with "land-use planning" acting as "a critical component of effective heat mitigation, as the built environment affects local climates" (Keith & Meerow, 2022). Many land development regulations are also known mitigation strategies for the urban heat island effect. Why would it be unreasonable to regulate urban heat islands using this same strategy? The question becomes what is the external benefit of the existing land use regulations and how do we leverage land use regulations to mitigate urban heat islands more effectively?

Research Objectives

This study addresses why land uses have different effects on urban heat islands and how they can be manipulated or addressed to further mitigate the urban heat island effect. The objective of this study is not to re-establish the correlation between land use and urban heat islands that has been substantiated by multiple researchers. Specifically, I will consider the effects of land development regulations using solar reflectivity as a proxy for the urban heat island effect to demonstrate how we might be able to mitigate urban heat islands using land development regulations.

CHAPTER 3
METHODOLOGY

Overview of Study Design

The study utilized a quantitative approach with a cross-sectional design. The concept I explored is the relationship between the urban heat island effect and land development regulations. I compared the solar reflectivity measurement of multiple sets of parcels, each subject to a different set of land development regulations, as an approximation of the urban heat island effect. Because of the study design, the variables I measured are attribute variables, meaning there was not a manipulation of the variables. The independent variables are various surface areas within individual parcels, such as concrete, roofs, asphalt, etc. (Table 3-2). To connect surface areas to the urban heat island effect and land development regulations, solar reflectivity was used as the confounding indicator and served as the intervening variable. I explored this relationship between solar reflectivity and the urban heat island effect in the research instrument and literature review sections.

The resulting dependent variable was a solar reflectivity score for individual parcels, organized by zoning district. The resulting solar reflectivity score (dependent variable) established the current conditions of a site and allowed for comparison of this variable’s outcome between specific aspects of land development regulations by zoning designation. I considered these specific aspects of land development regulations for each parcel and zoning designation sampled:

- minimum lot area
- density (dwelling units per acre/DUA)
- intensity (floor area ratio/FAR) where applicable
- impervious surface area ratio (ISR)
- building setbacks

These aspects all directly manipulate concepts known to influence the urban heat island effect as established in the literature review.

Setting

This study was conducted within the city boundaries of St. Petersburg, Florida. The city is an expansive coastal community within southern Pinellas County, boasting a population of approximately 258,308 (US Census Bureau, 2022). It borders Tampa Bay to the east and south, with the Gulf of Mexico just past the western border. Temperatures in the area ranged from a high of 95 degrees Fahrenheit to a low of 73 degrees Fahrenheit throughout the summer months (May-August) in 2021 (NOAA, 2021). While Florida and St. Petersburg do receive a lot of rain, the city is nicknamed the Sunshine City as the sun shines at least once a day for 361 days out of the year on average (City of St. Petersburg, 2022). Being bordered by water, the city does receive a coastal breeze. The City's natural factors of high sunshine exposure and coastal location make St. Petersburg a topical and interesting location to explore the urban heat island effect.

I chose this specific location for several reasons, the first being familiarity and convenience. I grew up in St. Petersburg and visit the city often, giving me opportunities to conduct site visits throughout the process of this study. While site visits are not a part of the study design, first-hand experience in the area was used to supplement my analysis of data. Additionally, I was already familiar with the city zoning and land development regulations from my previous work experiences.

The city of St. Petersburg offers very comprehensive zoning and land use codes, including some from based codes. This was a crucial requirement for identifying, comparing, and analyzing differences between the regulations and attempting to draw conclusions from the data. These regulations also yield a large variety of zoning designations which were beneficial to compare; however, it was impractical to explore every zoning designation. Because of the city's size, St. Petersburg has a dense downtown core juxtaposed to sprawling retail centers and suburban neighborhoods. This is exactly what I wanted to explore: The relationship between these different areas, land development regulations, and the urban heat island effect.

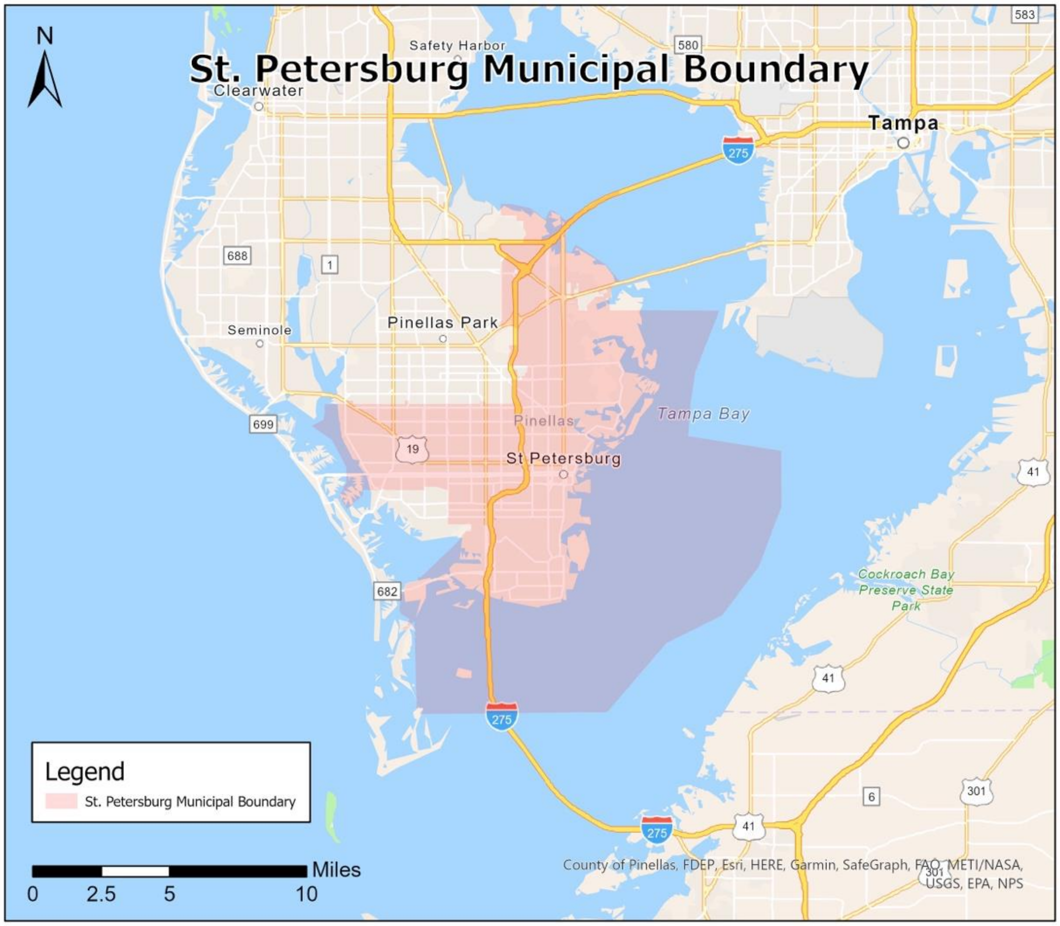

Figure 3-1. City of St. Petersburg, Florida municipal boundary

Data Source: (PinellasGISInternal, 2019).

Time Period

I conducted this study in 2022 and 2023. The time period of interest is 2011 through 2022. I used this period for two reasons. First, this period is relevant and recent. Second, the city has not made any significant changes to these specific zoning designations between 2011 and 2022 regarding these specific zoning designations. Appendix A displays these regulations in the years which they are applicable 2008, 2012, and 2022 to demonstrate the consistency. Consistency in the land development regulations is critical to ensure proper comparison of zoning designations and their regulations. If a consistency was present, I made sure the correct standard was applied to the corresponding measurements.

Sampling

Because St. Petersburg is a large city, measuring every impervious surface within the city is impractical. To compensate for this, I used a random sample of residential land parcels built in or after 2011 in St. Petersburg. Land parcels are property limits defined and maintained by the county property appraiser (Twitty, 2022). The associated parcel ID numbers that I reference throughout the study are used to distinguish these parcels from another. Residential land parcels were the only parcels necessary to obtain as the following residential zoning districts were the only ones measured –

- Neighborhood-Traditional 1 (NT-1);
- Neighborhood-Traditional 2 (NT-2);
- Neighborhood-Traditional 3 (NT-3);
- Neighborhood-Suburban 1 (NS-1);
- Neighborhood-Suburban 2 (NS-2);
- Neighborhood-Suburban-Multifamily 1 (NSM-1).

These specific zoning designations highlight differences in urban design, and to a lesser extent, density. The choice to exclude more variations in land use is one of scope and necessity. As explored, previous research shows an inherent difference between land uses and their impacts on the urban heat island effect. This study does not seek to establish this correlation using a new methodology . I wanted this study to focus more on the nuances between like land uses and their design differences that impact the urban heat island effect. Additional residential zoning designations were omitted because of a lack of construction in the zones after 2011 not providing a large enough sample size.

I obtained a list of every St. Petersburg address with a residential land use (as designated by Pinellas County Property Appraiser) from the Pinellas County Property Appraiser built in or after 2011. I assigned each address and accompanying parcel a simple row number of 2 through 3262. A random number generator with these limits then determined a sample list of parcels that still consisted of over 100 parcels, but this was not the final sample.

This study relies on having an equal sample of each zoning designation, which is different from the Pinellas County Property Appraiser assigned land use designation. Zoning designations reflect city policies regarding appropriate land uses in the city whereas the property appraiser assigns land use based on the property's actual use for appraisal and tax purposes. A sample of five NT-1 parcels and only four NS-1 parcels is not satisfactory. All zone designations must have an equal sample size. Creating this final sample group required first researching what zoning designation each parcel was, which was not information the Pinellas County Property Appraiser already had associated with the previously obtained parcel/address list.

I proceeded to identify each parcel on the original sample list within the City of St. Petersburg's zoning database, manually associating the pre-existing list with their zoning designation. This process also revealed that not every parcel sampled up to this point was within the city limits of St. Petersburg. The Pinellas County Property Appraiser organized the parcels by mailing address and the United States Postal Service gives a St. Petersburg address to some parcels outside of city limits. As these parcels were discovered, they were removed from the sample. Once each parcel had their zoning designation properly assigned, I was able to take the first five parcels from the desired zoning designations. For example, if there were 10 NT-1 parcels sampled, only the first five would be measured. This process was repeated for each zoning district, generating the final sample of parcels consisting of only 30 parcels, five from each of the measured zoning districts (Table 3-1.). Figure 3-2. shows the geographic location of the 30 parcels.

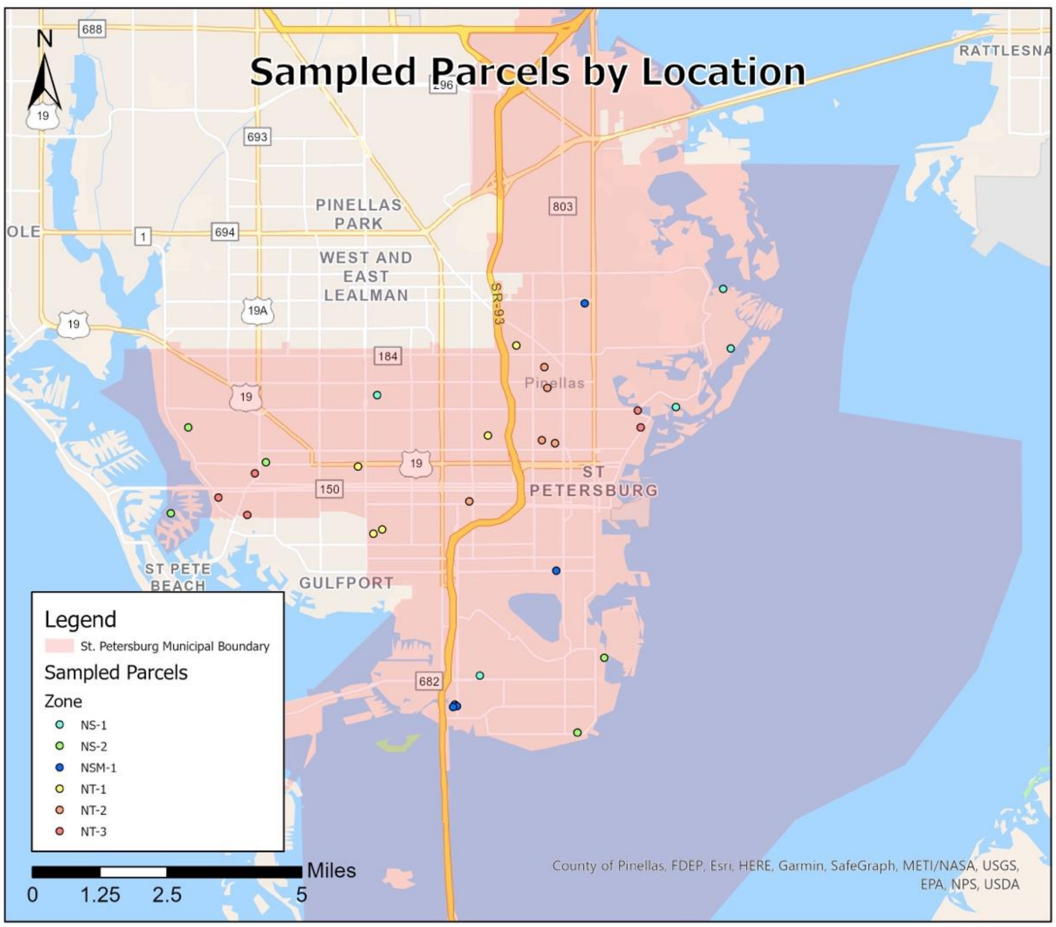

Figure 3-2. Location of sampled parcels across St. Petersburg, Florida

Data Source: (PinellasGISInternal, 2019) (City of St. Petersburg, 2022).

Table 3-1. Final sample of residential parcels in St. Petersburg, Florida

Parcel Number	**Zoning**	**Year Built**	**Land Area (ac)**	**Property Use Description**
01-31-16-45054-001-0140	**NT-1**	2012	0.1713	Single Family Home
14-31-16-77976-000-0190	**NT-1**	2019	0.145	Single Family - more than one house per parcel
21-31-16-63504-008-0130	**NT-1**	2019	0.1061	Single Family Home
28-31-16-21276-003-0130	**NT-1**	2019	0.1388	Single Family Home
27-31-16-94266-000-0530	**NT-1**	2019	0.1337	Single Family Home
12-31-16-74286-000-0010	**NT-2**	2016	0.0969	Single Family Home
12-31-16-94428-003-0210	**NT-2**	2018	0.1308	Single Family Home
13-31-16-25254-000-1010	**NT-2**	2015	0.1731	Single Family Home
13-31-16-40194-000-0130	**NT-2**	2016	0.1458	Single Family Home
23-31-16-65862-008-0050	**NT-2**	2018	0.1263	Single Family Home
17-31-17-83220-073-0040	**NT-3**	2016	0.1552	Single Family Home
17-31-17-83224-042-0060	**NT-3**	2019	0.4608	Single Family Home
19-31-16-20484-049-0100	**NT-3**	2017	0.2187	Single Family Home
19-31-16-67500-101-0060	**NT-3**	2017	0.5617	Single Family Home
19-31-16-96570-004-0160	**NT-3**	2012	0.1837	Single Family Home
02-32-16-49740-000-0160	**NS-1**	2015	0.3067	Single Family Home
04-31-17-81540-030-0090	**NS-1**	2013	0.1698	Single Family Home
08-31-17-83376-000-2740	**NS-1**	2014	0.405	Single Family Home
09-31-16-39600-006-0160	**NS-1**	2013	0.1807	Single Family Home
33-30-17-81278-017-0060	**NS-1**	2016	0.2085	Single Family Home
06-32-17-13788-000-0010	**NS-2**	2017	0.5615	Single Family Home
07-32-17-05580-001-0200	**NS-2**	2013	0.2473	Single Family Home
13-31-15-31788-026-1570	**NS-2**	2011	0.1881	Single Family Home
17-31-16-23634-018-0080	**NS-2**	2017	0.1785	Single Family Home
25-31-15-84096-001-0400	**NS-2**	2019	0.2876	Single Family Home
06-31-17-17523-001-1240	**NSM-1**	2015	0	Planned Unit Development
11-32-16-18731-000-0440	**NSM-1**	2018	0.0243	Planned Unit Development
11-32-16-18731-000-0490	**NSM-1**	2018	0.0243	Planned Unit Development
11-32-16-18731-000-0760	**NSM-1**	2016	0.028	Planned Unit Development
25-31-16-48960-000-0810	**NSM-1**	2019	0.1638	Single Family Home

Data Source: (Twitty, 2022).

Research Instruments and Data Measurement

Solar reflectivity is not a definitive measure of the urban heat island effect; however, as explored in the literature review, the two are clearly correlated variables. For this reason, I used the solar reflectivity measurement to approximate the extent of the urban heat island effect. I used the solar reflectivity value of individual impervious surfaces in each parcel to determine an overall site solar reflectivity value for the 30 sampled residential parcels (sites) within the city. I made this calculation by approximating the measurements of the surface areas of impervious surfaces, applying a solar reflectivity value across that surface, and weighting the solar reflectivity values across the total area to determine the solar reflectivity.

I included pervious surfaces, such as gravel, in measurements as well as vegetation; however, vegetation behaves differently because of evapotranspiration (Loughner, et al., 2012). Despite having lower reflectivity, vegetation is beneficial to a site because of the cooling effects from evapotranspiration, the biological processes they perform, and the ecosystem services they provide. To account for Vegetation's unique behavior, I formed two sets of every result and average: one that includes vegetation areas and one that does not include vegetation areas. I compared these two sets of data and discussed the implications of vegetation in Chapter 5 – Discussion.

To accomplish this process, I used ArcGIS Pro to take approximate measurements of surfaces. I utilized a feature layer consisting of all Pinellas County parcel boundaries from PinellasGISInternal to ensure the site extents of each parcel were accurate. The base maps in ArcGIS Pro proved to be difficult to work with, often displaying sites at an odd angle, making it difficult to take accurate measurements. I supplemented the base maps in ArcGIS Pro with georeferenced base maps taken from Google Earth to help with this issue. The Google Earth layer is adjusted to work with the 3D mesh in Google Earth, providing a more top-down imagery with much less error.

I then categorized the recorded surface areas into one of several surface types (Table 3-2.). I chose to use overarching categories of surface types rather than specific material types simply because there is no definitive way of properly identifying specific material types from ariel imagery. Categorizing a surface from ariel imagery is a more accurate process despite the result being a greater generalization. I derived category solar reflectivity values from predetermined solar reflectivity values associated with specific materials and calculating an average solar reflectivity across the category (Table 3-3.). Some categories contain only one or two materials while others average several types of materials.

After assigning each surface for a site the corresponding solar reflectivity value, I calculated the site reflectivity. Since each surface is of differing area, I applied a weighted system. I accomplished this by multiplying the solar reflectivity value of a given surface by the percentage of total site the surface occupies. These weighted solar reflectivity values are then added together, resulting in the site's reflectivity score. The process of calculating site reflectivity is outlined in the equation below where *a* is equal to the surface area of surface-a, *b* is equal to the surface area of surface-b, *t* is equal to the total input area (in this case $t = a+b$), *SRa* is equal to the solar reflectivity value of surface-a, *SRb* is equal to the solar reflectivity value of surface-b, and *r* is equal to the site's reflectivity.

$$\left[\left({}^{a}/_{t}\right) * SRa\right] + \left[\left({}^{b}/_{t}\right) * SRb\right] = r \tag{3-1}$$

As many surfaces as needed can be added to this equation to properly calculate the site reflectivity average and this equation is just an example of a simple version of this reflectivity average calculation. I gathered and calculated these site reflectivity averages for each sampled parcel throughout the city. After I gathered this data, I ran a bivariate correlation analysis of the site reflectivity scores against zoning designation, year built, site area, and the standards of minimum lot area, density (DUA), intensity (FAR), ISR, and lot setbacks using SPSS 28 statistical software. Appendix A displays these zoning standards in 2008, 2012, and 2022.

Other than establishing a correlation between land development regulations and the urban heat island effect, I created approximate site reflectivity averages for each zoning district and construction years across the sampled parcels. For example, all the NT-1 parcels had their individual site reflectivity scores averaged, creating a zone reflectivity average. The equation below (3-2) outlines this calculation where *r* is still the site reflectivity average, but the subscript refers to a parcel id number. For the sake of this example, the parcel id numbers are simply 1 through 5. *t* is the total number of parcels being averaged (in this case $t = 5$) and *z* is the zone reflectivity average.

$$\frac{r_1 + r_2 + r_3 + r_4 + r_5}{t} = z \tag{3-2}$$

Table 3-2. Materials and their generally accepted solar reflectivity value.

Category ID #	Material Description	Solar Reflectivity Value
1	White Cement Concrete (New)	0.7
2	White Cement Concrete (Aged)*	0.35
3	Gray Cement Concrete (New)	0.26
4	Gray Cement Concrete (Aged)*	0.18
5	Asphalt Concrete (New)	0.05
6	Asphalt Concrete (Aged)*	0.1
7	Sand	0.1
7	Gravel 1	0.36
7	Gravel 2	0.39
7	Gravel 3	0.4
7	Gravel 4	0.44
8	Gravel 5	0.29

Table 3-2. Continued

Category ID #	Material Description	Solar Reflectivity Value
8	Exposed Soil	0.17
9	Asphalt Shingles (New)	0.25
9	Asphalt Shingles (Aged)*	0.15
10	Terracotta (Clay) Shingles	0.36
10	Red Concrete Tile	0.17
10	Unpainted Cement	0.25
10	Brown Pavers	0.28
11	Almond Metal Roof	0.77
11	Light Grey Metal Roof	0.54
11	Light Tan Metal Roof	0.71
11	White Metal Roof	0.73
12	Bronze Metal Roof	0.31
12	Blue Metal Roof	0.33
12	Grey Metal Roof	0.28
12	Green Metal Roof	0.29
12	Black Metal Roof	0.24
12	Solar Panels	0.02
13	Ocean (Sun Above 30deg)	0.06
13	Ocean (Sun Below 30deg)	0.65
14	Conifer Forest	0.15
14	Deciduous Forest	0.18
14	Grass	0.25

*Three-year aged solar reflectivity value based on no cleaning (USGBC, 2015).

Data Source: (USGBC, 2015) (Betts & Ball, 1997) (Day & Mow, 2018) (Heat Island Group Roofing Tile, 1998) (Parker, n.d.) (Hanover Architectural Products, n.d.) (Tetzlaff, 1983) (McEvoy, Markvart, & Castaner, 2003) (Haby, n.d.) (Manchester Metropolitan University, 2013) (Berridge, n.d.) (Pisello, Pignatta, Castaldo, & Cotana, 2014).

Table 3-3. Surface categories and their averaged solar reflectivity values used in calculating the results.

Category ID #	Category Description	Averaged Solar Reflectivity Value
1	White Cement Concrete (New)	0.70
2	White Cement Concrete (Aged)	0.35
3	Gray Cement Concrete (New)	0.26
4	Gray Cement Concrete (Aged)	0.18
5	Asphalt Concrete (New)	0.05
6	Asphalt Concrete (Aged)	0.10
7	Sand, Light Gravel	0.34
8	Soil, Mulch, Dark Gravel	0.23
9	Asphalt Shingle Roof	0.20
10	Terracotta Roof, Brick Pavers	0.27
11	Light Metal Roof	0.69
12	Dark Metal Roof, Solar Panels	0.25
13	Water, Pool	0.36
14	Vegetation	0.19

CHAPTER 4
RESULTS

The following tables include the resulting site reflectivity scores, calculated using the methods described in Chapter 3 – Methodology. Each table includes two sets of results: vegetation and no vegetation. The vegetation scores account for the entire area of a site, including trees, grass, and other vegetation. The no vegetation scores account for the area of a site minus any vegetation present, omitting the vegetation areas. Table 4-1. displays the consolidated site reflectivity scores by parcel. A full list of surfaces and their associated parcel is available in Appendix B. Table 4-2. displays the results of the zoning category averages calculation. Table 4-3. displays the results of the year-built category averages calculation. Table 4-4. displays the results from the pearson correlation model. All results are discussed in Chapter 5 – Discussion.

Table 4-1. Resulting site reflectivity scores by parcel. Vegetation measurements include the entire area of the site including trees, grass, and other vegetation. No vegetation measurements omit these areas and does not factor them into the calculation. A full list of individual surface measurements and weighted solar reflectivity values is available in Appendix B.

Zone	Parcel ID	Area (ac)	Year Built	Site Reflectivity	
				Vegetation	No Vegetation
NT-1	01-31-16-45054-001-0140	0.171	2012	0.20	0.22
NT-1	14-31-16-77976-000-0190	0.145	2019	0.22	0.24
NT-1	21-31-16-63504-008-0130	0.106	2019	0.22	0.23
NT-1	28-31-16-21276-003-0130	0.139	2019	0.21	0.23
NT-1	27-31-16-94266-000-0530	0.134	2019	0.21	0.23
NT-2	12-31-16-74286-000-0010	0.099	2016	0.20	0.21
NT-2	12-31-16-94428-003-0210	0.131	2018	0.20	0.21
NT-2	13-31-16-25254-000-1010	0.173	2015	0.20	0.21
NT-2	13-31-16-40194-000-0130	0.146	2016	0.20	0.21
NT-2	23-31-16-65862-008-0050	0.126	2018	0.22	0.24
NT-3	17-31-17-83220-073-0040	0.155	2016	0.26	0.30
NT-3	17-31-17-83224-042-0060	0.461	2019	0.29	0.31
NT-3	19-31-16-20484-049-0100	0.219	2017	0.39	0.54
NT-3	19-31-16-67500-101-0060	0.562	2017	0.21	0.23
NT-3	19-31-16-96570-004-0160	0.184	2012	0.20	0.21
NS-1	33-30-17-81278-017-0060	0.209	2016	0.24	0.28
NS-1	09-31-16-39600-006-0160	0.181	2013	0.24	0.29
NS-1	08-31-17-83376-000-2740	0.405	2014	0.24	0.26
NS-1	04-31-17-81540-030-0090	0.170	2013	0.43	0.52
NS-1	02-32-16-49740-000-0160	0.307	2015	0.21	0.22
NS-2	06-32-17-13788-000-0010	0.562	2017	0.22	0.28
NS-2	07-32-17-05580-001-0200	0.248	2013	0.35	0.45
NS-2	13-31-15-31788-026-1570	0.188	2011	0.20	0.22
NS-2	17-31-16-23634-018-0080	0.179	2017	0.20	0.20
NS-2	25-31-15-84096-001-0400	0.288	2019	0.25	0.27
NSM-1	06-31-17-17523-001-1240	0.057	2015	0.34	0.38
NSM-1	11-32-16-18731-000-0440	0.024	2018	0.69	0.69
NSM-1	11-32-16-18731-000-0490	0.028	2018	0.69	0.69
NSM-1	11-32-16-18731-000-0760	0.028	2016	0.69	0.69
NSM-1	25-31-16-48960-000-0810	0.164	2019	0.21	0.24

Table 4-2. Site reflectivity scores averaged across like zoning designations. Vegetation measurements include the entire area of the site including trees, grass, and other vegetation. No vegetation measurements omit these areas and does not factor them into the calculation.

Zone	**Reflectivity Average**	
	Vegetation	**No Vegetation**
NT-1	0.21	0.23
NT-2	0.20	0.22
NT-3	0.27	0.32
NS-1	0.27	0.31
NS-2	0.24	0.28
NSM-1	0.52	0.54

Table 4-3. Site reflectivity scores averaged by year. Vegetation measurements include the entire area of the site including trees, grass, and other vegetation. No vegetation measurements omit these areas and does not factor them into the calculation.

Year Built	**Reflectivity Average**	
	Vegetation	**No Vegetation**
2011*	0.20	0.28
2012	0.24	0.27
2013	0.28	0.34
2014*	0.35	0.45
2015	0.22	0.23
2016	0.52	0.54
2017	0.21	0.23
2018	0.20	0.22
2019	0.25	0.29

*Year built 2011 and 2014 had only one parcel sampled.

Table 4-4. Bivariate correlation model results. Vegetation measurements include the entire area of the site including trees, grass, and other vegetation. No vegetation measurements omit these areas and does not factor them into the calculation.

Criteria Against	**Site Solar Reflectivity**			
	Vegetation		**No Vegetation**	
	Pearson Correlation	**Sig. Level***	**Pearson Correlation**	**Sig. Level***
Zone	0.562	0.001	0.562	0.001
Year Built	0.082	0.665	0.033	0.861
Parcel Area	-0.387	0.034	-0.330	0.075
Minimum Lot Area	-0.293	0.116	-0.212	0.260
DUA	0.186	0.326	0.088	0.645
FAR**	0.392	0.032	0.396	0.030
ISR	0.147	0.438	0.086	0.652
Front Setback (Building)	-0.494	0.006	-0.406	0.026
Front Setback (Porch)	-0.388	0.034	-0.295	0.113
Side Setback (Interior)	0.250	0.182	0.289	0.121
Side Setback (Exterior)	0.402	0.028	0.422	0.020
Rear Setback (Building)	0.402	0.028	0.409	0.025
Rear Setback (Alley)	0.443	0.014	0.452	0.012
Waterfront Setback	0.704	< 0.001	0.647	< 0.001

*A correlation is considered statistically significant if the significance level is below 0.05.

**FAR correlation calculations only apply to NT-1, NT-2, and NT-3 zoning designations as NS-1, NS-2, and NSM-1 do not have any FAR standard associated with them.

CHAPTER 5
DISCUSSION OF RESULTS

Vegetation and No Vegetation Scores

When designing the study, I was concerned that the results may misconstrue the low reflectivity of vegetation as a negative impact on urban heat islands despite the proven track record of vegetation – especially trees – improving site conditions. I chose to make the no vegetation calculation in addition to the vegetation calculation to better exhibit a site's reflectivity because of this. When comparing the two reflectivity scores, no vegetation clearly performs higher than the vegetation scores. This confirmed that including vegetation surfaces in the results skewed the reflectivity scores lower despite being beneficial to a site.

I feel it necessary to stress that outside of this comparison, the two scores should not be compared to one another and will not be compared to one another in this study. It is not possible to encapsulate the outweighing benefits vegetation has on a site in a reflectivity score alone. Vegetation's impact on the urban heat island effect is outside the scope of this study and the two calculations were only made to properly exhibit site averages, categorical averages, and correlation while accounting for the positive impact vegetation can have. Both scores contain useful information and can reasonably be compared with other like scores (i.e., vegetation to vegetation and no vegetation to no vegetation), but conclusions should not be drawn across those categories (i.e., vegetation to no vegetation).

Sample Outliers

Prior to analyzing the results, I highlighted a few surfaces and parcels that are under unique circumstances that affected their final solar reflectivity scores. Foremost, no parcel contained traditional asphalt surfaces for roadways or driveways. The only asphalt present was in the form of roofing tiles. I measured at least one surface from every other category.

Parcels 11-32-16-18731-000-0440, 11-32-16-18731-000-0490, and 11-32-16-18731-000-0760 all had unusually high reflectivity scores. These three parcels are all part of the same NSM-1 zone development, constructed as townhomes that share walls (Figure 5-1.). The way these parcels were subdivided by the Pinellas County Property Appraiser meant that the entirety of the structure occupied a parcel, and these structures were made with light metal roofs. These factors contributed to unusually high solar reflectivity scores.

Parcel 17-31-17-83224-042-0060 is zoned as NT-3 but also has unusual parcel parameters (Figure 5-2.). The parcel is split into two segments where the primary structure is on one side of the road and across the road is a sea wall with a dock segment. This dock segment is part of the same parcel, resulting in approximately 50% of the parcel being made up of water. These unique circumstances left the vegetation score slightly higher than most parcels and the no vegetation score significantly higher than most parcels.

Not including these significant outliers, the single most reflective site both when accounting for vegetation and not accounting for vegetation was parcel 04-31-17-81540-030-0090 (NS-1) with a score of 0.43 and 0.52 respectively (Figure 5-3). This parcel likely reached these high scores with its light metal roof, white cement concrete pavement, and a pool. The least reflective site both when accounting for vegetation and not accounting for vegetation was parcel 17-31-16-23634-018-0080 (NS-2) with a score of 0.20 for both (Figure 5-4). Unlike the higher reflective sites, there were several sites that shared a vegetation reflectivity score of 0.20 and a no vegetation reflectivity score of 0.21. Most of these low scoring parcels were concentrated in the NT-2 zone, and to a lesser extent, the NT-3 and NS-2 zones.

Figure 5-1. Parcels 11-32-16-18731-000-0440, 11-32-16-18731-000-0490, 11-32-16-18731-000-0760. These three parcels are part of the same NSM-1 zone development and consist only of their respective building footprints.

Data Source: (Google, 2022) (Twitty, 2022)

Figure 5-2. Parcel 17-31-17-83224-042-0060. The NT-3 zoned parcel has a unique layout, with the parcel being divided into two segments divided by a roadway. The west segment behaves like a typical parcel where the east segment only contains a private dock and water access.

Data Source: (Google, 2022) (Twitty, 2022)

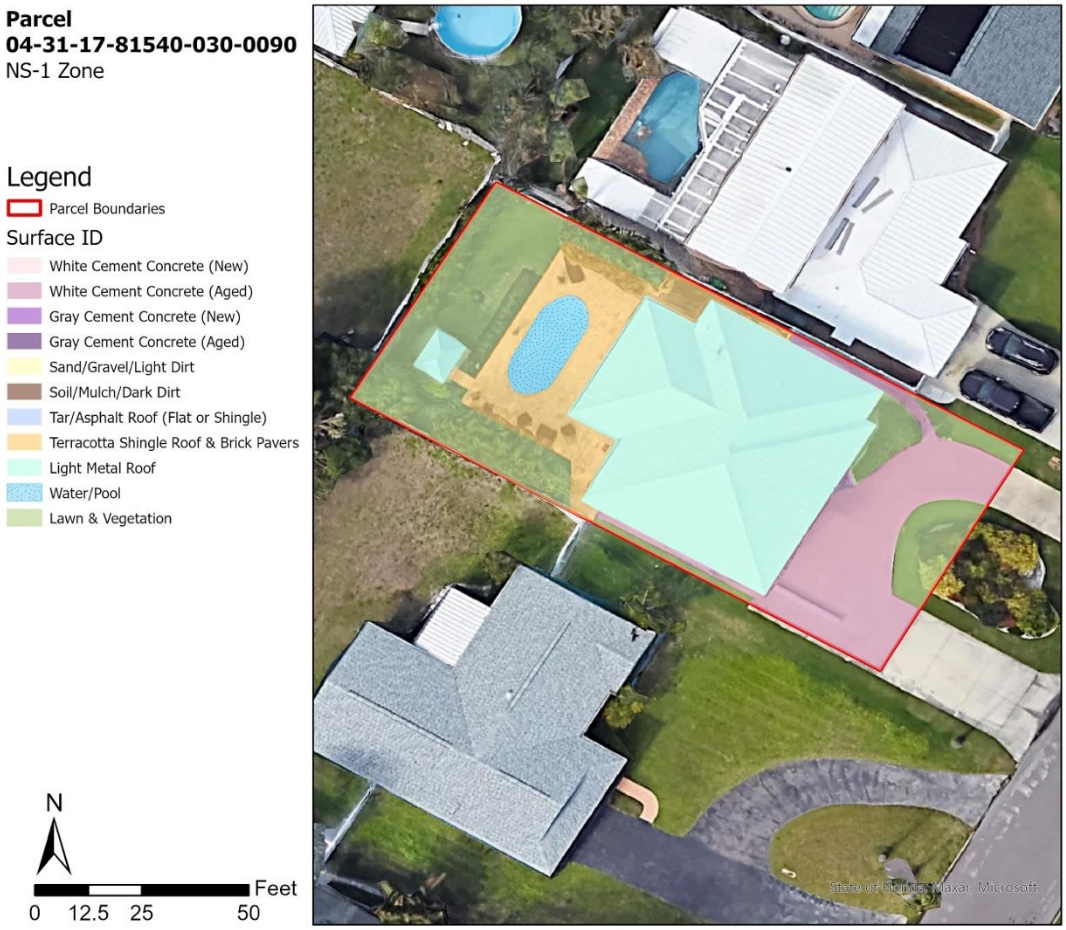

Figure 5-3. Parcel 04-31-17-81540-030-0090. This NS-1 parcel has the highest reflectivity scores in both vegetation and no vegetation scores, likely due to the light metal roof and white cement concrete (aged).

Data Source: (Google, 2022) (Twitty, 2022)

Figure 5-4. Parcel 17-31-16-23634-018-0080. This NS-2 parcel has the lowest solar reflectivity scores overall, with 0.20 for both vegetation and no vegetation scores. Solar panels are designed to absorb sunlight, not reflect it. The presence of solar panels on an already unreflective roof, and the presence of a painted driveway are likely responsible for the low score.

Data Source: (Google, 2022) (Twitty, 2022)

Zone Average and Year Built Average Results

Tables 4-2. shows the site reflectivity scores condensed and reorganized into like categories of zoning designation. NSM-1 had by far the highest reflectivity score, both with and without vegetation; however, it is difficult for me to call this average representative of the NSM-1 zone. The way in which NSM-1 parcels are subdivided results in a lack of context around structures, generally only accounting for the roof and a few square feet of driveway. In contrast, every other residential zone measured consisted of context surrounding the primary structure. I could not include the context necessary to accurately represent these NSM-1 sites because of the study design focusing on parcel limits.

We can see an NSM-1 site with context with parcel 25-31-16-48960-000-0810 (Figure 5-5.). This NSM-1 parcel was the only one out of the five sampled that did not have a shared wall. Rather, the parcel was in a more traditional neighborhood setting. When comparing this parcel's reflectivity scores of 0.21 and 0.24, the parcel and NSM-1 zone falls near the middle of the other zoning designations.

NT-3 and NS-1 zoning designations are the zones with the next highest averages and exhibit a more comprehensive set of parcels when compared to the NSM-1 sample. A lower percentage of roof area compared to pavement and vegetation is likely responsible for these scores rising above the other zones; however, I find it difficult to attribute any one factor as responsible for the shift in the overall zoning categories. NS-2 has the next highest solar reflectivity and NT-1 and NT-2 have the lowest solar reflectivity. Again, this decrease is likely due to roof sizes in relation to parcel size. NT-1 and NT-2 zones have smaller parcel areas overall. If a roof is the same size in an NT-3 zone compared to an NT-1 zone, the roof area will impact the NT-1 zone more heavily because the total area of the site is smaller.

One factor unaccounted for by these zone averages are roadways. The NS-1, NS-2, and NSM-1 zones generally have higher reflectivity scores than the NT-1, NT-2, and NT-3 zones; however, suburban style developments generally require greater lengths of roadway per mile than more traditional neighborhood developments (Randolph, 2012). If I had included some segment of roadways in the measurement process, I would expect to see the suburban zone reflectivity scores fall and the traditional zone reflectivity scores rise. The impact of roadways on urban heat island and cities overall is studied more comprehensively than land use and is outside the scope of this study.

Tables 4-3. shows the parcel scores condensed and reorganized into like categories of year built. Unfortunately, I believe the sample of parcels is too small to draw any meaningful conclusions from. Both 2011 and 2014 only had one parcel in the sample; however, year 2019 had seven parcels in the sample. If I were to draw an overarching trend despite the lack of data, we could see an increase in solar reflectivity from 2011 to 2014 before falling in 2015 and rebounding in 2016 and again falling in 2017 (Figure 5-6.). Building trends and construction materials do change from year to year; however, I must stress that the data derived from this study is not sufficient to draw a meaningful understanding of the face value trend exhibited by Table 4-3. The correlation model results in Table 4-4. further shows the lack of a discernable trend in relation to year built and solar reflectivity.

Figure 5-5. Parcel 25-31-16-48960-000-0810. This parcel is the only NSM-1 parcel that does not contain shared building walls and provides sufficient context past the building footprint within its parcel boundary.

Data Source: (Google, 2022) (Twitty, 2022)

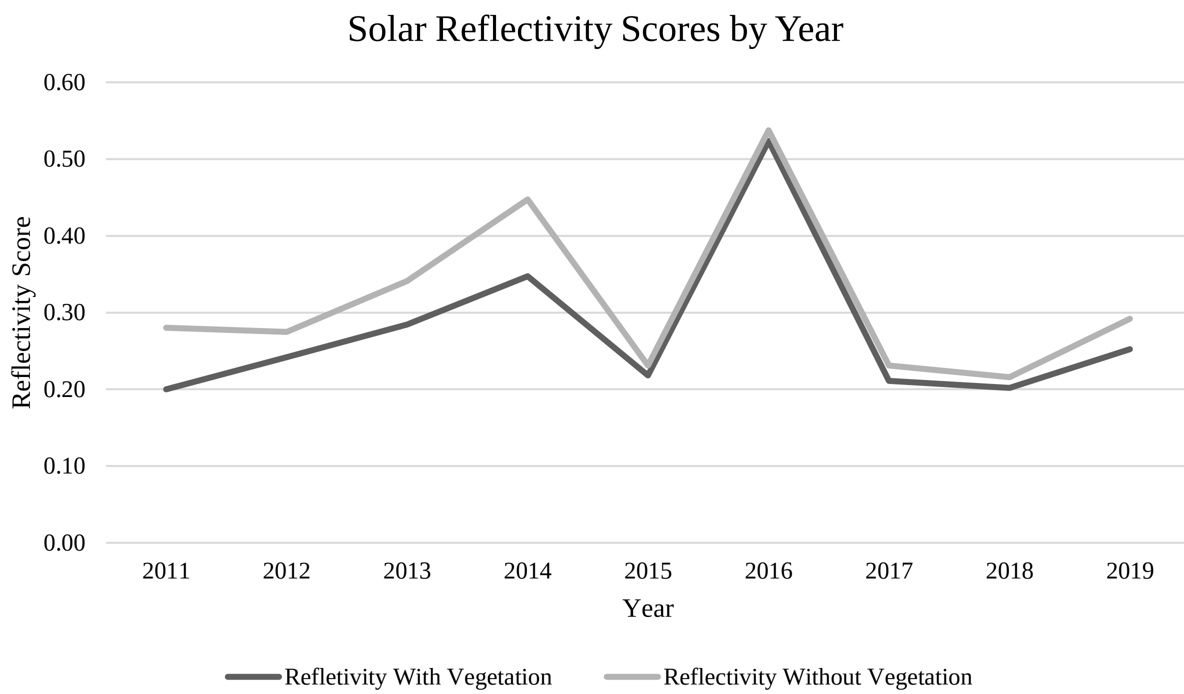

Figure 5-6. Solar reflectivity scores by year trends. The sample size of each year is not large enough to draw conclusions from this visual trend.

Bivariate Pearson Correlation Results

I cannot attribute overarching trends in zoning and building year to individual land development regulations in Chapter 16 of the St. Petersburg City Code as the variables impacting these averages are too broad; however, I can compare individual standards and regulations to individual reflectivity scores. Table 4-4. shows the resulting correlation model. This model can reasonably demonstrate which land development regulations are more closely associated with site reflectivity and to what extent, but the model will not establish causality.

Zoning designation showed one of the highest and most significant correlations across both the vegetation and no vegetation reflectivity scores. The strong correlation demonstrates the preestablished relationship between land use, zoning, and urban heat islands explored in other studies. The significance between zoning and solar reflectivity also demonstrates a combined impact of regulations. While any one regulation may have a small impact, the sum of the impact of all the regulations in place is much greater.

Minimum Lot Area, Density, and Intensity Standards

Parcel area demonstrated a significant correlation with solar reflectivity, though not as strong as the correlation with zoning. While zoning's correlation was positive, the correlation between parcel area and solar reflectivity is negative. This suggests as parcel area increases, solar reflectivity decreases. Interestingly, more dense urban spaces experience the effects of urban heat islands more than spread out rural communities, though this correlation suggests the opposite. The outlier NSM-1 parcels with small parcel sizes and high reflectivity could be contributing to this measurement.

The correlation may suggest that although denser areas do experience heat island to greater extents, a collection of fewer, more dense centers could contribute to heat islands less overall than a collection of many, less dense centers despite experiencing the effects of heat islands more. This could also be an aspect of the correlation existing; however, it is a loose theory that would require much greater research outside of this study. The correlation between parcel area and solar reflectivity is also insignificant for no vegetation measurements. This further suggests that the relationship between parcel size and solar reflectivity is one that does not have standing and could have been influenced by the outlier parcels.

Further evidence suggests the correlation between parcel size and solar reflectivity is insignificant when accounting for minimum lot size requirements. Despite being a similar measure as parcel size, a correlation was not found between minimum lot size requirements and solar reflectivity. For the purposes of this study, I will not consider parcel size a significant factor in solar reflectivity and heat islands. The extent of these measures is still largely unknown in relation to this study, and it appears that what is on the parcel matters more than the parcel itself.

Density regulations (in the form of dwelling units per acre (DUA)) did not show a significant correlation with solar reflectivity despite there being relatively significant differences between the zoning designations. NT-1, NT-2, and NSM-1 all allow 15 dwelling units per acre. NS-1 allows 7.5 dwelling units per acre whereas NT-3 allows 7. NS-2 allows the fewest at only 5 dwelling units per acre. The lack of correlation could possibly be a factor of not enough difference in density even if some of these zones have twice as much, if not more, allowable dwelling units per acre than other zones. Regardless, I focused less on density differences with this study by choosing to focus more on nuances between regulations in like zoning districts. I generally expected a lack of significant correlation in this area.

Conversely, intensity regulations (in the form of floor area ratio (FAR)) did show a significant correlation. This correlation between floor area ratio and solar reflectivity only applies to the NT-1, NT-2, and NT-3 zones. The NS-1, NS-2, and NSM-1 zones do not have floor area ratio standards that apply to residential developments. Only a difference of 0.1 floor area ratio exists between the NT-1, NT-2, and NT-3 zones (Appendix A).

I could draw two conclusions when accounting for this information. First is that the significance is much lower than stated and the correlation model behaved oddly when only looking at the 15 parcels. Second is that the floor area ratio has a significant effect on solar reflectivity as a difference of only 0.1 created a significant, albeit lower, correlation. The lack of correlation in density makes me skeptical of the latter. Additionally, the correlation between floor area ratio and solar reflectivity is positive. A positive correlation would suggest we increase floor area ratio allowances to increase solar reflectivity. Increasing floor area allowances to combat the urban heat island effect would be naïve at best, increasing thermal mass for solar radiation to be absorbed by.

I attribute this positive and significant correlation to a sample size that is simply too small and to the variable that is being measured. Solar reflectivity very well may increase as the floor area ratio increases, but solar reflectivity is just one part of a larger urban heat island system. While the measure works well for two dimensional measurements and impervious surfaces, floor area ratio is a three-dimensional measurement. I would find accepting floor area ratio as a mitigation strategy irresponsible based on these factors without first completing further research using variables and measurements better suited to floor area ratio’s three-dimensional space.

Impervious surface area ratio (ISR) and solar reflectivity have a severe lack of correlation. If there were any one standard, I expected to exhibit a strong correlation, it would have been the impervious surface area ratio. While both correlations are low, the correlation using vegetation measurements is higher. The low correlation could be a factor of low sample size, or the types of parcels measured. No parcel measured had excessive amounts of impervious surface areas, including parking lots or large warehouses. Additionally, every zone designation had an impervious surface area ratio allowance of either 0.60 or 0.65, providing little to no difference for the correlation model to measure. There is hardly enough evidence to draw anything conclusive from this correlation or lack thereof.

Building Setback Standards

The correlation model in Table 4-4. became more revealing when examining site setback standards. Interior side setbacks were the only standards to have an insignificant correlation with solar reflectivity; however, the model shows conflicting narratives. Some setback standards were positively correlated while some were negatively correlated with solar reflectivity. Both front setback regulations exhibited a negative correlation, meaning as the setback requirement increases the solar reflectivity is expected to decrease. If this correlation only appeared with the vegetation reflectivity scores, I could attribute the negative correlation to reducing vegetation and increasing the area of more reflective surfaces. The correlation between front setbacks and the no vegetation reflectivity score was also negative, meaning I cannot attribute this negative correlation to vegetation alone.

Conversely, waterfront and rear setbacks contain strong and significant positive correlations with solar reflectivity. Differences in the front and rear setback correlations suggest that varying types of setbacks could have different impacts on solar reflectivity. After reviewing the setback standards for each zone, I noticed a pattern. The front setback requirements had greater variation between zones where the rear setback requirements had less variation between zones. A small sample spread over six variables could be the cause of such a negative correlation as well as a positive correlation when the small sample is spread over fewer variables.

What I can conclude is not necessarily that setbacks contribute to solar reflectivity in a certain way, but that setbacks do contribute in general. It is possible that different types of setbacks impact solar reflectivity to varying degrees, though I find this unlikely simply because of the similarity between the different standards and how the standards are implemented.

I also consider the implications increasing setback standards would pose. Increased setbacks may lead to larger lot sizes on average to combat the greater restrictions or they may lead to more condensed structures on similarly sized lots. These more condensed structures could carry a higher thermal mass over a smaller amount of area in comparison to a typical home today, contributing to the heat island effect more than mitigating it. Further research would be required to understand this relationship more clearly.

Additional Observations of Parcels

I noticed several site factors when conducting this study that are not apparent in number form. Many of the parcels sampled were adjacent to pre-existing homes and the structures on them were a product of recent redevelopment. I found that these newer homes I was measuring were significantly larger than the neighboring homes, especially in the NT-1 and NT-2 districts where many homes were constructed in the 1920s, 30s, and 40s. Out of curiosity, I measured one of these neighboring homes. Figure 5-7. shows the structure neighboring one of the parcels in the sample, parcel 12-31-16-94428-003-0210 (NT-2). The footprint of the sampled parcel was approximately one and a half times that of the existing home.

I found some historical imagery that demonstrated the redevelopment of these neighborhoods in the form of infill development. Parcel 12-31-16-94428-003-0210 (NT-2) was constructed over an empty portion of yard previously part of the neighboring home (Figure 5-8.). This redevelopment is typical of the national average for home sizes as the average continues to increase (Statista Research Department, 2022). Also notice that the neighboring parcel was redeveloped, adding an addition to the pre-existing home. The implications this could have on urban heat islands are concerning as more land is consumed by homes without necessarily increasing the density or number of residents who can occupy the land.

Figure 5-7. Sampled parcel 12-31-16-94428-003-0210 and neighboring parcel 12-31-16-9448-003-0220.

Data Source: (Google, 2022) (Twitty, 2022)

Figure 5-8. Sampled parcel 12-31-16-94428-003-0210 prior to infill development.

Data Source: (Google, 2022) (Twitty, 2022)

Limitations of Study Design

Any study comes with its limits and caveats, and this study is no different. Perhaps the most obvious limit is that of the solar reflectivity measurement used to approximate the impact of the sampled parcels on the urban heat island effect. The measurement is just that, an approximation that proved to not always behave as expected, especially when considering floor area ratio. Solar reflectivity works well in a two-dimensional space and on maps, but the urban heat island effect is more complex than that of a two-dimensional sphere.

Ideally, I would have used actual surface temperatures or local air temperatures approximately 1-2 meters above the surfaces to then calculate the true impact of these parcels on urban heat islands. Unfortunately, this scale of data collection would have become increasingly complex while attempting to accurately measure 30 sites, each with multiple surface types at varying altitudes, while simultaneously coordinating with 30 property owners. I stand by solar reflectivity being a good approximation of urban heat islands. Although the measurement did not always behave as expected and is not the most accurate, it allows for the study of urban heat islands in otherwise impossible manners.

Similar to solar reflectivity being an approximation, the measurements made are estimates in both area and the reflectivity scores assigned to them. Ariel imagery does not always line up at a perfect top-down angle given the spherical nature of Earth; however, I did my best to combat this. The base maps in ArcGIS Pro proved to be too difficult to work with. Instead, I employed the use of Google Earth Pro. Google Earth renders ariel imagery over a three-dimensional mesh layer, roughly adjusting the ariel imagery to properly appear from a top-down angle regardless of where the parcel is on the planet. Georeferencing and importing this imagery in ArcGIS Pro improved the accuracy of the resulting calculations significantly.

I still took the measurements by hand. Although I cannot guarantee a 100% accuracy in my measurements, I can ensure that I used a careful eye. Zooming into the lowest grain of detail on the maps made it clear where rooflines ended, and yards began. Such minute differences in measurements would not affect the final reflectivity scores in any significant manner; however, my choice to use reflectivity score categories instead of individual surface scores could have had a larger affect.

I chose to use categories of reflectivity scores rather than the true scores of individual surfaces since it is not possible to discern with high accuracy what a surface is from ariel imagery. An apparent difference in roof color or material could be a result of a different source image being used for the base map rather than a true difference. Slight changes in paver textures or gravel type are not discernable from the higher altitudes that the base maps displayed imagery at. Adjacent to the topic of solar reflectivity categories is the lack of consideration for vegetation and tree canopies more specifically.

Tree canopies and the urban heat island effect are well studied as a proven mitigation strategy; however, considering them as surfaces in a parcel is outside the scope of this study. Proving the merit of tree canopies and vegetation is not the goal of this study and would have required reworking the calculations to a large extent. The vegetation and no vegetation solar reflectivity scores are evidence of this and a compromise I chose to make to still consider vegetation while not making vegetation a focal point in the study.

Limits in Sampling

If I restarted this study with the experience I now have, I would increase the sample size and alter some of the zoning designations I chose to sample. The city of St. Petersburg has 130,944 parcels with records filed with the Pinellas County Property Appraiser (Twitty, 2022). A 30-parcel sample size is less than 0.01% of parcels across the entire city. I utilized a smaller sample size due to time constraints in completing this study. What the smaller sample yielded were less discernable relationships in the city land development regulations and the parcel reflectivity scores. Several of these relationships were insignificant, and those that were significant had caveats attached with more research being required.

Similarly, I utilized a smaller selection of zoning designations to accommodate a smaller sample. This led to zoning designations with too few differences between their standards in the study. I don't disagree with only including residential zones; however, the inclusion of more residential zones (such as corridor residential traditional (CRT) or corridor residential suburban (CRS)) could have expanded the study across more varying regulations.

Expanding the study to include a longer time frame of construction could also be beneficial. New construction and redevelopment may be more topical when addressing urban heat islands, but that does not mean lessons could not be learned from older construction and zoning standards. The largest inhibitor with expanding this aspect of the sample was the availability of the St. Petersburg land development regulations. I did obtain a 1997 copy of the entire city code of ordinances from St. Petersburg, but the chapter on zoning and land development regulations was oddly missing. The absent codes proved to be a problem in multiple years. This issue also extends to sample size. Assuming I were able to locate more versions of the city code, the sample of only 30 parcels would have been spread thin across multiple decades of construction. Even with a sample spanning less than a decade, some years only had one parcel sampled from them.

These limitations are sacrifices of practicality in this study's design. I discuss these limits, not to discredit the results of the study, but to enhance one's understanding of the process in how these results can be reasonably examined and used. I would not have been able to reasonably complete this study without these limits and the limits in place still result in estimations with reasonable accuracy and analyzable data.

Limits in Site Areas and Parcels

I encountered unintended consequences when using land parcels to delineate sites in the study design. The land parcels used are generally not used for the purpose of site design but for the purpose of land appraisal and ownership information. While the parcels did provide neat site boundaries to take measurements within, the parcels also lacked site context, especially when looking at the NSM-1 parcels. The land development regulations of the NSM-1 zone do not allow for a zero-foot building setback, but several of these parcels had shared wall developments. St. Petersburg does allow for these types of shared walls dependent on land use and the parcels are generally formed after development is completed.

I could have measured a standardized area instead of individual sites, mitigating this limitation. For example, a one-acre square of land could have been randomly located within a given zoning district and any surface in that square would be measured. I could repeat this process for the other zoning district. This process could have provided me with more site context, including roads, parking lots, parks, greenspace, neighborhood amenities, etc. Additionally, using standardized areas could have created a more robust sample size. Unfortunately, I did not consider this process when forming the methods of this study and only understood the benefits after understanding the limits of using land parcels.

Future Research

I can unfortunately not recommend the implementation of any policies from the results of this study. There are too many limits inhibiting the results of the study to do so, but I can still draw some lessons from the results of this study. If nothing else, this study further reenforces previous work establishing connections between urban heat island and land use. Several correlations exist in manners that show some level of connection, albeit the connection is not always clear.

I would suggest simply repeating this study with a larger sample size over more zoning designations to enhance these results and make these relationships clearer. This study was severely limited in its sample size; however, I believe that this study demonstrated its practicality in how the methodology was carried out. Repeating this study with a larger sample size across more zoning designations could conceivably yield more accurate results with clearer conclusions to be drawn from them, possibly resulting in suggestions for policy actions.

Several tangential research topics presented themselves in this study as I analyzed the results, specifically when discussing the bivariate pearson correlation model. Repeating this study with a larger sample should address these issues, such as with floor area ratio and setbacks. In a case where repetition of the study does not answer these questions, a new study could be developed, and further research could occur on those topics as they present themselves.

Multiple paths into further research with land development regulations and urban heat islands does exist. I focused on theoretical relationships between site design, land development regulations, and solar reflectivity. While land development regulations and solar reflectivity are more easily measured, site design introduces a human element. I would be interested to see how human behavior in developers and designers reacts to changes in standards meant to help these regulations.

If given a hypothetical set of land development regulations to develop a new site with, the final designs could be measured rather than the present-day parcels measured in this study. A benefit to measuring these hypothetical developments would be knowing exact dimensions and materials used. The study could introduce a third dimension of thermal mass in addition to solar reflectivity and possibly even account for vegetation in a more measured environment. The study would involve those who design our cities and these developments. Sample size and developer participation would likely become the most challenging aspect of this study; however, a study such as this would remove many limitations and offer great insight past theoretical correlations.

Focusing more on real world situations, thermal imaging offers possible real time measurement of surfaces and their emitted heats. A researcher could set up thermal imaging at several sites, logging temperatures at peak times, and comparing the resulting temperatures to land development regulations similarly to how this study used a correlation model.

CHAPTER 6
SUMMARY OF FINDINGS

An established the connection between urban heat islands and land development regulations is the key finding of this study. Future research will be able to build off this connection and work towards implementation and policy recommendations. Significant correlations were found between solar reflectivity and zoning designation, parcel area, floor area ratio, front setbacks, rear setbacks, and waterfront setbacks. The correlation between zoning and solar reflectivity was the clearest and was demonstrated in both the correlation model and the averages shown in Table 4-3. Zoning designations are comprised of many regulations that create a larger impact than any individual part.

The correlations drawn between setbacks, parcel areas, and floor area ratios were not conclusive enough to influence policy decisions. The study only exhibited that correlations do exist, further establishing the connection between land development regulations and urban heat island. Other results increased an understanding of building trends and the urban heat island effect. The trend exhibited in categorizing parcels by year built is not robust; however, the concept of construction trends evolving over time is topical. By analyzing older structures near the sampled parcels, an anecdotal trend of increasing home sizes presented itself. Increasing home sizes is a trend consistent with the overall United States trend in average home sizes.

I cannot draw any specific action or policy suggestion from this study, but future research can built off of the established connection between land development regulations and urban heat islands. Land development regulations should be included in future discussions of urban heat island mitigation as specific strategies present themselves in future research. Many mitigation strategies incorporate some level of land development regulations, but never has a focus on land development regulations as a mitigating factor occurred at a high level.

Urban heat islands will only increase in their impact as home sizes increase, new pavements are laid, and more development occurs. Utilizing mitigation strategies to their fullest extent is required to tame urban heat islands, and this study shows that the fullest extent does include land development regulations. With further research, such as the topics explored in Chapter 5, specific policies and a path to implementation will present itself. Natural and human created phenomena like urban heat islands will not dissipate without taking some form of action. As urban heat islands are addressed across the world, I propose that land development regulations should play a larger role in the next era of mitigation strategies. Urban heat islands will likely continue to place people and the built environment at risk otherwise.

APPENDIX A
LAND DEVELOPMENT REGULATIONS OF CHOSEN ZONING DISTRICTS

Table A-1. Development Potential and Setbacks for Sampled Zoning Designations

Regulation/Standard	**Year**	**Zone**					
		NT-1	**NT-2**	**NT-3**	**NS-1**	**NS-2**	**NSM-1**
Minimum Lot Area	**2008**	5,800	5,800	7,620	5,800	8,700	4,500
(Sq Ft)	**2012**	5,800	5,800	7,620	5,800	8,700	4,500
	2022	4,500	5,800	7,620	5,800	8,700	4,500
Density	**2008**	15	15	7	7.5	5	15
(DUA)	**2012**	15	15	7	7.5	5	15
	2022	15	15	7	7.5	5	15
Intensity	**2008**	0.5	0.5	0.4	N/A	N/A	N/A
(FAR)	**2012**	0.5	0.5	0.4	N/A	N/A	N/A
	2022	0.5	0.4	0.4	N/A	N/A	N/A
ISR	**2008**	0.65	0.65	0.65	0.60	0.60	0.65
	2012	0.65	0.65	0.65	0.60	0.60	0.65
	2022	0.65	0.65	0.65	0.60	0.60	0.65
Front Setback (Building)	**2008**	25	25	30	25	30	20
(Ft)*	**2012**	25	25	30	25	30	20
	2022	25	25	30	25	30	20
Front Setback (Porch)	**2008**	18	18	23	20	25	15
(Ft)*	**2012**	18	18	23	20	25	15
	2022	18	18	23	20	25	15
Side Setback (Interior)	**2008**	6	6	8	8	8	8
(Ft)*	**2012**	6	6	8	8	8	8
	2022	6	6	8	8	10	8
Side Setback (Exterior)	**2008**	12	12	15	12	15	15
(Ft)*	**2012**	12	12	15	12	15	15
	2022	12	12	15	12	15	15
Rear Setback (Building)	**2008**	10	10	10	20	20	20
(Ft)*	**2012**	10	10	10	20	20	20
	2022	10	10	10	20	20	20
Rear Setback (Alley)	**2008**	10	10	10	20	20	20
(Ft)*	**2012**	10	10	10	20	20	20
	2022	10	10	10	10	10	10
Waterfront Setback	**2008**	20	20	20	15	15	35
(Ft)*	**2012**	20	20	20	20	20	35
	2022	20	20	20	15	15	35

*Chapter 16 of the St. Petersburg Code of Ordinances provides multiple setback requirements based on height of the structure, lot dimensions, or neighboring land uses. For the NT-1, NT-2, and NT-3 districts, the structure was assumed to be between 18 and 24 feet in height with alleys less than 16 feet in width and lot widths greater than 60 feet. For the NS-1 and NS-2 districts, the structure was assumed to be less than or equal to 24 feet in height, using the principal structure as the rear yard setback requirement. For the NSM-1 district, the structure was assumed to be less than or equal to 36 feet in height, using the principal structure as the rear yard requirement and abutting residential land uses.

Data Source: (City of St. Petersburg, 2008) (City of St. Petersburg, 2012) (City of St. Petersburg, 2022)

APPENDIX B
PARCEL MEASUREMENT SUMMARIES

Table B-1. NT-1 parcel measurement summaries.

Parcel Summary		**01-31-16-45054-001-0140**		**Vegetation**		**No Vegetation**	
Zone	**Area (SqFt)**	**Surface ID**	**SR Unweighted**	**Percentage of Total Area**	**SR Weighted**	**Percentage of Total Area**	**SR Weighted**
NT-1	2309.00	9	0.20	0.31	0.06	0.85	0.17
NT-1	408.29	2	0.35	0.05	0.02	0.15	0.05
NT-1	4744.47	14	0.19	0.64	0.12	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NT-1	7461.76	0.17	2012	0.20		0.22	

Table B-1. (Continued)

Parcel Summary		**14-31-16-77976-000-0190**		**Vegetation**		**No Vegetation**	
Zone	**Area (SqFt)**	**Surface ID**	**SR Unweighted**	**Percentage of Total Area**	**SR Weighted**	**Percentage of Total Area**	**SR Weighted**
NT-1	2278.52	9	0.20	0.36	0.07	0.62	0.12
NT-1	72.59	1	0.70	0.01	0.01	0.02	0.01
NT-1	29.67	1	0.70	0.00	0.00	0.01	0.01
NT-1	816.98	9	0.20	0.13	0.03	0.22	0.04
NT-1	33.93	1	0.70	0.01	0.00	0.01	0.01
NT-1	322.28	2	0.35	0.05	0.02	0.09	0.03
NT-1	96.41	2	0.35	0.02	0.01	0.03	0.01
NT-1	104.17	14	0.19	0.02	0.00	--	--
NT-1	996.48	14	0.19	0.16	0.03	--	--
NT-1	1564.03	14	0.19	0.25	0.05	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NT-1	6315.07	0.14	2019	0.22		0.24	

Table B-1. (Continued)

Parcel Summary		21-31-16-63504-008-0130		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NT-1	2687.57	9	0.20	0.58	0.12	0.87	0.17
NT-1	44.22	11	0.69	0.01	0.01	0.01	0.01
NT-1	181.17	8	0.23	0.04	0.01	0.06	0.01
NT-1	10.99	8	0.23	0.00	0.00	0.00	0.00
NT-1	6.36	8	0.23	0.00	0.00	0.00	0.00
NT-1	75.22	1	0.70	0.02	0.01	0.02	0.02
NT-1	70.50	1	0.70	0.02	0.01	0.02	0.02
NT-1	768.17	14	0.19	0.17	0.03	--	--
NT-1	775.82	14	0.19	0.17	0.03	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NT-1	4620.01	0.11	2019		0.22		0.23

Table B-1. (Continued)

Parcel Summary		28-31-16-21276-003-0130		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NT-1	1997.41	9	0.20	0.33	0.07	0.78	0.16
NT-1	450.55	2	0.35	0.07	0.03	0.18	0.06
NT-1	104.35	2	0.35	0.02	0.01	0.04	0.01
NT-1	1161.38	14	0.19	0.19	0.04	--	--
NT-1	2334.29	14	0.19	0.39	0.07	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NT-1	6047.98	0.14	2019		0.21		0.23

Table B-1. (Continued)

Parcel Summary		27-31-16-94266-000-0530		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NT-1	1698.62	9	0.20	0.29	0.06	0.77	0.15
NT-1	109.19	2	0.35	0.02	0.01	0.05	0.02
NT-1	283.80	2	0.35	0.05	0.02	0.13	0.05
NT-1	101.66	2	0.35	0.02	0.01	0.05	0.02
NT-1	2777.07	14	0.19	0.48	0.09	--	--
NT-1	854.23	14	0.19	0.15	0.03	--	--
Zone	Area (SqFt)	Area (ac)	Year Built	Solar Reflectivity Score		Solar Reflectivity Score	
NT-1	5824.56	0.13	2019		0.21		0.23

*SR (solar reflectivity)

Table B-2. NT-2 parcel measurement summaries.

Parcel Summary		12-31-16-74286-000-0010		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NT-2	1805.08	9	0.20	0.42	0.08	0.75	0.15
NT-2	101.06	2	0.35	0.02	0.01	0.04	0.01
NT-2	112.96	8	0.23	0.03	0.01	0.05	0.01
NT-2	83.94	8	0.23	0.02	0.00	0.04	0.01
NT-2	17.20	8	0.23	0.00	0.00	0.01	0.00
NT-2	64.82	9	0.20	0.02	0.00	0.03	0.01
NT-2	190.78	4	0.18	0.04	0.01	0.08	0.01
NT-2	6.57	4	0.18	0.00	0.00	0.00	0.00
NT-2	15.15	4	0.18	0.00	0.00	0.01	0.00
NT-2	757.96	14	0.19	0.18	0.03	--	--
NT-2	1144.93	14	0.19	0.27	0.05	--	--
Zone	Area (SqFt)	Area (ac)	Year Built	Solar Reflectivity Score		Solar Reflectivity Score	
NT-2	4300.46	0.10	2016		0.20		0.21

Table B-2. (Continued)

Parcel Summary		12-31-16-94428-003-0210		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NT-2	3393.22	9	0.20	0.60	0.12	0.93	0.19
NT-2	96.92	2	0.35	0.02	0.01	0.03	0.01
NT-2	139.99	2	0.35	0.02	0.01	0.04	0.01
NT-2	1029.73	14	0.19	0.18	0.03	--	--
NT-2	1042.18	14	0.19	0.18	0.03	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**		**Solar Reflectivity Score**		**Solar Reflectivity Score**
NT-2	5702.04	0.13	2018		0.20		0.21

Table B-2. (Continued)

Parcel Summary		13-31-16-25254-000-1010		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NT-2	1531.52	9	0.20	0.20	0.04	0.55	0.11
NT-2	456.26	9	0.20	0.06	0.01	0.16	0.03
NT-2	132.67	2	0.35	0.02	0.01	0.05	0.02
NT-2	108.62	2	0.35	0.01	0.01	0.04	0.01
NT-2	180.15	8	0.23	0.02	0.01	0.06	0.01
NT-2	212.49	4	0.18	0.03	0.01	0.08	0.01
NT-2	158.07	4	0.18	0.02	0.00	0.06	0.01
NT-2	761.25	14	0.19	0.10	0.02	--	--
NT-2	2524.96	14	0.19	0.33	0.06	--	--
NT-2	1476.44	14	0.19	0.20	0.04	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**		**Solar Reflectivity Score**		**Solar Reflectivity Score**
NT-2	7542.43	0.17	2015		0.20		0.21

Table B-2. (Continued)

Parcel Summary		**13-31-16-40194-000-0130**		**Vegetation**		**No Vegetation**	
Zone	**Area (SqFt)**	**Surface ID**	**SR Unweighted**	**Percentage of Total Area**	**SR Weighted**	**Percentage of Total Area**	**SR Weighted**
NT-2	1473.14	9	0.20	0.23	0.05	0.65	0.13
NT-2	448.20	9	0.20	0.07	0.01	0.20	0.04
NT-2	127.89	4	0.18	0.02	0.00	0.06	0.01
NT-2	71.53	2	0.35	0.01	0.00	0.03	0.01
NT-2	87.98	9	0.20	0.01	0.00	0.04	0.01
NT-2	73.07	2	0.35	0.01	0.00	0.03	0.01
NT-2	1726.66	14	0.19	0.27	0.05	--	--
NT-2	2341.68	14	0.19	0.37	0.07	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**		**Solar Reflectivity Score**		**Solar Reflectivity Score**
NT-2	6350.16	0.15	2016		0.20		0.21

Table B-2. (Continued)

Parcel Summary		**23-31-16-65862-008-0050**		**Vegetation**		**No Vegetation**	
Zone	**Area (SqFt)**	**Surface ID**	**SR Unweighted**	**Percentage of Total Area**	**SR Weighted**	**Percentage of Total Area**	**SR Weighted**
NT-2	2864.11	9	0.20	0.52	0.10	0.89	0.18
NT-2	108.93	2	0.35	0.02	0.01	0.03	0.01
NT-2	233.87	1	0.70	0.04	0.03	0.07	0.05
NT-2	1065.96	14	0.19	0.19	0.04	--	--
NT-2	1229.03	14	0.19	0.22	0.04	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**		**Solar Reflectivity Score**		**Solar Reflectivity Score**
NT-2	5501.90	0.13	2018		0.22		0.24

*SR (solar reflectivity)

Table B-3. NT-3 parcel measurement summaries.

Parcel Summary		**17-31-17-83220-073-0040**		**Vegetation**		**No Vegetation**	
Zone	**Area (SqFt)**	**Surface ID**	**SR Unweighted**	**Percentage of Total Area**	**SR Weighted**	**Percentage of Total Area**	**SR Weighted**
NT-3	3035.07	9	0.20	0.45	0.09	0.72	0.14
NT-3	240.06	13	0.36	0.04	0.01	0.06	0.02
NT-3	30.80	9	0.20	0.00	0.00	0.01	0.00
NT-3	140.96	1	0.70	0.02	0.01	0.03	0.02
NT-3	326.77	1	0.70	0.05	0.03	0.08	0.05
NT-3	181.08	3	0.26	0.03	0.01	0.04	0.01
NT-3	273.08	1	0.70	0.04	0.03	0.06	0.05
NT-3	1293.11	14	0.19	0.19	0.04	--	--
NT-3	1238.38	14	0.19	0.18	0.03	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NT-3	6759.32	0.16	2016		0.26		0.30

Table B-3. (Continued)

Parcel Summary		**17-31-17-83224-042-0060**		**Vegetation**		**No Vegetation**	
Zone	**Area (SqFt)**	**Surface ID**	**SR Unweighted**	**Percentage of Total Area**	**SR Weighted**	**Percentage of Total Area**	**SR Weighted**
NT-3	7098.73	9	0.20	0.35	0.07	0.43	0.09
NT-3	288.05	13	0.36	0.01	0.01	0.02	0.01
NT-3	7075.16	13	0.36	0.35	0.13	0.43	0.16
NT-3	497.53	11	0.69	0.02	0.02	0.03	0.02
NT-3	495.17	2	0.35	0.02	0.01	0.03	0.01
NT-3	189.49	1	0.70	0.01	0.01	0.01	0.01
NT-3	530.63	1	0.70	0.03	0.02	0.03	0.02
NT-3	213.46	3	0.26	0.01	0.00	0.01	0.00
NT-3	2128.74	14	0.19	0.11	0.02	--	--
NT-3	1554.08	14	0.19	0.08	0.01	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NT-3	20071.03	0.46	2019		0.29		0.31

Table B-3. (Continued)

Parcel Summary		19-31-16-20484-049-0100		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NT-3	2290.44	11	0.69	0.24	0.17	0.43	0.29
NT-3	556.33	2	0.35	0.06	0.02	0.10	0.04
NT-3	464.36	2	0.35	0.05	0.02	0.09	0.03
NT-3	708.24	11	0.69	0.07	0.05	0.13	0.09
NT-3	78.82	11	0.69	0.01	0.01	0.01	0.01
NT-3	370.29	2	0.35	0.04	0.01	0.07	0.02
NT-3	225.98	2	0.35	0.02	0.01	0.04	0.01
NT-3	211.11	8	0.23	0.02	0.01	0.04	0.01
NT-3	1162.65	14	0.19	0.12	0.02	--	--
NT-3	52.73	14	0.19	0.01	0.00	--	--
NT-3	2163.47	14	0.19	0.23	0.04	--	--
NT-3	777.98	14	0.19	0.08	0.02	--	--
NT-3	462.19	13	0.36	0.05	0.02	0.09	0.03
Zone	Area (SqFt)	Area (ac)	Year Built	Solar Reflectivity Score		Solar Reflectivity Score	
NT-3	9524.60	0.22	2017	0.39		0.54	

Table B-3. (Continued)

Parcel Summary		19-31-16-67500-101-0060		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NT-3	6718.84	9	0.20	0.27	0.05	0.52	0.10
NT-3	370.11	12	0.25	0.02	0.00	0.03	0.01
NT-3	1419.49	12	0.25	0.06	0.01	0.11	0.03
NT-3	4159.10	3	0.26	0.17	0.04	0.32	0.08
NT-3	166.68	4	0.18	0.01	0.00	0.01	0.00
NT-3	9547.64	14	0.19	0.39	0.07	--	--
NT-3	1894.95	14	0.19	0.08	0.01	--	--
NT-3	151.65	14	0.19	0.01	0.00	--	--
NT-3	41.05	14	0.19	0.00	0.00	--	--
Zone	Area (SqFt)	Area (ac)	Year Built	Solar Reflectivity Score		Solar Reflectivity Score	
NT-3	24469.51	0.56	2017	0.21		0.23	

Table B-3. (Continued)

Parcel Summary		19-31-16-96570-004-0160		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NT-3	362.61	3	0.26	0.05	0.01	0.08	0.02
NT-3	606.87	4	0.18	0.08	0.01	0.13	0.02
NT-3	2778.26	9	0.20	0.35	0.07	0.58	0.12
NT-3	125.41	2	0.35	0.02	0.01	0.03	0.01
NT-3	249.08	10	0.27	0.03	0.01	0.05	0.01
NT-3	37.68	10	0.27	0.00	0.00	0.01	0.00
NT-3	26.46	14	0.19	0.00	0.00	--	--
NT-3	238.40	8	0.23	0.03	0.01	0.05	0.01
NT-3	34.48	8	0.23	0.00	0.00	0.01	0.00
NT-3	322.53	8	0.23	0.04	0.01	0.07	0.02
NT-3	604.42	14	0.19	0.08	0.01	--	--
NT-3	2615.57	14	0.19	0.33	0.06	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NT-3	8001.77	0.18	2012	0.20		0.21	

*SR (solar reflectivity)

Table B-4. NS-1 parcel measurement summaries.

Parcel Summary		33-30-17-81278-017-0060		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NS-1	3300.28	10	0.27	0.36	0.10	0.58	0.16
NS-1	392.59	13	0.36	0.04	0.02	0.07	0.02
NS-1	716.57	10	0.27	0.08	0.02	0.13	0.03
NS-1	59.42	4	0.18	0.01	0.00	0.01	0.00
NS-1	1190.30	10	0.27	0.13	0.04	0.21	0.06
NS-1	1899.83	14	0.19	0.21	0.04	--	--
NS-1	126.48	14	0.19	0.01	0.00	--	--
NS-1	1398.58	14	0.19	0.15	0.03	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NS-1	9084.05	0.21	2016	0.24		0.28	

Table B-4. (Continued)

Parcel Summary		09-31-16-39600-006-0160		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NS-1	488.16	1	0.70	0.06	0.04	0.12	0.09
NS-1	2166.72	9	0.20	0.28	0.06	0.54	0.11
NS-1	103.33	7	0.34	0.01	0.00	0.03	0.01
NS-1	588.59	8	0.23	0.07	0.02	0.15	0.03
NS-1	299.96	7	0.34	0.04	0.01	0.07	0.03
NS-1	353.69	7	0.34	0.04	0.02	0.09	0.03
NS-1	2816.79	14	0.19	0.36	0.07	--	--
NS-1	1052.60	14	0.19	0.13	0.03	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**		**Solar Reflectivity Score**		**Solar Reflectivity Score**
NS-1	7869.83	0.18	2013		0.24		0.29

Table B-4. (Continued)

Parcel Summary		08-31-17-83376-000-2740		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NS-1	9613.26	9	0.20	0.54	0.11	0.71	0.14
NS-1	81.70	1	0.70	0.00	0.00	0.01	0.00
NS-1	1388.93	10	0.27	0.08	0.02	0.10	0.03
NS-1	793.43	1	0.70	0.04	0.03	0.06	0.04
NS-1	679.04	13	0.36	0.04	0.01	0.05	0.02
NS-1	44.11	13	0.36	0.00	0.00	0.00	0.00
NS-1	616.30	14	0.19	0.03	0.01	--	--
NS-1	893.01	7	0.34	0.05	0.02	0.07	0.02
NS-1	330.74	14	0.19	0.02	0.00	--	--
NS-1	1076.43	14	0.19	0.06	0.01	--	--
NS-1	14.87	14	0.19	0.00	0.00	--	--
NS-1	292.14	14	0.19	0.02	0.00	--	--
NS-1	199.10	14	0.19	0.01	0.00	--	--
NS-1	1626.22	14	0.19	0.09	0.02	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**		**Solar Reflectivity Score**		**Solar Reflectivity Score**
NS-1	17649.27	0.41	2014		0.24		0.26

Table B-4. (Continued)

Parcel Summary		04-31-17-81540-030-0090		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NS-1	2757.80	11	0.69	0.37	0.26	0.52	0.36
NS-1	74.43	11	0.69	0.01	0.01	0.01	0.01
NS-1	231.21	13	0.36	0.03	0.01	0.04	0.02
NS-1	971.87	10	0.27	0.13	0.04	0.18	0.05
NS-1	1319.45	2	0.35	0.18	0.06	0.25	0.09
NS-1	103.65	14	0.19	0.01	0.00	--	--
NS-1	152.24	14	0.19	0.02	0.00	--	--
NS-1	282.92	14	0.19	0.04	0.01	--	--
NS-1	59.03	14	0.19	0.01	0.00	--	--
NS-1	1449.24	14	0.19	0.20	0.04	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NS-1	7401.83	0.17	2013		0.43		0.52

Table B-4. (Continued)

Parcel Summary		02-32-16-49740-000-0160		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NS-1	5291.68	9	0.20	0.40	0.08	0.75	0.15
NS-1	652.74	3	0.26	0.05	0.01	0.09	0.02
NS-1	753.94	2	0.35	0.06	0.02	0.11	0.04
NS-1	129.47	14	0.19	0.01	0.00	--	--
NS-1	19.47	14	0.19	0.00	0.00	--	--
NS-1	6196.97	14	0.19	0.46	0.09	--	--
NS-1	319.26	8	0.23	0.02	0.01	0.045	0.010
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NS-1	13363.52	0.31	2015		0.21		0.22

*SR (solar reflectivity)

Table B-5. NS-2 parcel measurement summaries.

Parcel Summary		06-32-17-13788-000-0010		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NS-2	2981.44	9	0.20	0.12	0.02	0.44	0.09
NS-2	903.30	2	0.35	0.04	0.01	0.13	0.05
NS-2	428.24	13	0.36	0.02	0.01	0.06	0.02
NS-2	2245.71	2	0.35	0.09	0.03	0.33	0.12
NS-2	223.75	8	0.23	0.01	0.00	0.03	0.01
NS-2	17682.20	14	0.19	0.72	0.14	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NS-2	24464.63	0.56	2017	0.22		0.28	

Table B-5. (Continued)

Parcel Summary		07-32-17-05580-001-0200		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NS-2	2081.92	11	0.69	0.19	0.13	0.32	0.22
NS-2	4333.74	7	0.34	0.40	0.14	0.66	0.22
NS-2	180.56	8	0.23	0.02	0.00	0.03	0.01
NS-2	787.64	14	0.19	0.07	0.01	--	--
NS-2	3415.09	14	0.19	0.32	0.06	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NS-2	10798.94	0.25	2013	0.35		0.45	

Table B-5. (Continued)

Parcel Summary		13-31-15-31788-026-1570		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NS-2	2702.12	9	0.20	0.33	0.07	0.61	0.12
NS-2	529.09	9	0.20	0.06	0.01	0.12	0.02
NS-2	615.26	10	0.27	0.07	0.02	0.14	0.04
NS-2	490.28	10	0.27	0.06	0.02	0.11	0.03
NS-2	116.07	4	0.18	0.01	0.00	0.03	0.00
NS-2	1693.87	14	0.19	0.21	0.04	--	--
NS-2	101.48	14	0.19	0.01	0.00	--	--
NS-2	71.77	14	0.19	0.01	0.00	--	--
NS-2	1886.51	14	0.19	0.23	0.04	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NS-2	8206.46	0.19	2011		0.20		0.22

Table B-5. (Continued)

Parcel Summary		17-31-16-23634-018-0080		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NS-2	425.07	12	0.25	0.05	0.01	0.13	0.03
NS-2	2089.79	9	0.20	0.27	0.05	0.62	0.12
NS-2	683.78	4	0.18	0.09	0.02	0.20	0.04
NS-2	157.13	8	0.23	0.02	0.00	0.05	0.01
NS-2	4420.55	14	0.19	0.57	0.11	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NS-2	7776.31	0.18	2017		0.20		0.20

Table B-5. (Continued)

Parcel Summary		25-31-15-84096-001-0400		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NS-2	5548.54	10	0.27	0.44	0.12	0.57	0.15
NS-2	389.93	13	0.36	0.03	0.01	0.04	0.01
NS-2	1534.31	3	0.26	0.12	0.03	0.16	0.04
NS-2	1774.07	3	0.26	0.14	0.04	0.18	0.05
NS-2	49.66	7	0.34	0.00	0.00	0.01	0.00
NS-2	55.35	7	0.34	0.00	0.00	0.01	0.00
NS-2	251.89	7	0.34	0.02	0.01	0.03	0.01
NS-2	113.19	3	0.26	0.01	0.00	0.01	0.00
NS-2	1620.51	14	0.19	0.13	0.02	--	--
NS-2	1068.75	14	0.19	0.09	0.02	--	--
NS-2	24.28	14	0.19	0.00	0.00	--	--
NS-2	51.82	14	0.19	0.00	0.00	--	--
NS-2	52.46	14	0.19	0.00	0.00	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NS-2	12534.74	0.29	2019		0.25		0.27

*SR (solar reflectivity)

Table B-6. NSM-1 parcel measurement summaries.

Parcel Summary		06-31-17-17523-001-1240		Vegetation		No Vegetation	
Zone	Area (SqFt)	Surface ID	SR Unweighted	Percentage of Total Area	SR Weighted	Percentage of Total Area	SR Weighted
NSM-1	1423.63	10	0.27	0.58	0.16	0.72	0.20
NSM-1	499.16	1	0.70	0.20	0.14	0.25	0.18
NSM-1	6.82	8	0.23	0.00	0.00	0.00	0.00
NSM-1	37.19	8	0.23	0.02	0.00	0.02	0.00
NSM-1	150.15	14	0.19	0.06	0.01	--	--
NSM-1	350.76	14	0.19	0.14	0.03	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NSM-1	2467.70	0.06	2015		0.34		0.38

Table B-6. (Continued)

Parcel Summary		11-32-16-18731-000-0440		Vegetation		No Vegetation	
Zone	**Area (SqFt)**	**Surface ID**	**SR Unweighted**	**Percentage of Total Area**	**SR Weighted**	**Percentage of Total Area**	**SR Weighted**
NSM-1	1060.02	11	0.69	1.00	0.69	1	0.69
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NSM-1	1060.02	0.02	2018	0.69		0.69	

Table B-6. (Continued)

Parcel Summary		11-32-16-18731-000-0490		Vegetation		No Vegetation	
Zone	**Area (SqFt)**	**Surface ID**	**SR Unweighted**	**Percentage of Total Area**	**SR Weighted**	**Percentage of Total Area**	**SR Weighted**
NSM-1	1218.36	11	0.69	1.00	0.69	1	0.69
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NSM-1	1218.36	0.03	2018	0.69		0.69	

Table B-6. (Continued)

Parcel Summary		11-32-16-18731-000-0760		Vegetation		No Vegetation	
Zone	**Area (SqFt)**	**Surface ID**	**SR Unweighted**	**Percentage of Total Area**	**SR Weighted**	**Percentage of Total Area**	**SR Weighted**
NSM-1	1219.01	11	0.69	1.00	0.69	1	0.69
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NSM-1	1219.01	0.03	2016	0.69		0.69	

Table B-6. (Continued)

Parcel Summary		25-31-16-48960-000-0810		Vegetation		No Vegetation	
Zone	**Area (SqFt)**	**Surface ID**	**SR Unweighted**	**Percentage of Total Area**	**SR Weighted**	**Percentage of Total Area**	**SR Weighted**
NSM-1	1874.17	9	0.20	0.26	0.05	0.73	0.15
NSM-1	523.53	2	0.35	0.07	0.03	0.20	0.07
NSM-1	36.54	7	0.34	0.01	0.00	0.01	0.00
NSM-1	19.78	8	0.23	0.00	0.00	0.01	0.00
NSM-1	103.76	2	0.35	0.01	0.01	0.04	0.01
NSM-1	2558.31	14	0.19	0.36	0.07	--	--
NSM-1	2017.25	14	0.19	0.28	0.05	--	--
Zone	**Area (SqFt)**	**Area (ac)**	**Year Built**	**Solar Reflectivity Score**		**Solar Reflectivity Score**	
NSM-1	7133.34	0.16	2019	0.21		0.24	

*SR (solar reflectivity)

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BIOGRAPHICAL SKETCH

Carson received his Bachelor of Science in Sustainability and the Built Environment from the University of Florida in the Spring of 2022 before returning to the University of Florida, earning his Master of Urban and Regional Planning in the Spring of 2023. Carson enjoyed being a member of the University of Florida Marching Band, Tau Beta Sigma – Beta Xi, and the Student Planning Association while at the university. Carson's interests led to a continued focus on sustainability and land use in his planning background and a continued love of music, cities, and the outdoors in his everyday life.