Adopting Sustainable Transportation Design: Mitigating Heat Island Effects in Tucson Communities

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Abstract

This study looks at the communities located in two zip codes of Tucson, AZ, which are 85713 & 85757. In this research, solutions for issues such as Urban sprawl, Urban heat island effects, and insignificant usage of active transportation methods are explored. Residents of both areas participated in two surveys. We concluded that many of the residents heavily rely on automobiles for travel, especially in the area of 85757 because they are far from the major urban centers. Also, many of the residents of both zip codes felt that their neighborhood was too hot to consider active transportation methods and that activities such as biking and walking were unsafe or inaccessible. However, through the surveys, many participants are open to consider and adopt active transportation methods should their neighborhoods and built environments allow for it. We can allow this to become a reality through sustainable design. With programs such as Tucson's complete streets and Bike Boulevards, we can promote healthier and safer transportation. A sustainable street model was developed to promote safe active transportation, create shade while lessening heat island effects, and beautify the city of Tucson.

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Introduction

With the world constantly evolving, our built environment must adapt to several circumstances. In specific, issues are arising that are detrimental to our natural environment, generated mainly by our built environments, such as a change in climate, decaying air quality, and scarcity of vital resources. These issues are causing major concern because these environmental issues occur not only locally, or even nationwide, but also globally. These pressing issues alter our natural world, depleting our access to resources, and eventually altering our lifestyle. We must try and design communities for the present-day world and keep the future in mind (Roseland 2000), which will significantly impact our natural environment over the years to come (Bueno-Suárez, Carlos, & Coq-Huelva, 2020).

As an example of how design can refashion our communities for the better, we can look at communities that were rapidly constructed after World War II and how they shaped today's American lifestyle. These communities had no real depth under them. The main purpose was to provide a living space for the small family and provide a carport for their cars, which became a mainstream personal desire of that era. Authors Milena Dinić, & Petar Mitković, describe these communities as "Mono-Functional." As described earlier, the only purpose is to provide a living space in the suburbs away from the main city, causing urban sprawl, simultaneously increasing the desire but mainly reliance on a personal vehicle. There are many issues with this design that can be resolved in sustainability strategies and concepts. Some ideas that combat today's issues of rising climate, excessive carbon emissions, and urban sprawl, are to reduce urban heats islands by the usage of green and blue spaces (Zinzi & Agnoli 2012), encourage active transportation such as biking or walking (Southworth 1997) or public transportation (Steg & Gifford 2005) while still providing us the same level of living comfort we are accustomed. Through proposals for sustainable community retrofitting, design can help enhance our communities and lifestyles.

This study will examine the relationship between active transportation and fluctuation in microclimates, specifically in neighborhoods located in Tucson, Arizona, in the zip codes of 85713 and 85757. This study gathers data from the respective communities' members and utilizes it to help design strategies to mitigate these environmental obstacles. To begin implementing proposals for sustainable strategies in these communities, the most important aspect is community involvement. The education aspect plays a significant role in the residents' understanding of how to execute these ideas to achieve a high potential of efficiency in terms of

using our resources. Since many are foreign to the ideas of sustainability, two surveys were administered to gather data on sustainable tactics, the type of environment they currently live in, and their willingness to adopt these ideals. The initial survey focused on questions pertaining to:

- How can we design our communities to lessen Urban Heat Island effects & local climate?
- What is the importance of protecting the environment and willingness to adopt sustainable ideas?
- How much does the general local resident (in Tucson, AZ) know about sustainability?

The second survey that was administered, was oriented toward finding the specifics of which zip code, gender, and age are more likely to use alternative transportation. The survey helped better understand the residents' opinions of the neighborhoods they live in and if they feel their neighborhood promotes cyclist and walkers' safety. The survey consisted of questions related to the likeliness of using certain modes of transportation as the temperature increases or decreases due to the seasons.

Literature Review

This review provides support for the ideas of adopting sustainable ideas and community design. There was a focus on documents from an international standpoint and a national standpoint to gain different perspectives of what strategies might work in different environments. The keywords used for the literature review to find documents were "Sustainable Designed Communities," "Walkable Communities," and "Education of Sustainable Strategies." From these searches on the University of Arizona Library, many documents were found to support this study

Urban Sprawl

Discussed briefly in the introduction, we will gain a thorough understanding of what urban sprawl is, which described by F.J. Osborn, "coupled with the rise of real incomes, rapid transport has enabled the people moving out of the center (of the city), to find the open residential surrounding they desired" (Nechyba & Walsh 2004). This definition is great in understanding the rapid spread of citizens to rural and suburban areas, wasting the natural environment and becoming more reliant on automobiles for transport, which emit carbon emissions. Urban sprawl is related to the (physical) structure of our communities as well as social and economic factors. To fully understand the effect of sprawl on Tucson's communities and transportation methods, we must discuss the topic's history in depth. Starting in the early

1900s, families began to move outward from the city for peace and tranquility if they could afford housing and not just apartments. Seeing a steady increase in families moving to rural areas began to trend until the Great Depression. This transitions into the period where many families cannot afford housing until after World War II where the housing industry and American lifestyle were remodeled.

As the economy stimulated during the war, America eventually regained somewhat financial stability, allowing citizens to reenter the housing market. One case that serves as a housing paradigm starting in the late 1940s is Levittown. Levitt & Sons Co. found the formula to construct affordable housing in mass amounts and quickly. Their philosophy was to build homes in the suburban areas or the outskirts, away from the city, because it appealed to the American family for peace and tranquility (Rome 2001). Because these communities that Levitt & Sons Co. created were so far from the city, they promoted the desire for a privatized car as a main mode of transportation. The financial incentives of these suburban homes enabled these communities to spread rapidly, as homes were cheaper to build. Levitt & Sons Co. were able to receive government loans to construct these communities, expanding their company which made building faster (Rome 2001). The story of Levittown is just one example; this formula to build suburban homes rapidly was used all over the country. This idea of leaving the city for a mix between rural and developed communities was a desire of the young adults, ultimately achieving the American dream. This neighborhood format developed the social standard for Americans, which enables urban sprawl until this day.

Active Transportation

Active Transportation is one strategy of sustainability that can promote physical health, lessen harmful emissions of vehicles, and also, in some cases, dedicated pedestrian or bicycle lanes to ensure ease of travel and safety. In order to promote active transportation, the built environment conditions must allow for it. To fully comprehend the benefits of active transportation, we can look at examples in Tucson, Arizona, and its infrastructure to help promote this idea. First, we can look at the city of Tucson's Bike Boulevards initiative, which provides ease and safe travel for cyclists, although several other benefits are attached. Starting in the mid-1970s, the City of Tucson identified Third street near the University of Arizona, as a heavy bicycle traffic street (City of Tucson 2017). Since then, they have designed crossing solutions for bikers as well as pedestrian crossings. This idea eventually grew into a program

officially established in 2008 known as Tucson Bike Boulevards, converting major bike traffic roads all over Tucson into safer traffic ways shared with vehicles.

Designers of the bike boulevards had to consider many factors to promote active transportation, such as climate conditions and safety. To reduce vehicle-related accidents with cyclists, they added a bicycle-only lane that clearly distinguishes boundaries by using vibrant green colors painted on the roads and median traffic calming installations. By not allowing thru traffic on roads, this gives opportunities for the cyclists to move and cross major streets or even neighborhood streets safely. These traffic calming installations include raised medians, chicanes, or edge islands, and low-speed traffic is enforced (City of Tucson 2017). The installation of the traffic calming devices is also an opportunity for green infrastructure, which provides many benefits such as shade/reducing UHI's, improved air quality, rainwater harvesting devices/retainage, and neighborhood beauty (City of Tucson 2017).

Another strategy of active transportation is walking as a mode of transportation, in which many of the ideas for infrastructure coincide with that of cycling. The City of Tucson has established plans for the Comprehensive Street Tree plan designs and a program known as "Complete Streets." Both of these programs protect pedestrians when crossing main intersections or heavy traffic ways and promote walking. The Comprehensive Street Tree plan aims to be used mainly for the downtown area, encourages walkability of the area, beautifies the area with native vegetation, and uses the trees for shading mechanisms (Dept. of Transportation Planning Division 1998). This particular plan aims to distinguish a street hierarchy by planting certain trees that identify with three types of streets in the downtown area. Those types being pedestrian core streets (which would have native mesquite and Southern Live oak trees), calming traffic streets (containing Sweet Acacia and Blue Palo Verde trees), and entry streets (trees such as Western Hackberry, Ironwood, Aleppo Pine, and Red Oak trees). The streets in the heart of the downtown in Tucson are heavily occupied by pedestrian traffic, hence the need for shade during the spring through the summertime. Having these canopy trees will provide shade for most of the walkways and allow for more ideal conditions to walk (Dept. of Transportation Planning Division 1998).

With the Complete Street design, the city has started to implement an idea of a connected transportation network for vehicles, pedestrians, and cyclists, so they all have safe travels (City of Tucson 2020). As the city has stated through their plan for complete streets, this does not

mean every street will contain bike lanes, traffic calming instruments, pedestrian crossings, and vehicle lanes. Instead, it is a comprehensive study of streets in Tucson, and the best solutions are offered based on which mode of transportation is used most on the street in that specific area. Some features that favor active transportation include enhanced crosswalks, raised medians to calm traffic, comfortable transit stops for public transportation use, and inviting public spaces for users that bike and walk (City of Tucson 2020). The Complete street plan would invite more people to use alternative transportation rather than just an automobile, especially if the travel duration is not very far. However, since Tucson reaches high temperatures of approximately 100.3° F (Weather Atlas 2021), many citizens are discouraged from using active transportation methods for travel, even if there is the ease of travel and safety provided. The climate alone may be too much to bear for many Tucsonans.

Urban Heat Islands (UHI)

The change in a microclimate of a neighborhood in Tucson is most likely due to the Urban Heat Island effect (UHI). Most of our communities' structures, such as roads, roof types, and other materials, happen to absorb and radiate heat off certain materials causing higher temperatures. Ultimately, this is due to the neglect of environmental issues and contributes to increasing temperatures (Theobald 2005). To explain the effects of an event of a rise in microclimate due to Urban Heat Islands, we can look at figure 1 above. In areas containing natural vegetation, such as Tucson's desert, we can see that there will be cooler temperatures than in Tucson's urban center. This is because plants and trees work as natural cooling

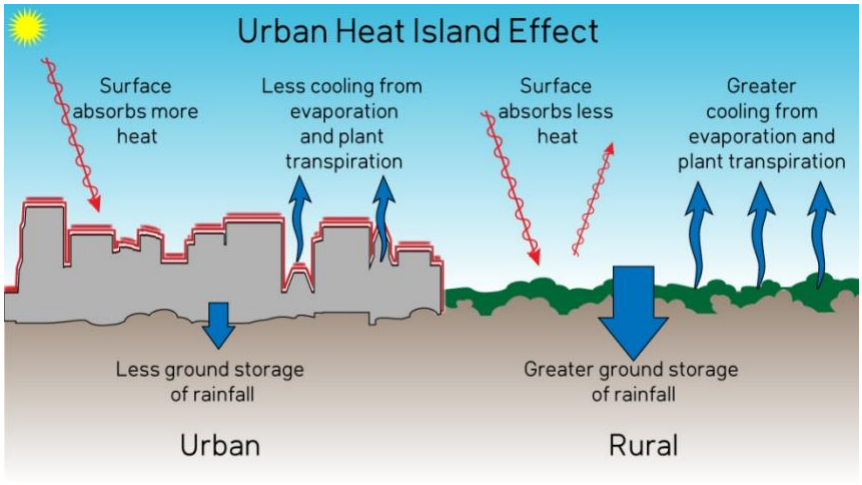


Figure 1. Shows the effects of urban development on climate vs. the natural world (https://www.skepticalscience.com/graphics.php?g=251)

mechanisms and use transpiration to cool the area as much as possible. When you enter the urban center, which almost always uses great amounts of pavement and concrete, the heat is more absorbed, and there is not enough vegetation to cool the surfaces (Theobald 2005). Often this heat is absorbed and released slowly and can be felt even in the nighttime, causing uncomfortable conditions not only during the day but also through the night.

To reduce urban heat islands, there must be a reduction in concrete, asphalt and other materials that radiate heat (Zinzi, M, & Agnoli, S. 2012). Green and blue areas help mitigate rising climate in the area and lead to better land usage, such as parks, ponds, less wastewater, and even plant diversity, offsetting CO2 emissions of the urban area (Brown, K, & Mijic, A. 2019). Additionally, with developers being more cautious with design and accounting for the rising environmental issues, they can help mitigate these rising issues. Implementing green and blue spaces and using alternate materials replacing asphalt and concrete will reduce the local area's heat. For example, Blue-Green infrastructure helps with the community's aesthetic quality and shades the community to cool down areas, combats carbon emissions, and brings high plant diversity (Brown & Mijic 2019). Designing communities with these strategies may seem subliminal to the average resident, but the effects of design will quickly positively impact the environment.

Considering the topics of urban sprawl, active transportation, and urban heat island effects previously discussed, we can now start to assess how the City of Tucson's built environment is affected by these topics. With the knowledge of efforts from the City of Tucson to mitigate high temperatures in neighborhoods and promote active transportation, we can measure the community's willingness to engage in active transportation. Understanding the Tucson community and their lifestyles is crucial to proposing any ideas that might strengthen our sustainability of the built environment. This will improve our natural environment, our resident's health, and create a more socially engaged Tucsonan community.

Methodology

Study Area and Site Analysis

This study occurred in Tucson, Arizona, United States, in two zip codes which are 85713 and 85757. Tucson is located in the Sonoran Desert, which is generally sees sunny hot days reaching average temperatures of about 82.4°F to about 100.3°F in the summertime (Weather Atlas 2021). The study site contains two rain seasons, the majority of rain coming from the monsoon season (June – September), and the other season is the winter rains that do not

Figure 2. Map of Arizona counties, Pima county being right in the middle of the most southern portion of Arizona. Image courtesy of https://webcms.pima.gov/cms/One.aspx?pageId=30543.

accumulate to that of the monsoon season. The annual average rainfall for Tucson is just about 11" total (Weather Atlas 2021). An active environmentalist practice is (rain) water harvesting to retain water into the soil and restore the aquifer. Tucson is a great example of a large city, with a portion of an urban community and suburban communities on the city's outskirts and rural living. Reducing local climate and using our scarce resources efficiently are ideas that would benefit the Tucson community and Tucson's natural environment.

Specifically looking at the zip codes in this study, 85713, is located just south of downtown Tucson and is better known as South Tucson. This area is in the city and is very populous with about 47,272 citizens and is a blueprint of an urban community. On the other hand, the zip code of 85757 is located in Tucson's southwest area and surpasses city limits reaching westward. This area is populated with about 20,350 citizens (United States Census Bureau 2019). Much of this area is filled with residences containing multiple acres of land and a mix of subdivision developments that are located west of Valencia road. This zip code contains a

Tribal Reservation of the Pascua Yaqui Nation, in which their community is shaped much like neighborhoods in the city.

Figure 3. Map of the zip code 85713. Image courtesy of https://www.google.com/maps/place/Tucson,+AZ+85713/@32.2027781,-111.0190492,12.1z/data=!4m5!3m4!1s0x86d6712a949e61f5:0xe8b00b3a071d7f5d!8m2!3d32.1922127!4d-110.9923904

Figure 4. Image of the zip code 85757, in southwest Tucson. Image courtesy of https://www.google.com/maps/place/Tucson,+AZ+85757/@32.1089327,-111.1774563,11.69z/data=!4m5!3m4!1s0x86d678a45eeb9dd1:0x167a3da6714c4428!8m2!3d32.089181!4d-111.1175767

Research Design

To gather data on the types of built environments we live in, two surveys were conducted to understand how sustainability occurs in citizens' everyday routines. The first survey consisted of 9 simple questions. The questions related to the ideas of Urban Heat Islands, the environment the participants live in, and their opinion on the importance of protecting the natural environment. The questionnaire also explored how residents are open to the ideas of sustainable tactics, but many live-in neighborhoods where sustainable ideas are not present or they do not know about their local efforts. The goal was to make the survey simple enough for those who may not know about sustainability and can still answer the survey with no complications. The survey was distributed through social media, and any person who wished to participate was welcome to answer the questionnaire. This survey had 40 participants.

The second survey consisted of 15 questions: three questions associated with demographics, three questions were associated with the accessibility of walking and biking of neighborhoods in their respective zip codes, three questions associated with the likeliness to use alternative transportation, three questions based on UHI, and finally three questions on their preferred mode of transportation, and also a general recommendation for an addition to their neighborhood. This survey had 66 participants, and for this survey, the participant's answers were scored in three categories mentioned in the next section of Data & Measures. The survey results then helped draw conclusions, and create proposals for neighborhoods in these zip codes, to help mitigate UHIs while promoting alternative modes of transportation.

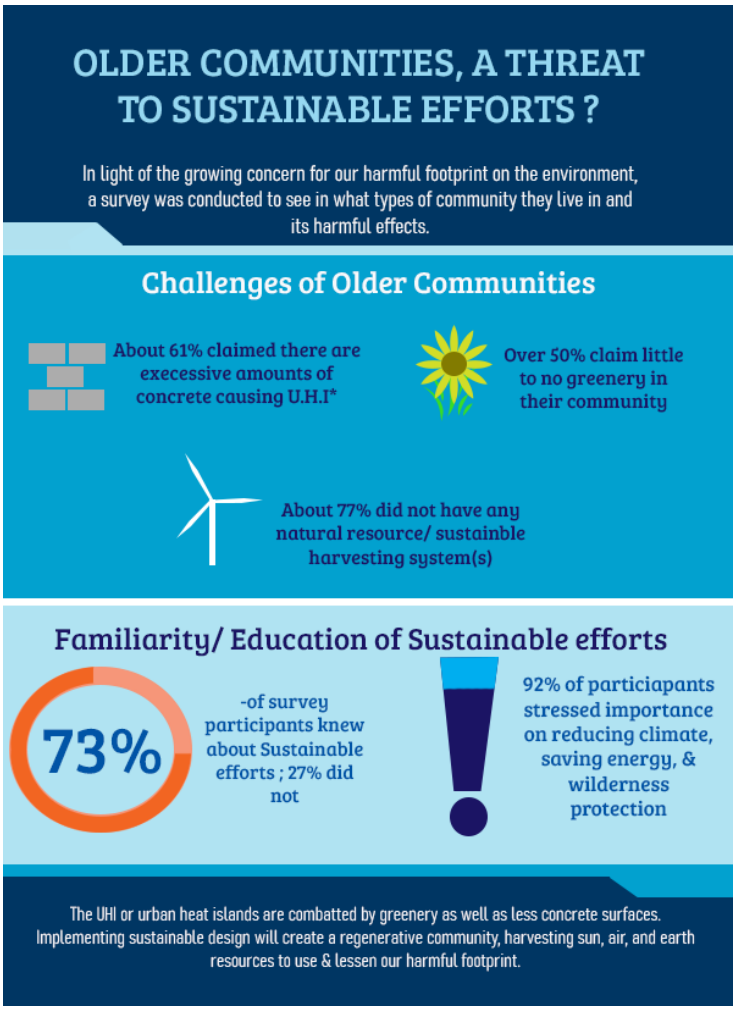
Data & Measures

Data for the initial survey was gathered and processed to illustrate the opinions of the residents of Tucson. The second survey scored the participants on three main categories: their likeliness to use alternative modes of transportation rather than a vehicle, walkability/bikeable community, and UHIs. Each category contained three questions worth ten points, and each category's highest score is 30 points, which is equivalent to being very open to sustainability strategies. The survey results were then compared by scoring the participants' answers against this rubric. Lastly, the data was then separated into zip code, gender, and age categories to find more specific data on which groups are more likely to adopt sustainability in their neighborhoods.

Results and Discussion

Initial General Survey

A total of 40 participants took the first survey. The main aspects to focus on are that many residents are open to sustainability ideas, but many reside in areas where much of these tactics are not implemented. For example, 92% of the participants stressed the importance of reducing the local climate and protecting environmental boundaries. Another main point that was emphasized through the survey was that many are somewhat familiar with sustainable professionals' efforts. However, many do not have a very good understanding or grasp of the concept. This is where education will play a major role in changing the communities to be more sustainable. If the people living in these communities are exposed to these ideas, many will adopt these strategies because these systems have incentives such as tax breaks and lower costs for energy in terms of heating and cooling during seasons.



In connection with the survey data, many of the research articles in the literature review are supporting these results from the survey. For example, we see the community in Sweden, in which the community that was open to sustainable strategies underwent a survey that calculated the subject's carbon footprint and displayed how much that can be dramatically reduced by (Axelsson 2016). After a year of living in the community, they were administered the survey again, and they reduced their footprint based on the study. This reiterates the idea that if a population is willing to learn and adapt these

ideals of sustainability, then most of them will carry on and pass down this knowledge, eventually becoming normalized.

From these results of the study, many participants had some knowledge of sustainable ideas and strategies. The Sweden study showed similar results when tracking participants for their carbon footprint (Axelsson 2016). We can see that many seem to believe that the importance of protecting the natural environment (in Tucson specifically) should be a priority. Based on this sample, Urban heat islands seem to be a major concern in this region, at least in Tucson's urban areas. A greater sample may be needed to understand Tucson's general population and their opinions on the survey subjects. However, from these results, we can pinpoint the topics of mitigating urban heat islands, focusing on sustainability education, and implementing more natural resource harvesting systems in Tucson.

Are you familiar with the topic of sustainability and its strategies?

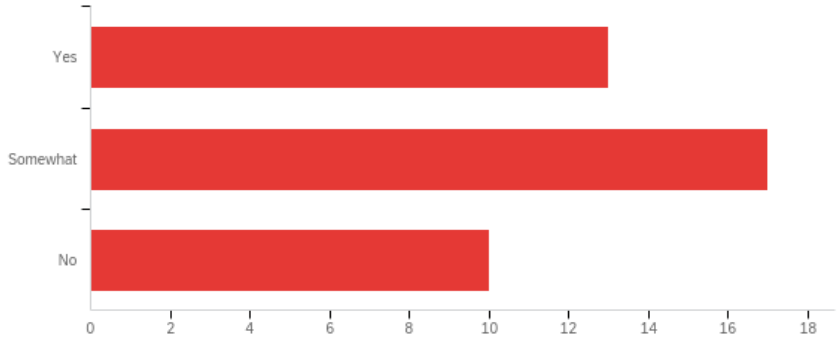


Figure 5. Shows the familiarity of Tucsonans and Sustainability.

Walking and Cycling Survey

The results for the second survey were parallel to the first survey. In zip code 85713, we can look at the "sustainability scores" (referring to the scoring rubric set up) for each category. As a whole collective, this particular zip code participants scored under the rubric's midpoint; the members earned 34.6/ 90 points across all 3 categories. The total participants of 85713 (33 participants) earned an average score of 13.8/ 30 for likeliness to walk or bike assuming the travel duration was about 30 – 60 minutes long. This is mainly due to the heat.

Switching gears to the accessibility of a walkability and bikeable community, the score underwhelmingly performed, earning an average score of 10.8/30. When specifically looking at age, the numbers dramatically fluctuate. As seen in figure 6, middle-aged adults are more likely to make an effort to walk or bike, while the older the age adults have opinions that their community is non-walkable or bikeable. Another important piece of data is the willingness to travel using alternate modes of transportation while the temperature is high, considering Tucson is extremely sunny. The majority answer an ideal temperature to walk, skate, or bike, was 70°F - 79°F, with a very large number of people claiming 80°F - 89°F also, but not as much as that of the 70°F. Tucson only reaches this temperature consistently in the fall and late winter seasons. Mitigating as much heat radiation as possible is key to encouraging sustainable transportation (noting that Tucson is a very naturally hot place, achieving such dramatic change in temperature is very narrow).

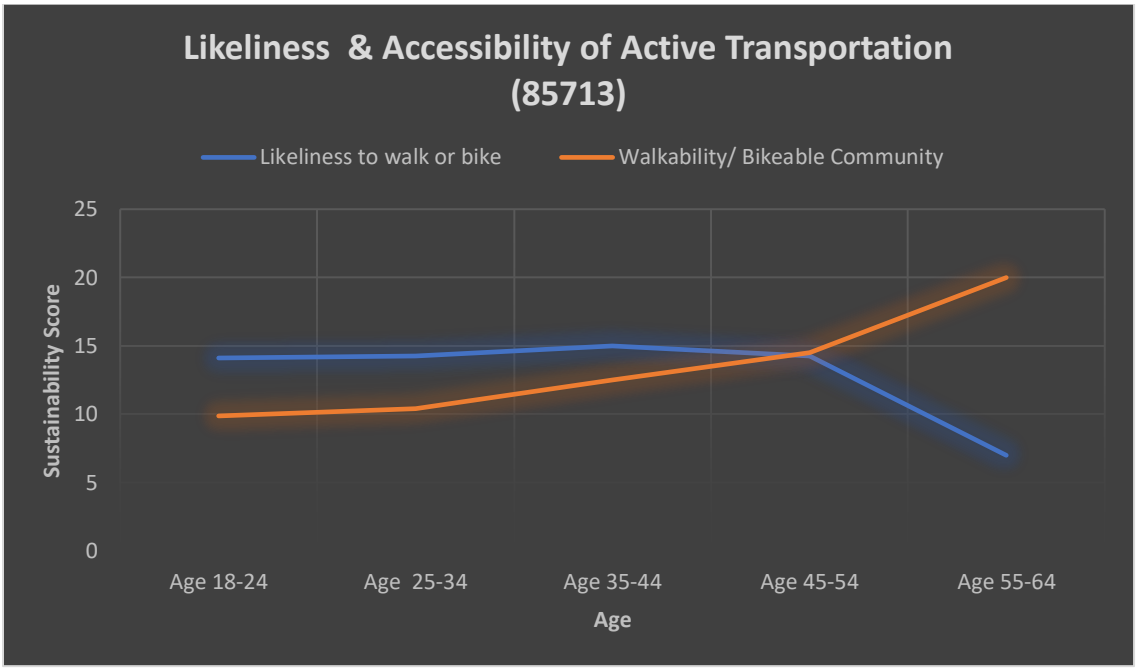


Figure 6. Displays the scores of 85713, and also shows many feel their community is very hard to go for a walk or bike ride.

Now we will concentrate on the results of other the location on the outskirts of Tucson, which is the zip code of 85757. After gathering and scoring the data, we can now look at the "sustainability scores" and compare them to the previously mentioned rubric. In 85757, as a collective, the average total sustainability score was 37.13 / 90 points. The average score for only the likeliness to walk or bike category was 15.9/ 30, again assuming the duration of travel is 30 – 60 minutes.

The results gathered related to their current communities' design and accessibility to active transportation were just as underwhelming as the previous area code of 85713. The score for neighborhoods allowing active transportation in 85757 was 10.5 / 30, as depicted in figure 7. There is a trend in both categories, both of which increase for 45- 54 years old, meaning they are more likely to utilize active transportation and feel their community is just slightly accessible to active transportation.

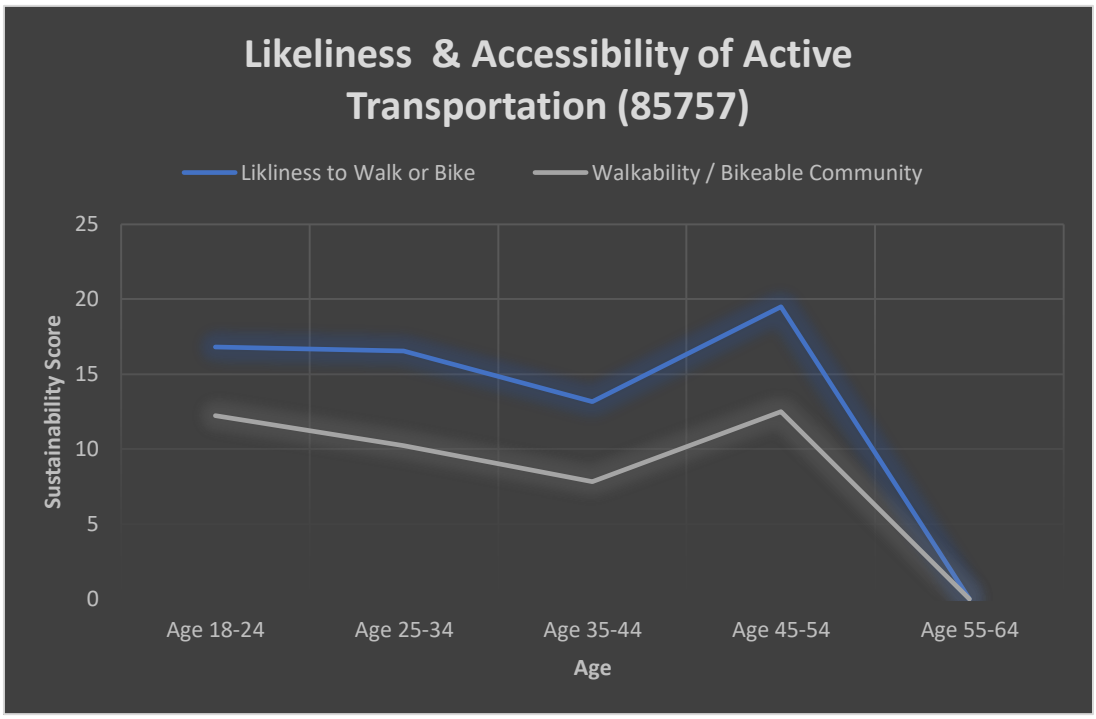


Figure 7. Displays a contrasting trend compared to the 85713 participants. In this location, participants scored slighter higher in their sustainability score, especially the age group of 45-54.

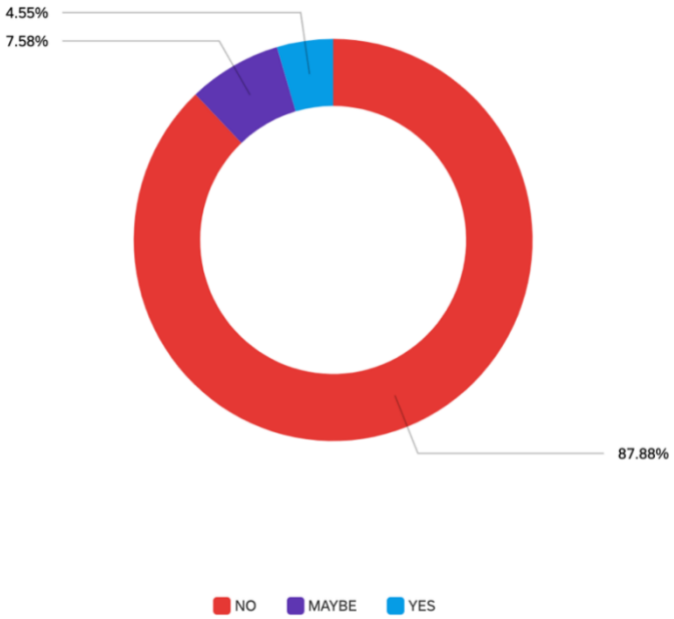


Figure 8. When presented with the question, "Does your neighborhood feel well shaded from the sun?" the majority of the participants disagreed, leading to more reason for greenery and vegetation, but also sustainable design for neighborhoods.

Sustainable Street Design Model/ Proposal

By gathering data from the two conducted surveys and the literature review, a simple but effective design has the potential to transform our neighborhoods. As seen in figure 9 below, the left side of the street is the current layout, with little or no shade, and just the street area with a curb as a buffer between pedestrians and vehicles. In some cases, a small painted line is provided for bicycle riders but no significant protection from vehicle traffic. On the right side of the road is the model inspired by Tucson's Bike Boulevards and participants' requests from the second survey. To summarize the image, there are delineators for bicycle riders that serve as protection from the vehicles, or at least a buffer between the two traffic lanes. To the right of the dedicated bike lane, we have a curb that has been cut, which will allow for optimal storm and floodwater management, especially during monsoon seasons. The water will not only prevent street flooding, but it will drain into an infiltration basin that feeds native vegetation. This vegetation can be shady trees such as the Mesquite trees, Palo Verdes, or smaller shrubs such as creosote. In any case, native vegetation requires little water demand, and can withstand periods of heat.

Recalling the design of the Downtown Comprehensive Street Tree plan, ideas such as this program could be implemented into our Tucson neighborhoods. Not only will the vegetation

shade and beautify our communities, but they will also distinguish a hierarchy of major traffic ways within our neighborhoods. This compliments active transportation because many will create a walking or bicycling routine along the path of the different trees. This also can be used as a location marker, understanding exactly where you are in the neighborhood.

As mentioned, the trees will provide a source of shade and cool the materials that absorb and radiate heat. This will cool the area, making a stride towards comfortable temperatures, which the participants may be motivated to bike or walk. Outside of the summer season, these shade and cooling mechanisms will be optimal. Having this simple design along our neighborhood roads will provide, not only in the aspect of active transportation but also socializing amongst residents, health benefits, and improved air quality. As stated by Brad Lancaster during a lecture for rainwater harvesting, because of his community promoting biking and walking, the crime rate had dropped due to residents being more aware and becoming somewhat of a deterrent being that they are outdoors more.

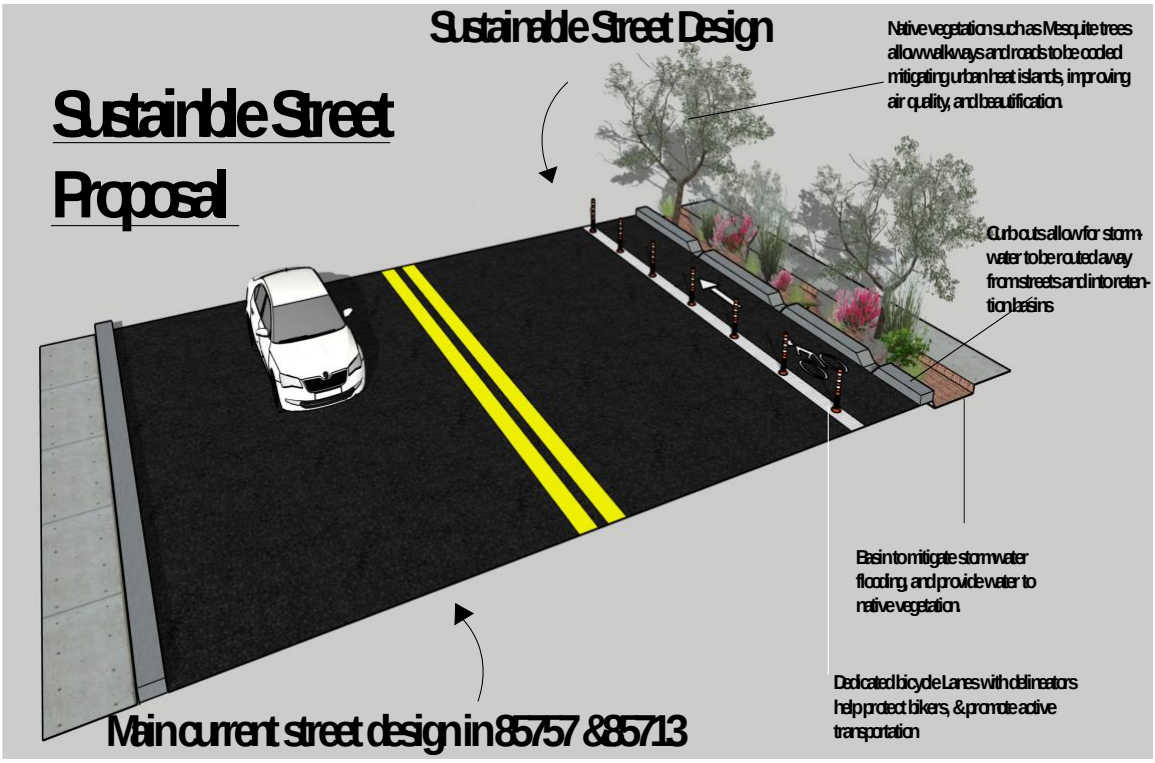


Figure 9. My proposal for neighborhood street design to promote active transportation, simultaneously mitigating heat island effects, flooding, and shade issues. Design is based off of survey responses, as well as local programs for active transportation.

Conclusion

Tucson has been a growing population over the years, expanding its urban territory in more rural areas. Although an urban center can be very appealing for many, it also causes several environmental issues. These concerns can be urban sprawl or the rapid growth of a city in "leapfrog development," rising microclimates due to materials that radiate heat such as asphalt and concrete, and dependence on automobiles that release carbon emissions into our atmosphere. These issues can be deterred through the sustainable design of our Tucson communities and help the communities lessen their impact on the surrounding natural world. This study set out to explore the following questions: what efforts are Tucson making to mitigate high temperatures in built environments? What measures is the city of Tucson taking to promote active transportation as well as the use of Public transportation? What is the community's willingness to use active transportation when the climate can be extreme? How do Tucsonans feel about their communities?

In the literature review, documents were found to support sustainable design. As an example, peoples of their respective communities are more open to learning and implementing sustainable strategies either at home or in the community. When many community people adopt these ideals, the community becomes more efficient, and these tactics are continuously followed. For example, in this study from Sweden, community members who moved into the new community answered a survey about their carbon footprint and then learned how to reduce it, which covers some time they stayed true to lessening the carbon footprint (Axelsson 2016). Investing in their communities can lead to an efficient future life of the community. Whether it is planting, recycling, composting, or more advanced systems like solar power, solar heating, or rainwater harvesting, these strategies create a regenerative community and less waste.

Based on the survey results, both zip codes respectfully scored just around 35/90 on their sustainability scores, meaning that their willingness to use alternative transportation is low. This is due to their neighborhoods' structure, not allowing for easy or safe active transportation, and the climate of their neighborhoods, which they have mentioned in the surveys. The key points to understand from the survey results are that many Tucsonans in the zip codes studied are

unsatisfied with their built environments, in terms of climate and use of vegetation, which would help promote active transportation and better temperature.

In terms of the other two categories discussed in this study, sustainable design such as Figure 9 is needed to mitigate the urban heat island effect and make communities more accessible and promote active transportation. Programs such as the previously mentioned Tucson Bike Boulevards and initiatives such as Tucson's Downtown street plan, and urban heat strategy plans, help mitigate these environmental issues our built environments create. By bringing these programs to the public's awareness, we can educate our communities on sustainable strategies for a healthier environment and healthier lifestyles.

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