Urban Heat Islands and The University of Florida:

An Audit of the University of Florida "A" Planning Sector

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Abstract

Urban heat island effect is a negative phenomenon that plagues our cities and communities. This study aims to address it in a commonsense fashion. Urban heat islands are caused by the excess absorption of solar radiation in hard surfaces, therefore, if we can reduce the amount of radiation being absorbed, we can lower the impact of urban heat islands (EPA, 2022). For this reason, the study focuses on the solar reflectivity of surfaces, using the University of Florida as a testing ground. Surface measurements were taken and assigned solar reflectivity values to evaluate the current conditions of the site before suggesting possible improvements. The section of the university campus explored, the A planning sector, recorded an 83% reflectivity rate before mitigation strategies were implemented. The improvements, such as an increase in vegetation and upgrades to roofing materials, yielded a 91% reflectivity rating. This was supplemented by a site visit to ensure logical consistency of these results in the real world. The main takeaway of this study is not that of the university campus, but rather how we address urban heat islands. It is a matter of urban design and form. Mitigation strategies all fit into this idea of improving urban form. As such, the true finding of this study is one of necessity. We must make changes today to save out cities tomorrow and make them truly sustainable.

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Urban Heat Island and the University of Florida

Section 1 – Introduction

How is it a plague that affects everyone, every day, on an individual level can be allowed to continue? Across the world, in countries of all shapes, sizes, ethnicities, and economic standings, weather continues to impact the daily lives of their citizens; yet it's more specific than that. Weather is a natural phenomenon after all. Rather, it's the presence of extreme weather and extraordinary heat. Heat is a necessary life force, but left unchecked, it can grow and spread without end in sight. Heat is an element of many phenomena, both good and bad, but I'm not referring to what you may think. I'm referring to the urban design that has led to the unintentional cause of urban heat islands (UHI). The most basic cause of UHI is the excess absorption of heat radiation from the sun by hard surfaces (EPA, 2022). These surfaces could be asphalt, concrete, or buildings, all of which are human interventions in the natural environment (EPA, 2022). It stands to reason that if human interventions are the cause, then maybe human interventions can be the answer. If we can reduce the excess absorption of radiation, we can reduce the effect UHI has in our communities. This is a concept readily accepted; however, that is not the main focus of this study.

Before it's possible to consider how one might reduce the impact of UHI, it is necessary to know the current state of the community. This follows the basic principles of planning. Ask the question of where we are first, then ask where we want to be, and finally, determine how to get there (Kelly, 2010). This study focuses on the main question of where we are, assumes that our destination is a desire to reduce the UHI effect, and finally, briefly explore the concept of how to get there by demonstrating the theoretical implementation of strategies to reverse the negative impacts of previous human interventions.

Before diving into the research study, it is important to standardize the definition of UHI. While an UHI can be urban, suburban, exurban, or rural, during the course of this study, urban heat island will be a generally accepted term for all these (EPA, 2022).

Section 2 – Literature Review

Section 2.1 – Contextualizing the Urban Heat Island Effect

Urban heat island (UHI) effect is a known problem that is growing in significance throughout cities across the world. Many might think that UHIs contribute to climate change, but it's arguable that the reverse is the true case. As the climate changes and global temperatures rise, specifically surface temperatures, UHI effect is worsened. This is caused by a few factors, one being the higher starting temperature of surfaces. Surfaces cool off over-night at different rates depending on the starting temperature, their specific heat, reflectivity, and location relative to other structures (The Surface Temperature Record and the Urban Heat Island, 2004). Even wind can affect the cooling rate. Therefore, if the starting temperature of a climate remains higher, but the amount of time to cool a surface is the same, the surface will reemit a higher heat than it would have otherwise. This time to cool is one reason UHIs are exacerbated in summer conditions. Longer days means more time to absorb and reemit heat and less time to cool off at night. This is a concept of high importance: reflectivity and absorption of solar radiation. Solar radiation being absorbed by surfaces is what causes them to remit heat into the local atmosphere; however, if a surface is reflective, a majority of that solar radiation will bounce off the surface (Figure 2.1) (Krarti, 2018). This is the key theory behind many UHI studies and mitigation strategies.

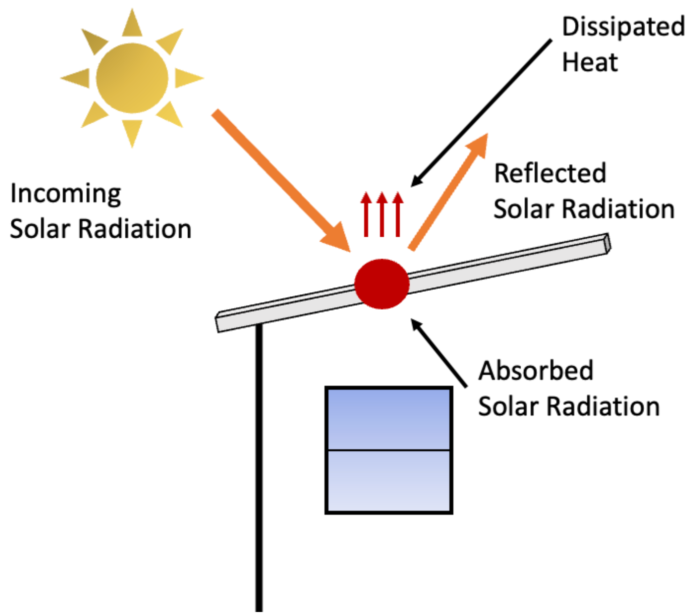

Figure 2.1
Diagram of Solar Radiation and Dissipated Heat

Source: (OPTM, n.d.)

Many studies have attempted to explore these phenomena and factors, including the article "Assessment of Urban Versus Rural In Situ Surface Temperatures in the Contiguous United States: No Difference Found" by Thomas Peterson (2003). Based on the factors that contribute to surface cooling, it would generally be assumed that more rural areas have faster cooling rates because of increased wind and open space. Conversely, urban areas face the challenge of buildings blocking wind and absorbing energy themselves, almost acting as a sort of insulation for surfaces; yet according to Peterson, "no statistically significant impact of urbanization could be found in annual temperatures" (2003). There are a few problems with this conclusion that Peterson acknowledges, the main issue being that it is more likely for metrological observations to be taken in open space and cool park areas than the industrial and high-density areas that UHI is more relevant to. Taking this into account, it frames how local UHI effect acts. It really is a matter of UHI affecting the micro-climate and not one of UHI affecting the global climate. Rather, it is the global climate affecting UHI, in turn affecting the micro-climate of cities and urban areas.

If this is the case, UHI effect may seem like a trivial matter in our battle for sustainability and the built environment, but local and micro-climates affect humans daily more than that of the changing global climate. It may be a localized issue, but it's localized for everyone. It's been estimated that since the 1980s, the number of people living in UHIs has more than tripled (Henson, 2021). It's not just global warming either. Climate change may be raising the Earth's temperatures, but those temperature rises are also causing an influx of natural disasters, including heat waves, which are exacerbated for people in UHI prone areas to the point of possible injury and even death. For those living in UHIs, it can affect physical and mental health, the willingness to use active transportation methods, utilize communal plazas and street level commerce, and more. These reasons prompt a need to mitigate UHI effect in unique ways.

It may be surprising to see how a community design may affect UHI in both positive and negative ways. It's important to recognize that just because the word "Urban" is used in describing UHI does not mean suburban, rural, and exurban developments don't suffer the same consequences as those of urban spaces regarding the UHI effect. They may have smaller or varying degrees of UHI, but every surface, man-made structure, farm field, altered water body, and tree cut down can contribute to an UHI. That's why these are the main areas of mitigation effects that this study will be focusing on: vegetation (natural and planted), pavements, and roofing (including cool and green roof technologies).

Section 2.2 – Mitigation Techniques

Section 2.2.1 – Vegetation and Urban Greenery

Urban parks and greenspaces have widely been assumed to successfully mitigate UHI based on the number of trees and vegetation present in addition to some even having large water bodies. A study published in 2022 that took place across 31 parks in Fuzhou, China used Landsat Temperature data to test this claim. They found not only do these urban parks help mitigate UHIs by a significant amount, but that in this region there is an optimal size for these parks. To gain the most efficiency in mitigating UHIs to the amount of land consumed, the study concluded urban parks should be approximately 1.08 ha (Xiong Yao, 2022). To place that into perspective, Central Park in New York City is 341 ha (Google, 2022). The optimal size for an urban park in regards to UHI is a fraction of what we actually perceive it to be; however, not every city can afford to place 1.08 ha urban parks every couple of city blocks to reduce the effects of UHI. Dense cities must turn to alternative methods of inserting vegetation and green spaces into their urban landscapes to receive similar benefits as the urban parks without sacrificing the land in their city, but it is a feat that is accomplished worldwide.

Even the densest cities on the planet, such as Singapore, have found methods to increase their vegetation despite not having a wealth of land to allocate towards parks, green spaces, and conservation lands (Uli, 2014). Singapore has done this by inserting vegetation wherever possible, from streetscapes and sidewalks to building facades and rooftops. This strategy is a concept known as “Pervasive Greenery” (Uli, 2014). This strategy works because of the effect that individual trees and isolated vegetations can have despite not being a part of an open space. If buildings are the insultation for cities, then vegetations are the natural air conditioner. Urban trees provide not only shade, but ecosystem services such as clean air, habitats for wildlife, wind breaks, and they absorb heat that otherwise would have been absorbed and reemitted by pavements (Pengyu Zhuab, 2008). Urban trees and forests are also positively correlated to land value according to a study done considering different forest types and regions across numerous cities in the United States (Pengyu Zhuab, 2008). A correlation to land values can be considered mostly positive when attempting to convince residents and city officials to implement urban tree programs; however, when land values increase, gentrification and displacement can occur.

In addition to urban trees, dense cities implementing Pervasive Greenery have used techniques that affix vegetation directly to buildings (Uli, 2014). This has taken different forms, but the two main forms are Green Roofs and Living Walls. These are both techniques that are less relevant to the scope of this study but are nonetheless important in the realm of UHI mitigation as we develop new and innovative strategies.

Section 2.2.2 – Cool Roofs

Cool roofs are a simple yet effective application of UHI mitigation concepts, specifically that of reflectivity and ease of implementation. Cool roofs generally consist of a special reflective paint that is applied directly to an existing roof scape (Junjing Yang, 2018). These roofs tend to be constructed from underperforming materials such as tar or asphalt, both of which absorb a large amount of solar radiation due to their dark nature (Junjing Yang, 2018). This issue with roofs can also effect the efficiency of a building, determining how much energy must be put towards climate control and facility operations. Cool roofs are a very particular strategy, but we can find the same concept of increasing the reflectivity of roofs and applying it to buildings with metal roofing material. Metal roofing by itself is a relatively reflective material; however, some metal roofs are painted or coated to be a specific color. Metal roofs of darker colors face the same challenges of asphalt and tar roofs whereas light, reflective metal roofs have some of the benefits of cool roofing.

EPDM is another roofing material with a split personality. It is an extremely durable rubber like material, and rubber by itself is not a supper reflective material. When EPDM roofing is used with dark coloring, almost like a pitch black, it absorbs almost all the solar radiation that hits it. It's not good. But light-colored EPDM materials, specifically white, reflect that solar radiation more than an aluminum metal roof. This makes it a very effective roofing material to increase building efficiency and reduce the impact of the UHI effect.

Section 2.2.3 – Pavements

When we think of hard surfaces, pavements such as roadways and sidewalks are the first thing that comes to mind. As such, it would make sense for this to be one of the most prevalent ways to mitigate UHIs. The foremost method regarding pavements would be to simply reduce the amount of paved area, but this is not always feasible. There are some unique ways to reduce the impact of UHIs while not necessarily reducing the amount of paved area. This concept mainly deals with the type of pavement chosen. Light concrete is significantly more reflective than a dark asphalt (Chenghao Wang, 2021). By choosing concrete roadways over asphalt roadways, there can be a significant improvement in UHI effect; however, this can be costly. Concrete roads have a more expensive upfront investment than asphalt roadways, but accounting for the lifespan of the roadways, concrete roads can be approximately 7% cheaper (Yeginobali, 2009). It's a tradeoff that must be considered in these situations, but concrete can also bring the benefit of durability depending on the road use.

While not usable in every case, pervious concrete is also a relatively new mitigation strategy that also helps with stormwater runoff. It is made of a porous material that reduces the actual density of the structure allowing for less heat radiation to be absorbed, and because of the construction in a kernel type fashion, it allows for water drainage (Wilson, 2004). These pavements are generally not suitable for high traffic roadways but can be useful in parking stalls within parking lots and on sidewalks (Chenghao Wang, 2021).

Section 2.3 – Benefits of Addressing Urban Heat Island Effect

Addressing the UHI effect in communities can impact people and sustainability in multiple ways. Frist and foremost is the aspect of thermal comfort. This is an indicator that dictates how people make decisions about what they do both indoors and outdoors (A. Mendes, 2014). For sustainability, such an indicator has implications for transportation, communal spaces, and some retail. Specifically on transportation, thermal comfort may dictate the amount of active transportation users, such as cycling or walking. This can impact the amount of road users and who those road users are, causing a shift towards more car traffic or more pedestrian traffic depending on the situation. Communal spaces that are outdoors, such as parks, are completely controlled by weather and climate. If there is low thermal comfort, the access to outdoor spaces becomes irrelevant if no one uses them. It's about sharing experiences with others and providing green spaces to escape to in urban locations. Finally, ground level retail is a necessity in a walkable community, but beyond that, it supports local economies (Grant, 2006). If there is an extremely low thermal comfort level, there could be a decrease in foot traffic causing losses for these ground level retail locations.

Another unique aspect of mitigating UHI effect is the positive impact it can have on other issues in the realm of sustainability. One such prevalent issue that has a large overlap with UHI mitigation strategies is stormwater management. Many of the mitigation strategies discussed in this literature review impact impervious surfaces. This is the basis of stormwater management; reduce the amount of impervious surface area (Wilson, 2004). It stands to reason that if one of these areas is mitigated it causes an extraneous, positive effect on the other; however, this is an area that would require further research beyond the scope of this study.

Finally, it appears that some mitigation strategies increase the land value of nearby properties. This can be both a good thing or a bad thing depending on how mitigation strategies are implemented. This is not true of all mitigation strategies. The specific mitigation strategy with the most evidence for this land value phenomenon is that of street trees and urban forests. A study carried out across the United States linked demand for urban forests to higher income populations (Pengyu Zhuab, 2008). It wasn't just demand though. It was true of supply. A greater supply of urban forests was connected to higher income populations (Pengyu Zhuab, 2008). "As the status of urban forest is a good indicator of urban environmental quality, higher income populations afford the expense of alternative land use, planting and maintaining of urban trees" (Pengyu Zhuab, 2008). It stands to reason from the conclusions of Zhuab and Zhanga that an increase in urban forestry could raise land values, but it is more likely that an increase in land values and economic standing is what causes the increase in urban forestry, not the other way around. There is still something to be said about this correlation and it would be beneficial to see more research done on this topic outside of urban forests and on other mitigation strategies as well.

What these benefits show is just how ingrained UHI effect as a concept is in the realm of sustainability. It reaches cultural impact, environmental well-being, and the economy. Implementing mitigation strategies is more than just about UHIs. It has unintended consequences outside of its purview, but these consequences are beneficial in almost every case.

Section 2.4 – Research Overview

Section 2.4.1 – Framework

It has become clear that the main cause of UHI effect is linked to the reflectivity of surfaces and the abundance of surfaces. If a surface is reflective, then its contribution to UHI effect is less. It could then be determined that if an overall site is more reflective, the same is true. As such, the key indicator of UHI that can be used to operationalize the study is solar reflectivity. Solar reflectivity can then be used to compare the effectiveness of mitigation strategies and apply those strategies to the study site.

Section 2.4.2 – Research Objectives

The main problem being addressed in this study is simply an UHI audit of the University of Florida planning A sector; however, this is not the sole purpose of this study. The audit includes a portion that applies the mitigation strategies that were discussed in this literature review to the site itself. Those results will make it possible to discuss the implications of the UHI audit at this specific site to sites around the world, specifically applying the lessons that are derived from the study. As such, the key objectives of this study are:

- Evaluate the current conditions of the urban heat island effect in the A planning sector of the University of Florida campus by completing an urban heat island audit of the planning sector.
- Practically consider improvements or urban heat island effect mitigation strategies that could be applied to the planning sector based on the results of the urban heat island audit before theoretically applying them to the results of the urban heat island audit.
- From the urban heat island audit results and the theoretical application of mitigation strategies, form conclusions that demonstrate how concepts of urban heat island can be applied to other communities around the world.
- Conduct the urban heat island audit in a way that a community member might replicate for their own community.

Section 3 – Methodology

Keeping in mind the lessons learned from the Literature Review, this study conducted an UHI audit of Planning Sector A (Figure 3.1) of the University of Florida (University of Florida, 2020). The University of Florida is located within the city of Gainesville in North-Central Florida. This sector is mostly flat with a wide array of land uses. The site is bordered by Southwest 34th Street to the West, Southwest 2nd Ave to the North, Museum Road and Mowry Road to the East, and Archer Road to the South, with some exceptions. The Northern most area contains the University of Florida golf courses. The main segment of the site contains Southwest

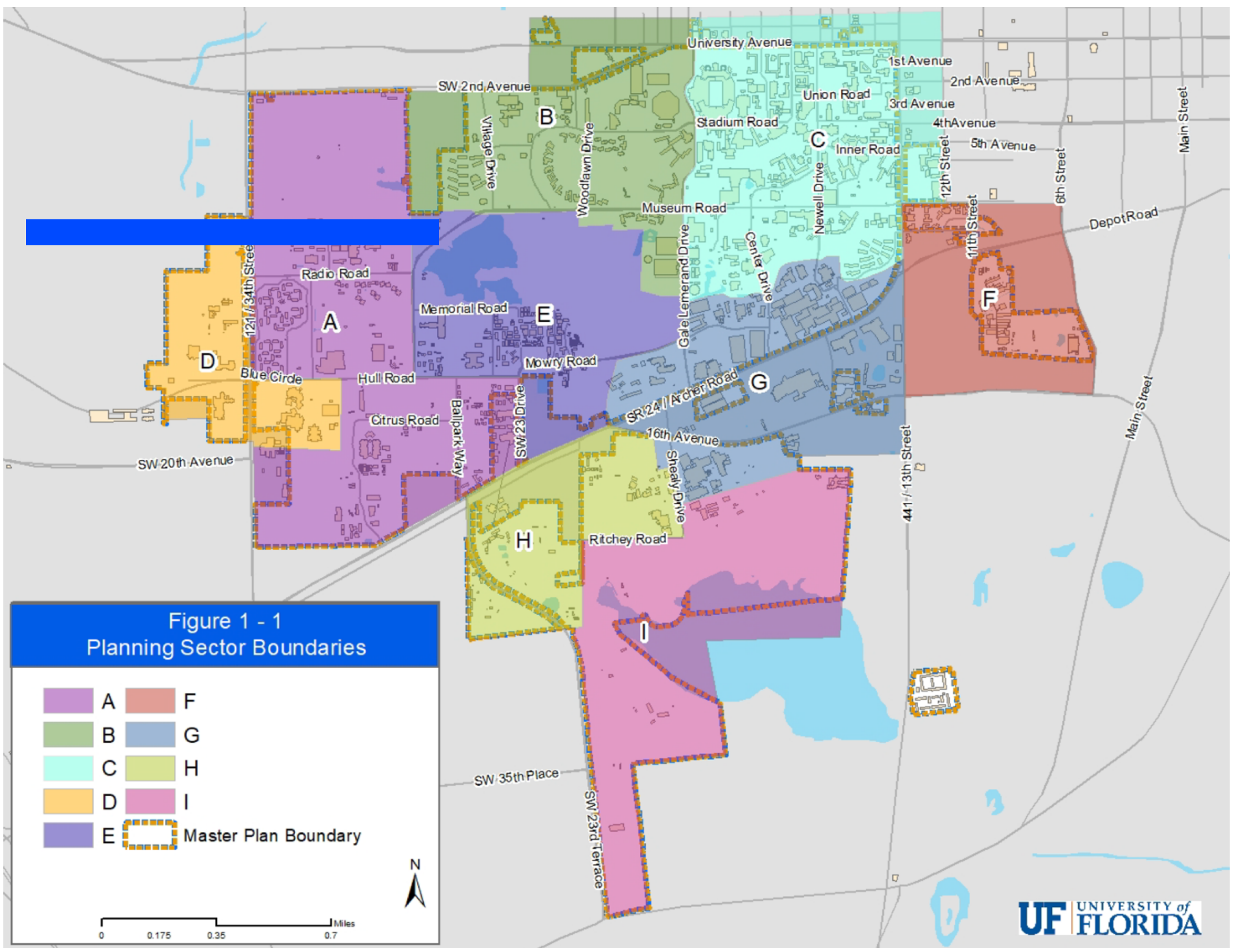

Figure 3.1
University of Florida Master Planning Sector Boundaries

Source: (University of Florida, 2020)

Recreation Complex, Maguire Village Family Housing Complex, UF Counseling and Wellness Center, Document Services, Motor Pool, and the Lakeside Housing Complex. On the Eastern side, there are several UF Institute of Food and Agricultural Sciences fields and greenhouses. Additional facilities of note are the Dizney Stadium, Katie Seashole Pressly Stadium, and Florida Ballpark.

Figure 3.2
Site Study Area
Blue = Study Area, Orange = Omitted Area

Source: (Google, 2022)

Average temperatures for the area have been taken from the city of Gainesville, Fl, where the site is located. Average highs reach 80 degrees Fahrenheit and lows reach 55 degrees Fahrenheit during the Spring, the season that this study is taking place in (U.S. Climate Data, 2022). While there are many factors that contribute to UHIs, the main focus is that of exposed surfaces such as parking lots, roofs, playing surfaces, etc. Due to ongoing construction projects at the time of imaging, the following surfaces have been omitted from the study: Florida Ballpark, Ballpark Way road extension. Figure 3.2 shows the omitted areas. Surfaces were measured using Google Earth and those measurements were categorized by their construction material. The surface type categories that were used are:

- White Cement Concrete
- Asphalt Concrete
- Gray Cement Concrete
- Tennis Court (Dark Concrete)

- Sand/Gravel
- Tar/Asphalt Roof
- White EPDM Roof
- Clay
- Light Metal Roof
- Colored Metal Roof (Dark)
- Black EPDM Roof
- Field/Grass
- Forest & Tree Canopy
- Water

Based on these categories, a Solar Reflectivity Index (SRI) value was assigned based on Table 3.1. Although the SRI is not a perfect measure of UHIs, the two concepts of solar reflectivity and UHI effect are clearly correlated as I discussed in the literature review. For this reason, solar reflectivity was used as a proxy to the UHI effect.

Table 3.1 – Solar Reflectivity by Surface Type Category

Category ID	Surface Type Category Description	Solar Reflectivity Index (SRI)
0	White Cement Concrete	0.35
1	Asphalt Concrete	0.10
2	Gray Cement Concrete	0.18
3	Tennis Court/Dark Concrete	0.00
4	Sand/Gravel	1.00
5	Tar/Asphalt Roof	0.01
6	White EPDM Roof	0.84
7	Clay	0.00
8	Light Metal Roof	0.50
9	Colored Metal Roof (Dark)	0.37
10	Black EPDM Roof	-0.01
11	Field/Grass	1.00
12	Urban Forest & Tree Canopy	1.00
13	Water	0.10

Source: (USGBC, 2015) (U.S. Climate Data, 2022) (OPTM, n.d.)

The SRI values were determined through various sources, including the United States Green Building Council. The corresponding SRI value was then multiplied against its category to standardize the SRI by land area. This ensures that the SRI values are weighted according to the surface area size within the overall site averaging calculations. This process is outlined in the equation below, where *a* is equal to the surface area, *S* is equal to the properly assigned and categorized SRI value, and *r* is the resulting reflectivity average score for the surface type.

$$a * S = r$$

This score is not the final result. All of the *r* scores were then added together and divided by the total area of the study site. The equation below builds on the previous equation, where *r* is still the result of the previous equation, but the subscript refers to the surface category id (see table 3.1), *t* is the total land area of the site, and *R* is the resulting total site reflectivity score average.

$$\frac{\sum_{i=1}^{13} r}{t} = R$$

The SRIs were compared with each other, and the overall covered area was calculated into a percentage that could then be a control point for making improvements to the area. This data was then manipulated to simulate the implementation of various mitigation strategies, namely the implementation of street trees which would result in a doubling of the current tree canopy (not urban forests) and the implementation of white EPDM roofing material across all the current tar and asphalt roofs in the planning sector. To accomplish this theoretical manipulation of the mitigation strategies, the land areas were simply altered or changed categories to accommodate for the calculations.

After the calculations were completed, an in-person visit to the site was conducted. This visit consisted of comparing the quantitative results of this methodology to subjective experience in the planning A sector of campus. This was done to address the thermal comfort aspect of the UHI effect and ensure logically consistency between the study results and the “real life” conditions of the site. The visit was completed on April 12th, 2022 at approximately 3:00pm. The results and implications of the site visit will be discussed together in the Discussion section, not the results section.

Section 4 – Results

The detailed surface measurements have been organized into Table A.1 in Appendix A. Table 4.1 shows those detailed measurements consolidated and coded into surface type categories with a corresponding SRI value.

Table 4.1 – Surface Area by Category

Category ID	**Surface Type Category Description**	**Area**	
		Square Feet (sq ft)	**Acres (ac)**
0	White Cement Concrete	1,661,569	38.14
1	Asphalt Concrete	1,740,791	39.96
2	Gray Cement Concrete	61,657	1.42
3	Tennis Court/Dark Concrete	61,975	1.42
4	Sand/Gravel	142,087	3.26
5	Tar/Asphalt Roof	698,806	16.04
6	White EPDM Roof	24,949	0.57
7	Clay	92,351	2.12
8	Light Metal Roof	279,705	6.42
9	Colored Metal Roof (Dark)	36,885	0.85
10	Black EPDM Roof	18,998	0.44
11	Field/Grass	9,469,746	217.40
12	Urban Forest & Tree Canopy	4,427,233	101.64
13	Water	61,993	1.42

The surface categories were also used to construct an overview of surface areas by percentage of land cover. It should be noted that the total coverage percentage is over 100%. This is due to the counting of tree canopy which overlaps other surface areas. For the purpose of these calculations, tree canopy was not considered, but urban forest was to ensure that the land coverage percentages were properly accounted for. Table 4.2 breaks down these calculations and Figure 4.1 visualizes the results.

Table 4.2 – Land Area Percentages by Surface Type Category

Category ID	Surface Type Category Description	Total Area (ac)	Percent of Site
0	White Cement Concrete	38.14	9.22%
1	Asphalt Concrete	39.96	9.66%
2	Gray Cement Concrete	1.42	0.34%
3	Tennis Court	1.42	0.34%
4	Sand/Gravel	3.26	0.79%
5	Tar/Asphalt Roof	16.04	3.88%
6	White EPDM Roof	0.57	0.14%
7	Clay	2.12	0.51%
8	Light Metal Roof	6.42	1.55%
9	Colored Metal Roof	0.85	0.20%
10	Black EPDM Roof	0.44	0.11%
11	Field/Grass	217.40	52.57%
12	Forest/Canopy	101.64	24.58%
13	Water	1.42	0.34%
	Total Surface Coverage Area (ac)	431.10	104.26%
	Total Site Area	**413.50**	**100%**
12	Tree Canopy	16.94	104.26% - 4.10% = 100.16%

Note the excess of 100% in surface area coverage. This approximate 4% excess is due to the double counting of surfaces when calculating tree canopy (not urban forests). When discussing surface type coverages, this 4% will not be considered.

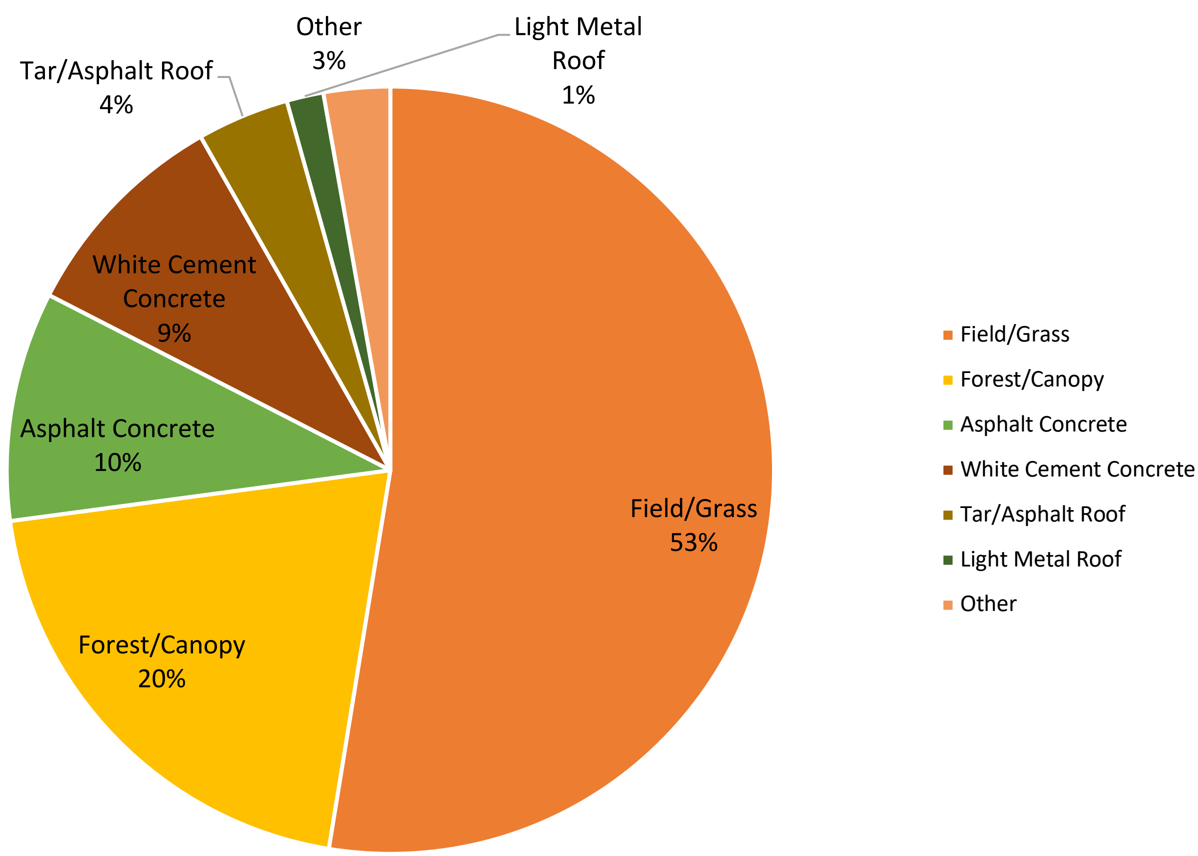

Figure 4.1
Land Area Percentages by Surface Type Category

Table 4.3 shows the completed SRI average calculations, which yielded an average SRI of 0.83, or 83% reflective, for the entire site. Tree canopy was added back in and considered for the SRI calculations.

Table 4.3 – Total Average Site SRI

Category ID	**Surface Type Category Description**	**Total Area (ac)**	**SRI**	**SRI by Ac (ac * SRI)**
0	White Cement Concrete	38.14	0.35	13.35
1	Asphalt Concrete	39.96	0.10	4.00
2	Gray Cement Concrete	1.42	0.18	0.25
3	Tennis Court	1.42	0.00	0.00
4	Sand/Gravel	3.26	1.00	3.26
5	Tar/Asphalt Roof	16.04	0.01	0.16
6	White EPDM Roof	0.57	0.84	0.48
7	Clay	2.12	0.00	0.00
8	Light Metal Roof	6.42	0.50	3.21
9	Colored Metal Roof	0.85	0.37	0.31
10	Black EPDM Roof	0.44	-0.01	0.00
11	Field/Grass	217.40	1.00	217.40
12	Forest/Canopy	101.64	1.00	101.64
13	Water	1.42	0.10	0.14

Total SRI	344
Divided by Total ac	431
Total Average Site SRI (Total SRI/Total ac)	**0.83**

Refer to Section 3, Methodology for an example of the full equation used.

Table 4.4 shows the manipulated data to simulate the implementation of the mitigation strategies. The manipulated data is highlighted. Following the theoretical implementation of the mitigation strategies, the new site SRI average was 0.91, or 91% reflective.

Table 4.4 – Theoretical Application of Mitigation Strategies Results

Category ID	Surface Type Category Description	Total Area (ac)	SRI	SRI by Ac (ac * SRI)
0	White Cement Concrete	38.14	0.35	13.35
1	Asphalt Concrete	39.96	0.10	4.00
2	Gray Cement Concrete	1.42	0.18	0.25
3	Tennis Court	1.42	0.00	0.00
4	Sand/Gravel	3.26	1.00	3.26
5	Tar/Asphalt Roof	0.00 (-)	0.01	0.00
6	White EPDM Roof	16.62 (+)	0.84	13.96
7	Clay	2.12	0.00	0.00
8	Light Metal Roof	6.42	0.50	3.21
9	Colored Metal Roof	0.85	0.37	0.31
10	Black EPDM Roof	0.44	-0.01	0.00
11	Field/Grass	217.40	1.00	217.40
12	Forest/Canopy	118.57 (+)	1.00	118.57
13	Water	1.42	0.10	0.14

Total SRI	374.45
Divided by Total ac	431
Total Average Site SRI (Total SRI/Total ac)	**0.91**

Orange notes the removal of surface area. Green notes an addition of surface area.

Section 5 – Discussion

Section 5.1 – Quantitative Findings

Overall, the A planning sector of campus carries a diverse and unique set of land uses that make it difficult to analyze. It is suburban in nature, but a majority of the sector is used by recreational facilities, such as the golf courses or sports fields, which are open fields that are not necessarily contributing to UHI effect. These fields and open space make up approximately 52% of the planning sector. While fields do not necessarily contribute to UHI effect, they don’t help either. The sports fields within the site are clustered together resulting in large spans of land area without any shade or trees. One of the sports fields was later discovered to be an Artificial Turf material during the site visit which does decrease the true reflectivity result presented in this study; however, this change is believed to be minimal. Regardless, sports fields present the issue of not only hot spots, but also maintenance which often includes heavy water use and fertilizers which can cause another host of issues for sustainability.

There is generally a generous tree canopy with over 20% of the land being categorized as urban forest another 4% of additional tree canopy over other surfaces compared to the 25% of the land being hard surfaces of any kind. That is an approximate 3:1 ratio of natural and permeable surfaces to hard surfaces. This could easily be an even better ratio if the buildings and complexes present were organized in a more efficient land pattern. For example, Maguire Village, the family housing complex, is an apartment style set-up, but with over 24 separate buildings each containing only a few apartments. If these buildings had been consolidated into a denser fashion, the surface area, and therefore urban heat island impact, could have been reduced.

While hard surfaces only accounted for 25% of the land area, there is a lot of room for improvement. Only one building in the entire planning sector had a section of white EPDM roofing material. Approximately 26% of the buildings had metal roofs, but of this, only half were non-colored metal roofs that have a higher reflectivity rate than those that are colored. Most of the asphalt roadways in the imaging were on the light side; however, these roads are in the process of being repaved which will darken the asphalt coloring and reduce reflectivity. Many materials present did not have high solar reflectivity; however, there weren't a lot of hard surfaces to begin with which does benefit UHIs. There are many improvements that could be made not just to benefit UHIs, but also the thermal comfort of pedestrians, residents, and athletes in the area. While there is room for improvement when it comes to structures, and the land could have been laid out in a denser configuration that preserved more forest space, the nature of the land uses makes the contribution to UHI effect minimal.

Section 5.2 – Qualitative Findings

The site visit took place at the hottest part of the day, 3:00pm on April 12th. The recorded high temperature that day was 84 degrees Fahrenheit (NOAA, 2022). Additionally, there was little to no cloud cover. Before visiting the site, I had already completed the calculations for the quantitative portion of the study, which gave me a rather positive outlook on the site's conditions regarding UHI effect; however, this was quickly swayed. I conducted the visit via bike, including some segments of walking. This was to help judge the overall thermal comfort of the site and how it may affect site users' decisions of transportation and facility use. Newer developments, including the Florida Ballpark, were considered in this portion of the study.

While I was aware that imaging would be limited or outdated, the site visit exposed the true extent of this. Many roadways that appeared to be lighter in color on the imaging, but it was clear that these surfaces had recently been repaved, resulting in a darker asphalt (Figure 5.1). Despite this, there were still some roads in disrepair, with many potholes and rough surfaces (Figure 5.2). These roads appear that they will be repaved soon to compensate for their current state. This would further increase the effect on UHI. The new

Figure 5.1
Comparison of New to Old Asphalt
Red = New Asphalt, Yellow = Old Asphalt

developments, including outside of Southwest Recreation Complex and the Florida Ballpark, had new concrete that was bright and reflective. It was reflective to a point that required pedestrians to squint or wear sunglasses while walking on it.

Figure 5.2
Current State of Bledose Drive

Though these surfaces were reflective, the pathways and roadways have little tree cover, despite a decent amount of urban forest land; yet the quantitative data shows a sizeable amount of tree canopy. This is because the tree canopy does not overlap with the roadways and sidewalks as much as it can. This isn't to say there are not street trees in the site. Figure 5.3 shows an example of some of these street trees. Despite this, sports fields clearly had a lack of tree cover around the perimeters. This was discovered within the quantitative portion of the study as well. The effect of this was more apparent during the site visit, especially due to the lack of cloud cover in the sky. Putting UHIs to the side, if there are athletes using these facilities, it quickly became clear that there were not sufficient areas to rest in the shade. This was also true of the agricultural fields. This was in stark contrast to some areas of the site that had an abundance of tree cover.

A great example of what works well in terms of tree canopy was near Maguire Village Family Complex on the corner of Radio Road and Bledose Drive (Figure 5.4). The area is far from being an urban forest, but it contained a collection of trees, strategically located, and spaced to avoid the creation of an underbrush in a carefully manicured area. These trees were of varying ages and varieties, but they created a sense of seclusion from the heat and acted as a sort of microclimate. Even outside of the direct shade, my thermal comfort increased. This phenomenon also was clearly illustrated while biking along Lake Alice. This is not a part of the study area, but it was necessary to bike this route while traveling between the Northern and Southern portions of the site. It became clear that the intrinsic value associated with bodies of water can immediately increase thermal comfort. The large body of water allowed for the creation of a cool breeze. While there was a breeze present in the site, the temperature of the breeze was not as cool.

Figure 5.3
Museum Road Street Trees

Notice the lack of street trees except for the small collection in the median.

Figure 5.4
Collection of Trees at Radio Road

What became clear from the results of this site visit was the difference between thermal comfort and UHI effect. UHI effect is a clear and measurable phenomenon while thermal comfort is a concept that is more subjective to the individual. Additionally, there were several areas for improvement that were not previously known from the quantitative study. This is especially true of the new construction areas. I find this ironic that the new developments were lacking in mitigation strategies more so than pre-existing developments. It isn't for a lack of age either. While trees do take time to mature and develop to create a canopy that can significantly mitigate UHI and improve thermal comfort, there weren't even saplings planted in many locations to develop into the future.

Roadway design was another area that was lacking and could be improved. Traditional roadways would have one lane in each direction, as all roadways in this site have at minimum; however, some roadways in the site do not warrant such a width and could be transitioned into a service drive. Despite this, they have been expanding and restricting many roadways in the site, such as Ballpark Way and Hull Road. While minor, these observations from the site visit gave worthwhile context to the previously established solar reflectivity score of 83%. The score alone is not enough to contextualize the true UHI effect, nor is the site visit by itself. The two work in conjunction to paint a true picture of a somewhat well performing site in relation to UHIs despite its downfalls in thermal comfort and newer developments. It shows clear and attainable improvements that can be made.

Section 5.3 – Strategies to Implement

There are a few clear areas for improvement that have already been discussed, but I believe are worth exploring in more depth. Before diving into specifics, it is important to recognize the overall urban design, land uses, and layout of the site. While the site is mostly pervious surfaces, the impervious surfaces that do exist are poorly arranged. There are several complexes, such as Maguire Village Family Complex, Lakeside Housing Complex, and the UF facilities area. These developments were constructed with suburban like styles and layouts instead of more urban designs. If these complexes were consolidated into denser land use patterns, there would be significantly less impervious surface area on the site. This would help curb UHI effect and open new lands for future development.

An additional oddity with the planning sector is the large grouping of sports fields and playing surfaces. There are over 10 unique playing fields on the site, excluding the golf courses. These playing surfaces and open spaces account for nearly 50% of the site – areas that could be composed of urban forestry. I don’t want to discount the benefit that recreation spaces bring to residents and students, but it does appear like an excessive number of fields grouped into one area. These fields could be spread out into other planning sectors of campus to make recreation facilities more accessible and reducing the amount of space taken up by the fields in the A planning sector. It should also be considered that the university may not need three sperate baseball fields and a cricket pitch to be used simultaneously at one time. In this case, they could be consolidated and not even relocated. Those baseball fields are in addition to the Florida Ballpark stadium and the Softball Stadium also within the sector. There is more to be said about having open, general use fields being used simultaneously, but in this case, there are still several fields of this type in the planning sector.

The golf courses are also an interesting land use. While the layout is rather efficient and allows for several trees, sand traps, and a water feature, it is a questionable if this is the best use for this land. While recreation fields are used by most able-bodied residents and students, golf courses have an additional barrier to entry for most users, whether that be an entrance fee, required equipment, or skill and interest. All these facilities and land uses could be reevaluated to better serve the university and community, become a more friendly destination for students, and reduce the impact of UHI effect. Urban design in itself seems to be a major impact of the UHI effect and as such should be paid greater attention in future developments, both in this area and in communities worldwide. This strategy is the simplest in concept. Reduce the affect of UHIs by reducing the amount of impacted space. The issue is that this is a strategy that must be applied on the front end of development creation, but there are multiple strategies that can be applied on the back end of developments once issues begin to emerge or for older developments that were constructed insufficiently for UHIs. Strategies that attack the mitigation of UHIs generally focus on altering existing surfaces.

The first surfaces to pay attention to are roofs. While roofs make up a minority of the site surface area, they are some of the most exposed surfaces to the sun and impact the efficiency of building operations. The site featured many metal roofs, which tend to be reflective and good at mitigating UHI effect, but a majority of metal roofs were colored in a dark tone (blue, red, green). These colored metal roofs don’t reflect sunlight as well as non-colored, metallic roofs. This isn’t a matter of cost or building design. It is a matter of atheistic choices. The buildings with colored metal roofs are primarily the softball stadium and golf course facilities. The more utilitarian buildings located near facilities services generally use plain metal. As such, there is no reason why, at minimum, a lighter colored roof cannot be used (such as white). It is possible that the roof pitches lend to reflection of sunlight into driver and pedestrian eyesight, in which case there is an argument to be made for the colored roofs.

Regarding the rest of the roofs in the site, they are mostly tar or asphalt surfaces. Only one white EPDM roof exists, and it is located on the newly extended portion of the Southwest Recreation Complex building. EPDM is a rubber like material that can reflect sunlight very well if it’s a light color, but if the EPDM is a dark color, it can absorb sunlight more than a tar roof. A few roofs in the site have black EPDM roofing. This roofing should be considered for replacement with white EPDM to increase building efficiency in addition to improving the UHI effect. Tar and asphalt roofs could also be considered for this treatment, but their impact is less drastic than the black EPDM. If it’s deemed infeasible, the tar and asphalt roofs could be improved by using cool roof paint, which would significantly increase the reflectivity of the surface and building efficiency.

A final mitigation strategy that was not explored in-depth in the literature review, but may be worth more research, is the installment of photovoltaic solar panels on the roofs, specifically the Southwest Recreation Complex as it has an expansive roof space. This is a strategy that would have less benefit when implemented on smaller roofs. One aspect to keep in mind with all of these surfaces is that there is an extraneous variable of cleanliness. Light surfaces reflect sunlight better, but light surfaces also get dirty over time which darkness the surface and causes the reflectivity to become less effective. This can easily be controlled by maintenance of surfaces. This may look like pressure washing concrete every three years or repainting cool roof paint every three years to ensure reflectivity is kept at its most efficient level (USGBC, 2015). This issue becomes less apparent with the next mitigation strategy that could be implemented on the site.

Vegetation offers a unique way to mitigate UHI effect at a small investment. As discussed in the quantitative section, there is plenty of urban forest land in the study area. What is lacking is urban tree canopy, particularly along roadways and recreational fields. Some roadways do contain street canopies, but they are minimal at best. My number one suggestion is to add more street trees. This will take time to fully implement as tree canopies take time to develop, but in the long run, it will make a large difference. I'd recommend this treatment along the exterior of recreation fields as well. It's not possible to have tree canopies in the middle of recreational fields but providing canopies on the perimeters helps mitigate UHIs and provides a shaded location for on-lookers and athletes to rest. Vegetation isn't just trees either.

A great example of low-lying vegetation is the rain garden in front of the Southwest Recreation Complex. This method of stormwater management can be brought to other swales and drainage systems around the site that are currently just open grass. This can serve two purposes: (1) to better manage and filter stormwater runoff and (2) to provide more ground vegetation that is better equipped to deal with sunlight radiation than just grass. Seeing these vegetation strategies implemented throughout the study area would truly transform the site from what feels like a sprawling suburban development to a walkable, park like setting without even altering the land uses or reconsolidating current buildings. It would allow for an increase in thermal comfort above what the surface mitigation strategies allow in addition to improving the UHI effect. It could bring with it broad implications of how students and community members use the site, making individual complexes not the destination, but the site as a whole a destination within itself.

One last mitigation strategy that could be worth exploring is a hybrid between vegetation and roofing surfaces: green roofs. Green roofs offer a unique opportunity to filter water, increase building efficiency, combat UHIs, and much more. Because of the sites pre-existing relationship with the UF Institute of Food and Agricultural Sciences, these green roofs could be more than green roofs, but also garden roofs that can function as an extension of the teaching garden facility located within the planning sector. The largest limitation to this implementation strategy is roof size. There are some buildings within the sector that have expansive roof space, such as the Southwest Recreation Complex, which could be both positive and negative for green roofs. Additionally, there are medium and smaller roofs which may be better suited for the scale of green roof being proposed. This specific mitigation strategy would require more research into the specifics of each individual building structure and site to determine suitability.

Section 5.4 – Theoretical Implementation Results

As discussed in the methodology and results sections, two mitigation strategies were applied to the original data from the study. Table 4.4 shows these results. The mitigation strategies implemented were a doubling of the urban tree canopy and a switching of all tar/asphalt roofs to white EPDM materials. There was a clear improvement shown in the results, an eight-point jump. It shows that these mitigation strategies do influence solar reflectivity, and therefore an effect on UHIs. The question that arises is, is the improvement worth the effort? To answer this question fully would require research outside the scope of this study; however, from an intrinsic value alone, my answer is yes. In fact, this question wouldn't even be a question if this eight-point increase in solar reflectivity occurred from a 52% to 60% increase. It would be clear that improvement is needed because of the poor conditions from the start. In a site that has decent conditions, it becomes a topic for debate. What impact does that eight-point increase have? Does it have more impact on a site with worse starting conditions than a site with good conditions? Is it an exponential function? are all questions worth asking in future research.

UHI aside, I think these improvements still benefit the site. Tree canopy provides more than UHI mitigation, but it allows for an increase in walkability and pedestrian comfort. Roof material can impact the efficiency of a building regardless of how bad the UHI effect is. As such, it can be easily determined that these improvements are worth making regardless of the UHI effect. It's when UHI effect is used as a justification for these improvements that we begin to ask the question, is it worth it? I believe the answer is yes, but further research is required to truly determine the answer.

Section 5.5 – Applying This Study Worldwide

While this study focuses on the University of Florida campus, one of its purposes is to draw conclusions of how we might take what is learned and apply it to other communities. Mitigation strategies are one key element of this, but I want to take a moment to focus on the process of UHI audits and the importance of both a quantitative and qualitative experience. If one thing has become clear throughout this study, it is the relationship of those two data types. If a resident believes that their community can be doing better with UHIs, it's necessary to define the current conditions of the site, otherwise, how can one know if the community has truly improved? The baseline must be measured. This also allows for the filtering of biases. The qualitative aspect of the study admits bias, but it isn't overpowering. A resident cannot just claim that UHI is bad in their community, they must go out and experience it and take notes of obviously lacking areas. The quantitative analysis forces residents and the researcher to consider things they may have missed. Maybe it's a matter of not accounting for the whole community, but only a small portion that a resident experiences daily. It forces the view of a larger picture.

Once this baseline is set, then the discussion of improvements can be had. It can be very similar to what has been discussed in this study. Talk about the observations and address the largest issues. Begin a dialogue with community leaders and planners. The mitigation strategies outlined here have a common theme that is likely to be seen in other communities: urban form and urban design. The layout of cities and density is an important factor. Different land uses require different facilities, each of which has a different impact on the environment and UHI effect. Even surface types and vegetation are, in a sense, a part of urban form and are impacted by development patterns. The best way to apply this study in communities across the world is not mitigation, but rather prevention. Similar to this study, UHI audit results can highlight the shortcomings of our current land use practices and what they allow to be constructed and developed. This is where meaningful changes can be made.

While this study does not highlight nor explore the specifics of this relationship, I will be conducting further research on this topic next year during my graduate thesis research project. Other mitigation strategies do help, but if we want to create truly sustainable communities, we should be implementing strategies like the altering of land use development patterns before we even construct our communities. However, this is not possible in many cases. Whether it be the age or historical significance of an area, or if the altering of land use patterns is not feasible, the simple mitigation strategies of reducing pavements, increasing reflectivity, and increasing vegetation can all make a difference.

Section 5.6 – Limitations

There are several limitations that became clear through the course of this study and during the study analysis. First, Google Earth is not a perfect measurement system. Whether it be an issue with the program or user error, the software does not provide 100% accurate measurements of land areas; however, the purpose of this study is to gain a general sense of the relationships of UHIs and complete an audit of the planning A sector of the University of Florida campus. For these uses, Google Earth provided accurate enough measurements to approximate the land areas. For this reason, it should be noted that the measurements recorded may not be accurate and should not be reused in any manner that requires a minimum level of confidence and accuracy for statistical analysis or development plans. A quality control system could have been implemented by comparing land surveys to the recorded measurements from Google Earth, but this would have required access to surveys of the area and an extensive increase in the time frame of the study. It was deemed unnecessary for the scope of work being completed.

Google Earth also introduced the challenge of dated imaging. This was the main case for not being able to include the new Florida Ballpark in the study, which I believe would have been beneficial. Unfortunately, this is an issue that would have been encountered on any mapping software, including ArcGIS due to the recency of the ballpark's construction. Regardless of the ballpark, there were many discrepancies found during the site visit, after the calculations had been completed. The main one being the presence of an artificial turf field were the imaging showed a natural turf surface. The difference is not believed to be significant, but other instances of small discrepancies, such as the shade of the asphalt and the existence of a roundabout at Radio Road and Museum Road were also discovered.

Second, the study site was a limited size and location. The A planning sector is very different in nature from other University of Florida planning sectors, making it difficult to draw assumptions about the entire UF campus. As such, the study did not make any assumptions of other planning sectors. It was beneficial, however, to view this specific site as it allowed for a large variety in land uses and development patterns. The limited site size could be solved by implementing a random sampling process to review specific land parcels rather than full planning sectors. This would allow for a more representative sample of the campus while still being feasible to complete.

Third, as mentioned many times already, SRI is not a perfect measurement of the UHI effect, and it only acts as a proxy. This specific indicator was chosen due to a lack of temperature data at fine grain enough detail; however, it may have been a good idea to cross check the location and concentration of surfaces with temperature data. Additionally, no qualitative data was collected. This was remedied by the late addition of a site visit to the course of this study, but it contained subjective conclusions from one individual (myself) with preconceived notions about the site. Thermal comfort data would have been a beneficial addition to supplement my own experiences and the solar reflectivity data. This could have been collected in a series of interviews or in a questionnaire distributed to users of the site.

Lastly, all the mitigation strategies discussed were not theoretically applied to the site. I chose a select few that I believed would be a reasonable response from the University of Florida. Additionally, of those mitigation strategies that were applies, it was still theoretical application. Site conditions change overtime in a way that calculations cannot account for. It is also likely that the mitigation strategies would have been implemented over a long period of time, especially the doubling of tree cover as it takes time for tree canopies to develop. There isn't necessarily a better system for accomplishing this theoretical application due to my chosen methodology. If I were to redo this study, I would start by creating measurements in ArcGIS by saving polygons in a feature layer. This would allow for a more organized approach to analysis, more reliable data, and open the door to more analysis tools.

Section 5.7 – Future Research

I have briefly mentioned future areas of research that are needed while discussing the results of this study, but I believe it to be beneficial to clarify these topics of future research. First, what is the true effect of improving solar reflectivity on UHI effect? As in, how much does a percentage increase in reflectivity help reduce the UHI effect? While I explored how mitigation strategies can clearly improve solar reflectivity, and therefore theoretically UHI effect, it is unclear to what magnitude that improvement looks like. It is difficult to determine what benefit the improvement of solar reflectivity has because of this. This is a topic that should be explored in future studies

Second is the issue of land use and is a topic I plan to carry out further research in. I did not come into this study expecting the common theme to be urban form and land use. It was only after carrying out the methodology that the concept began to reveal itself. I slowly began seeing the swaths of large surface areas inefficiently designed, but it was in analysis that it truly became apparent. The scope that urban design plays in UHIs seems to be rather large, and it's not a question of what, but a question of why? Why are urban spaces allowed to be designed in a way that encourages heat islands to form? What regulations are contributing to this? Can we leverage those regulations in a positive direction? Or maybe, there isn't as strong of a correlation between urban form and UHI effect as I have suggest here. I won't know until that research is carried out. This will be the basis of my Graduate Thesis Research Project over the course of the next year.

Section 6 – Conclusion and Summary of Findings

This study has highlight numerous overarching themes for the UHI effect across the University of Florida A planning sector. This was accomplished by measuring impervious surface areas and considering the solar reflectivity of those surfaces. Solar reflectivity, while not a perfect measurement, is correlated to the UHI effect and therefore works as close enough proxy for the purposes of this study (Krarti, 2018). This resulted in the discovery that the study site is 83% reflective. It was then determined how UHI mitigation strategies could be applied to improve the site's reflectivity, and this is where the unexpected lessons in urban design surfaced. It became clear that urban design of sites highly impacts the UHI through various means, such as density, impervious surface area, land use, vegetation, and more. When these mitigation strategies were theoretically applied to the site, it showed an increase of 8% to a total site reflectivity score of 91%. While 83% is not bad, 91% is better and could impact energy efficiency in buildings, storm water runoff, site-user interaction, and more in addition to the UHI effect. However, that's not the full picture.

A site visit was conducted to supplement the lack of qualitative data in this study, and it was found that the general thermal comfort of the site still lacked in many locations despite an overall high reflectivity score. The site visit supported the further discussion of the mitigation strategies. This discussion of mitigation strategies yielded a dialogue outside of the boundaries of the study area and into the wider realm of urban design practices worldwide. The question quickly became less about how we apply these mitigation strategies and more about the imbedded deficiency in urban design we see today. It's something that applies to every community in addition to the University of Florida. The urban design of the study site was a key area for improvement.

It must be considered that this study is about applying these findings in other communities outside of the university, including how to conduct an UHI audit. Because UHI is something that impacts everyone. The issue is individual mitigation won't have nearly the same effect as large scale changes to urban design in our communities. This study highlights how a resident could start to outline these changes with their city officials and planners. It's a matter of asking where we are and where are we going before saying how we'll get there. This is how we address UHI effect in an efficient and positive way. If left unchecked, it will continue to spread uncontrollably. We cannot let the plague that impacts people's health, their use of outdoor spaces, and the economy to continue. Now is the time to act before it becomes too large a task for some communities to address. Now is the time to put forth the research accomplished here, but more importantly, the hundreds of studies on UHI effect, of which only a small fraction were explored here. It can no longer be ignored. It's time to change your community for the better.

References

A. Mendes, J. T. (2014). Sick Building Syndrome. *Encyclopedia of Toxicology*, 256-260.

BuildingGreen. (1998, August 1). *Study of Urban Forests' Effect*. Retrieved from BuildingGreen: https://www.buildinggreen.com/newsbrief/study-urban-forests-effect

Chenghao Wang, e. a. (2021). Cool pavements for urban heat island mitigation: A synthetic review. *Renewable and Sustainable Energy Reviews*.

D.M. Senevirathne, e. a. (2021). Effects of pavement texture and colour on Urban Heat Islands: An experimental study in tropical climate. *Urban Climate*.

D.Stewart, I. (2019). Why should urban heat island researchers study history? *Urban Climate*.

EPA. (2022, February 24). *Heat Island Effect*. Retrieved from United States Environmental Protection Agency: https://www.epa.gov/heatislands

Federica Marando, E. A. (2022). Urban heat island mitigation by green infrastructure in European Functional Urban Areas. *Sustainable Cities in Society*.

Google. (2022). Google Earth.

Grant, J. (2006). *Planning the Good Community.* London: Routledge.

Henson, B. (2021, November 9). *Exposure to extreme urban heat has tripled worldwide since the 1980s, study finds*. Retrieved January 2022, from The Washington Post: https://www.washingtonpost.com/weather/2021/11/09/extreme-heat-exposure-urban-climate/

J. Feng, E. A. (2021). Urban Heat Island and Advanced Mitigation Technologies. *Reference Module in Earth Systems and Environmental Sciences*.

Junjing Yang, e. a. (2018). Green and cool roofs' urban heat island mitigation potential in tropical climate. *Solar Energy*, 597-609.

Kelly, E. D. (2010). *Community Planning: An Introduction to the Comprehensive Plan* (2nd Edition ed.). Washington, DC: Island Press.

Krarti, M. (2018). *Optimal Design and Retrofit of Energy Efficient Buildings, Communities, and Urban Centers.* Butterworth-Heinemann.

Melton, P. (2011, June 29). *Study Says Urban Heat Island Worsen Smog*. Retrieved 2022, from BuildingGreen: https://www.buildinggreen.com/newsbrief/study-says-urban-heat-islands-worsen-smog

NOAA. (2022). Record of Climatological Observations - Gainesville, Fl.

OTM Solutions. (2022). *Lab test of Solar Reflectance Index (SRI), SAC-SINGLAS accredited & internationally recognized*. Retrieved from OTM Solutions: https://www.otm.sg/solar-reflectance-index-sri

Pengyu Zhuab, Y. Z. (2008). Demand for urban forests in United States cities. *Landscape and Urban Planning*, 293-300.

Peterson, T. C. (2003). Assessment of Urban Versus Rural In Situ Surface Temperatures in the Contiguous United States: No Difference Found. *Journal of Climate*, 2941-2959.

The Surface Temperature Record and the Urban Heat Island. (2004, December 6). Retrieved February 2022, from RealClimate: https://www.realclimate.org/index.php/archives/2004/12/the-surface-temperature-record-and-the-urban-heat-island/

U.S. Climate Data. (2022). *Climate Gainesville - Florida*. Retrieved from U.S. Climate Data: https://www.usclimatedata.com/climate/gainesville/florida/united-states/usfl0163

Uli, A. B. (2014). *A City Within a Garden: Green Pervasive Concepts and Strategies.* Gainesville, Florida: Graduate School of the University of Florida.

University of Florida. (2020). *University of Florida Campus Master Plan, 2020-2030.* University of Florida, Planning, Design, & Construction. Gainesville, Fl: University of Florida.

USGBC. (2015). *LEED Interpretation ID#10411*. Retrieved from US Green Building Council: https://www.usgbc.org/leedaddenda/10411

Wilson, A. (2004, September 1). *Porous Pavement: A Win-Win Stormwater Strategy*. Retrieved from BuildingGreen: https://www.buildinggreen.com/feature/porous-pavement-win-win-stormwater-strategy

Xiong Yao, E. A. (2022). How can urban parks be planned to mitigate urban heat island effect in “Furnace cities” ? An accumulation perspective. *Journal of Cleaner Production*.

Yeginobali, A. (2009). Concrete or Asphalt Road - Which is More Expensive?

Zhixin Liua, C. J. (2021). Playing on natural or artificial turf sports field? Assessing heat stress of children, young athletes, and adults in Hong Kong. *Sustainable Cities in Society*.

Appendix A – Complete Surface Area Measurements

Table A.1 – Complete Surface Area Measurements

Object ID	Object Description	Category ID	Area (sq ft)	Area (ac)
1	TOTAL STUDY AREA		18,653,924	428.24
2	FLORIDA BALLPARK		641,983	14.74
3	Net Study Area		18,011,941	413.50
4	Roadway Network (Hull, Museum, Ballpark Way, Radio Rd, All Other Parking); Light to Standard Asphalt	1	1,300,221	29.85
5	Housing Complex Parking; Light Asphalt	1	270,757	6.22
6	Lakeside Housing Parking South Parking; Light Asphalt	1	26,972	0.62
7	Lakeside Housing Parking North Parking; Light Asphalt	1	57,942	1.33
8	Softball Drop off; Dark Asphalt	2	27,867	0.64
9	Southwest Rec; Light Asphalt	1	65,372	1.50
10	Southwest Rec Tennis Courts; Dark Green Court	3	61,975	1.42
11	Southwest Rec Volleyball Courts; Sand	4	24,929	0.57
12	Southwest Rec Old Roof; Dark Tar	5	101,034	2.32
13	Southwest Rec New Roof; Light	6	24,949	0.57
14	Baseball Field Concrete; Light	0	29,119	0.67
15	Baseball Field Clay	7	73,272	1.68
16	Cricket Field Clay	7	523	0.01
17	Southwest Rec, Misc. Building Roofs	Refer to Table A.2		
18	Southwest Rec Concrete; Light	0	515,885	11.84
19	Golf Course Parking Lot; Dark	2	33,790	0.78
20	Golf Course Clubhouse Roof, Blue Metal	9	6,994	0.16
21	Golf Course Maint. Building Roof, Metal	8	4,323	0.10
22	Golf Course Maint. Building Roof, Green Metal	9	7,875	0.18
23	Golf Course Maint. Building Roof, Green Metal; Parking lot, asphalt	1	19,527	0.45

Object ID	**Object Description**	**Category ID**	**Area (sq ft)**	**Area (ac)**
24	Golf Course Restrooms, Blue Metal	9	2,717	0.06
25	Golf Course Restrooms, Black Metal	9	860	0.02
26	Golf Course Fairways, Concete Light	0	145,857	3.35
27	Motorpool Area Complex, Dark Rubber	10	6,099	0.14
28	Motorpool Area Complex, Tar	5	174,727	4.01
29	Motorpool Area Complex, Metal	8	50,053	1.15
30	Lakeside Complex Roof, Asphalt Shingle	5	72,903	1.67
31	Maguire Housing Complex Roof, Tar	5	184,034	4.22
32	Maguire Housing Complex Concrete	0	71,602	1.64
33	Maguire Lakeside Concrete	0	39,301	0.90
34	Soccer Field Complex Roof, Metal	8	17,862	0.41
35	Soccer Field Complex Roof, Tar	5	9,658	0.22
36	Soccer Field Complex Concrete	0	44,838	1.03
37	Steinmetz Hall, Tar	5	102,089	2.34
38	Facilities Services, Tar	5	48,334	1.11
39	Facilities Services, Metal	8	43,489	1.00
40	Ballpark Way, IFAS Buildings	8	18,866	0.43
41	Hull Rd - Mowry Rd Building, Dark EPDM	10	9,951	0.23
42	IFAS Agricultural Fields	11	931,482	21.38
43	IFAS Agricultural Buildings	8	138,591	3.18
44	Misc. Sports Fields Grass	11	931,654	21.39
45	Baseball Fields Grass	11	249,084	5.72
46	Softball Field Concrete	0	39,634	0.91
47	Softball Field Roof, Red Metal	9	13,364	0.31
48	Softball Field Roof, Blue Metal	9	5,075	0.12
49	Softball Field Clay,	7	18,556	0.43
50	Softball Field Grass	11	30,867	0.71

Object ID	Object Description	Category ID	Area (sq ft)	Area (ac)
51	Substation, Gravel	4	46,008	1.06
52	Golf Course Sand Traps	4	71,150	1.63
53	Golf Course Greens	11	3,866,986	88.77
54	Urban Forests	12	3,689,379	84.70
55	Other Tree Canopy	12	737,854	16.94
56	Maguire Housing Complex Pool	13	1,471	0.03
57	Water Bodies	13	60,522	1.39
58	Remaining Open Spaces	11	3,459,673	79.42

Some objects have been combined with others for the ease of calculations. For example, the Maguire Family Housing Complex is a collection of multiple apartment buildings, but if they had the same roof characteristics, they were consolidated into one object. For this reason, you may notice “missing” objects. They have been accounted for, but they were grouped with other objects.

Table A.2 – Southwest Recreation Complex Miscellaneous Structures

Object Description	Category ID	Area (sq ft)	Area (ac)
Volleyball Court Restroom Building	5	1,174	0.03
CORE; Center for Outdoor Recreation and Education	8	6,521	0.15
Administration Maintenance	10	2,948	0.07
Chilled Water Plant #6	5	4,853	0.11