Planning for a Climate Driven Implementation of Mobility Hubs on Georgia Tech's Campus

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Abstract

Mobility hubs are an efficient and effective transportation solution that promotes connectivity and provides last-mile modal options for commuters and residents through integrating multi-modal transportation infrastructure in one convenient transitional space. While providing access to a diverse offering of travel options, mobility hubs encourage place-making efforts and create opportunities for community interaction. Mobility hubs have helped to transform cities and regions with innovative approaches to seamless modal transitions and integration of smart technologies for wayfinding, safety, and accessibility. At its foundation, mobility hubs are a strategy for addressing the climate change crisis, which is substantially driven by transportation related carbon and carbon-equivalent emissions (EPA 2023). Therefore, a focus on a climate driven implementation of mobility hubs is pertinent to accomplishing the goal of reducing carbon emissions and creating resilient transportation infrastructure.

University and college campus mobility hubs are the focus of this study as they foster an environment for studying travel patterns and implementation of mobility strategies in a practical and feasible manner within a shorter time frame than city or regional level mobility hub implementation plans. Successful case studies at the institutional level can inform a city or regional level approach to mobility hubs and can provide best practices for ensuring sustainable elements are incorporated into the implementation.

This paper provides a case study analysis of best practice strategies for implementing mobility hubs from three institutions across the United States, which informs a review of Georgia Tech's plans for improving mobility on campus as outlined by the 2023 Comprehensive Campus Plan (CCP). This analysis is used to determine what elements are critical to creating resilient, sustainable, and accessible mobility hubs and to propose a climate driven approach to implementing the mobility plans of the institution. Through this analysis, 14 locations are identified for potential mobility hubs throughout campus that incorporate 11 sustainability and accessibility elements, which include car, bike, and scooter parking; charging stations

for EVs, e-bikes, and e-scooters; transit shelters with seating, lighting, and digital wayfinding; and greenspace and solar panels.

Introduction

In Fulton, DeKalb, and Clayton Counties, which mark the extents of the MARTA rail network*, 57% of residents whose travel origins and destinations are within Georgia use cars as their primary mode of transportation for commute, and 85% use cars as their primary mode in general, as of 2022 (Replica Data Hub). The percentage of residents relying on other modes of transportation comes to 43% for commute and 15% for general purposes. On face value, car usage appears as a more popular option for daily travel than riding transit, cycling, or walking, but there are a host of factors that influence this trend, which have contributed to car dependency and a greater focus by governing authorities on car-oriented development. The socio-economic circumstances, economic goals, and political priorities of regions and neighborhoods within a state shape the direction of development for transportation systems. From their conception, cities have strived to expand their transportation system through inter-city passenger rail networks and highways to promote growth and ease of travel over long distances. The reliance on growth by expansion of the highway system has led to urban regions being built to accommodate highways. In the present day, there have been significant advancements made to alternative modes of transportation, from pedestrian facilities to bus rapid transit (BRT), and transportation systems all over the world have placed greater focus on expanding access and equitable practices in the implementation of these modes.

Cities have implemented and enhanced strategies over time to create accessible and equitable transportation solutions that are kept current with new technologies. Mobility hubs are one such strategy that has proven to provide connectivity between many different modes of transportation and encourage mobility in rural and urban areas. 'Mobility Hub' is a term that has grown to become familiar in urban and regional planning, but with such varied applications, a universal definition

* only airport coverage in Clayton

has yet to be identified. The reason is, in part, due to the difficulty in conceptualizing exactly what it means. Simply put, as described by the Bay Area's Metropolitan Transportation Commission, "Mobility hubs are places in a community that bring together public transit, bike share, car share and other ways for people to get where they want to go without a private vehicle" (2023). This idea provides last-mile connectivity and seamless transfers for people who use multiple modes of transportation daily.

The connectivity of mobility hubs and their ability to provide accessible transportation options is a direct result of a climate change mitigation strategy that is intended to alter car-oriented development and travel behavior. The rise of shared-use mobility options has been largely due to a growing societal concern for the future of the environment, economic vitality within the transportation sector, and energy usage (SUMC). Sustainable alternatives are required to initiate a shift in the transportation industry and travel behavior that will help address inequities related to transportation access, and climate change mitigation. A detailed review of Georgia Tech's current mobility plans and climate change concerns, including vulnerability to natural hazards and greenhouse gas (GHG) emissions, are provided in this paper to ensure that the goals of accessible and sustainable mobility hub infrastructure are at the forefront of this study.

Background

What is a Mobility Hub?

The concept of mobility hubs can be seen in many different forms; a large-scale example includes *The Oculus* in New York City which is an artistic landmark that incorporates retail and commercial spaces within the building that provides a connection to the subway and busses and is located conveniently by a financial district and tourist attractions which allows people to connect through walking and cycling as well. A smaller scale example is a park and ride or a train station that connects riders to buses and bike share.

Figure 1 Mobility hub rendering *Source: Intelligent Transport 2023*

It may also be of help to understand what it is not- Mobility hubs are not always transit specific as they incorporate additional modes of transportation such as walking, biking, driving, shared micro-mobility vehicles, and rideshare (TNCs). Mobility hubs should also be differentiated from transit-oriented development (TOD).

Mobility hubs are centered on bringing together different modes of transportation in one place that is most accessible to residents of an area, and it is an easier way of getting around, but transit-oriented development puts greater focus on "maximizing the amount of residential, retail, and leisure space within walking distance of transit" (University at Buffalo 2017). In essence, both are mutually significant to their respective success. Without adequate connected transportation systems, mobility hubs will not be able to provide the ease of access to transportation alternatives for residents, whereas poor locationality of residential, commercial, and leisure spaces will reduce accessibility for residents to these mobility hubs.

Components of a Mobility Hub

Locationality of mobility hubs can vary based on the demographics and economic objectives of a given area, and the scale may change according to usership and needs. Shared mobility hubs could be as simple as a bus stop, bike sharing station, or a park and ride if that meets the needs of the people it serves. Larger, regional scale mobility hubs could be located within city centers as highly accessible and central facilities that incorporate all major modes of transportation, as well as retail, commercial, and restaurant spaces that facilitate placemaking. A policy document by Metrolinx states "Anyone who has had to walk down a bleak and busy street to a cold and windy bus stop – with nowhere to find shelter or buy a paper or a cup of coffee – to wait anxiously, uncertain of when the next bus will arrive, while comfortable commuters whiz by in their cars knows what a mobility hub should be"(2008, 3).

As mobility hubs can vary by their scale and context, research was conducted to see what literature is available discussing mobility hub typology on university and college campuses and their essential components, from small to large scale. According to the North Central Texas Council of Governments, campus hubs are categorized by the number of amenities available at the hubs, available space, and travel modes served (2023, 3). Typically, smaller hubs may not have all the amenities such as wayfinding signage or spaces for gathering but focus more on quick facilitation of modal shift through simple transit or micro-mobility infrastructure.

Medium hubs may take into consideration larger spaces so that hubs that service a larger number of students or are connected to parking garages can have seating options such as tables and chairs, or digital wayfinding kiosks. Larger campus hubs can be used for accommodating transit junctions where multiple transit routes may converge, and spaces that can be transformed for events and gatherings with lawn space or green infrastructure.

In this study, areas on Georgia Tech's campus with the potential for implementing mobility hubs that have a climate focus, will be identified through factors pertaining to the end-user of the facility. The Comprehensive Campus Plan developed by Georgia Tech's planning team primarily focuses on retrofitting existing parking garages into mobility hubs and consolidating surface lots into a few high-density parking garages that can serve the function of mobility hubs. To facilitate a climate driven approach to the implementation of mobility hubs at Georgia Tech, additional hubs should be considered as well, that can be built at the small to medium scale as well, that utilize existing bus loops and central points on campus.

There are several factors that can influence the location of a suitable mobility hub, from an end-user perspective, which will be further discussed in the methods chapter, which will serve as the basis for proposing suitable locations for mobility hubs with climate elements.

Literature Review

Best Practices for Mobility Hubs on University and College Campuses

North Central Texas Council of Governments - Intermodal Transportation Hubs for Colleges and Universities Study

A study was conducted by the North Central Texas Council of Governments to determine what strategies can be implemented on college and university campuses to enhance intermodal connectivity throughout the campus and focus less on car centric development (NCTCG 2023). To accomplish this goal, existing transportation conditions and data on mode preference, ridership of public transit, patterns of development and format of the built environment was considered to first identify vulnerabilities and areas for improvement. The approach of this council focused on developing a catalog with guidelines to show what the campus could look like if the plan is implemented, that can be used in colleges and universities in any given area.

Implementing mobility hubs on campus can facilitate movement throughout the campus through various modes of travel that do not only rely on cars, especially when travelling short distances within the campus itself. This ensures a safer environment for those using active modes of transportation and prioritizes their right-of-way over gas powered vehicles. This will allow climate conscious development to be at the forefront in the decision making and implementation processes. For mobility hubs to be effectively integrated into the fabric of the campus, the characteristics and barriers of the campus environment should be included as well. Creating mobility hubs on campus will also help to prioritize the needs of individuals with a variety of mobility needs and remove barriers for traveling through the campus. Given that there is a diverse group of people who travel to campus for work, studies, research and other events, a mobility hub that provides different modes of transportation in a clear and accessible way will facilitate more usage of these modes and encourage people to use it rather than drive.

Georgia Tech's CCP team distributes a yearly commuter survey that collects information on the types of modes people use to travel to campus, where their origin locations are, why they choose to use the mode they do, what the purpose of their time on campus is (teaching, learning, visiting), as well as how many times they travel between campus on an average day. The NCTCG campus mobility team partnered with Nelson Nygaard to develop a commuter survey to collect data similar to what Georgia Tech has done to gain insight from the communities at different colleges and universities on people's travel patterns in an effort to develop an effective mobility strategy that would facilitate how people get to and around campuses. The NCTCG survey collected information on frequency of travel to and from campus, mode choice, barriers to modal shift, and origin locations among other data points (NCTCG 2023). Some key takeaways from this survey indicate that:

- most people live within 5 miles of campus, are staff or undergraduate students, and are between the ages of 18-34.
- most people drive because they don't have reliable access to other transportation options or accurate information on service schedules and disruptions.
- people would use transit as a last mile connection through campus if it was a feasible option for them.
- Cost is the main factor for why people drive and drive within/throughout campus.
- The primary concerns are safety, convenience, reliable connections, accurate schedules.
- while on campus, most people would choose to just use one mode because of ease of use, think it is a hassle to combine modes in a single trip; and
- 76.2% of people walked or used a mobility device such as wheelchair through campus to get where they needed to go within the campus.

These results overall indicate that the people are not only willing but want to enhance their daily travel experience if given the opportunity through effective mobility hubs. Through field research and the author's experience as a graduate student that visits campus 3-4 times per week, some observations were made that may impact the travel decisions of individuals. There are certain factors that may persuade drivers to use their car to drive across campus rather than utilize alternative modes of transportation, which can be addressed with the implementation of mobility hubs. Some of these factors are:

- if their destination is too far to walk.
- they may not want to use scooter share as it can become expensive.
- the campus shuttle does not service their desired destination.
- they are concerned with biking due to conflict points with pedestrians and motorists; and
- they do not have access to a personal bicycle or scooter for last-mile connectivity.

The strategies discussed in the methods and proposal sections provide solutions to these concerns from a driver perspective and can encourage use of alternative modes of travel through mobility hubs that address these concerns.

University of Maryland - Center for Multi-Modal Mobility in Urban, Rural, and Tribal Areas

Over the years, universities and colleges have incorporated more micro-mobility and shared-use transportation options to provide opportunities for accessibility throughout campuses. These efforts have a significant benefit to the diverse individuals that study, teach, research, or visit at the campuses, but with the greater number of options, there should be infrastructure that accommodate these options. The University of Maryland, Baltimore (UMB) conducted a study to see how different modes interact on campus, which is critical to understanding how mobility hubs can be implemented to enhance safety and create a network for reach mode used on campus (Madden et al. 2022). The study collected data on community member experiences on the interaction between different modes on campus, specifically in terms of safety, and where they think cyclist and e-scooter facilities should be located to address the safety concerns and reduce conflict points.

At Georgia Tech, most pathways that run throughout campus are used by pedestrians, cyclists, and e-scooters. There are certain locations that have motor powered vehicles as well such as food trucks, utilities vehicles, and law enforcement vehicles. These are most often stationary but with the amalgamation of all these modes, there are several conflict points that arise daily. The main pathways on campus are wide enough to fit a pedestrian and cyclist in line travelling one way; however most other pathways only provide room for a couple of individuals travelling in the same line if they are walking, or a single user otherwise. Considering the speed of cyclists and e-scooters in comparison to pedestrians, there are situations that could result in collisions with other cyclists or e-scooters, or pedestrians. This typically has a higher chance of occurring during class change periods. Having cyclist and e-scooter infrastructure within and throughout the campus, rather than just along the major road that cuts through campus, Ferst Drive, will create a safer and more comfortable environment for both pedestrians and micro-mobility users. The bike lanes located on Ferst Drive and 5th Street are identified as medium-protection facilities, with narrow lanes and no physical barrier between the cyclists and motorists.

Some suggestions for improvement that UMB suggested that can be implemented at Georgia Tech include enhancement to roadways to provide safer facilities for vulnerable users, ensuring connected bike infrastructure so people can rely on safe cycling infrastructure to get them to different points on campus through one mode. One of the most effective strategies that can be implemented to remove the potential for conflicts with motorists is to greatly remove vehicular access or remove It completely from the core of the campus, so cars can only be driven in the periphery. This would be a drastic change to the travel behavior on campus, but it would not impact people who rely on driving to campus as their primary mode for commute. Rather, this would promote the use of alternative modes of transportation when travelling within the campus, and to surrounding areas. In the case of Georgia Tech, access through the main campus, and east towards Tech Square could be easily accessible through alternative modes.

Many universities, including Georgia Tech, have experimented with implementing policies that regulated the use of bicycles and e-scooters, especially their speeds and zones for use to minimize the potential for conflict to occur with pedestrians (Bailey 2023). Often times, policymakers and university officials found that to be ineffective because riders did not adhere to regulations or were unaware of enforcement efforts. While developing strategies for reducing conflict points is important, redirecting the focus from enforcement and limitations on cyclists to creating safer and more reliable cycling infrastructure can encourage more users to bike throughout campus. Studies have even shown that this reduces the number of people who ride their bikes in pedestrian designated pathways and sidewalks, which addresses safety concerns for both micro-mobility users and pedestrians.

UMB conducted a survey intended to gauge the experience of people on campus to see how they feel about the potential conflict points between different modes. The findings indicate that there was a diverse distribution of the types of modes used to travel to and throughout campus, with the largest number being cars, second walking, and third transit. The results also show that more people use bicycles or scooters to travel throughout campus than travelling to campus. Students had a more diverse composition of modes, touching all categories of modes, than employees, which only either used cars or walked. When looking at the frequency at which students come to campus, the most diverse composition of modes is experienced by individuals that come to campus four or more times in a week. When measuring which modes experienced the most conflict points, the greatest category was between bikes or scooters and pedestrians, with the next greatest category being between cars and pedestrians.

This breakdown is interesting in comparison with the distribution of modes at Georgia Tech, as of 2019, which is shown in **Table 1**.

Table 1 Georgia Tech commuter mode distribution

	Drive (alone or carpool)	Transit	Multimodal (walk/bike)
Staff	74%	10%	13%
Faculty	66%	9%	22%
Student	35%	8%	54%

Source: CCP 2023

The distribution of travel frequency, as shown in **Figure 2** throughout campus indicates that the largest group of people who come to campus the most are undergraduate students, with the next highest groups being graduate students and faculty. The individuals who will contribute to a shift in the travel patterns on campus will most likely be undergraduate students because the structure of their curriculum often requires frequent class changes. It is important to ensure that the configuration of mobility hubs provides the required facilities for students that have to travel across campus multiple times in one day.

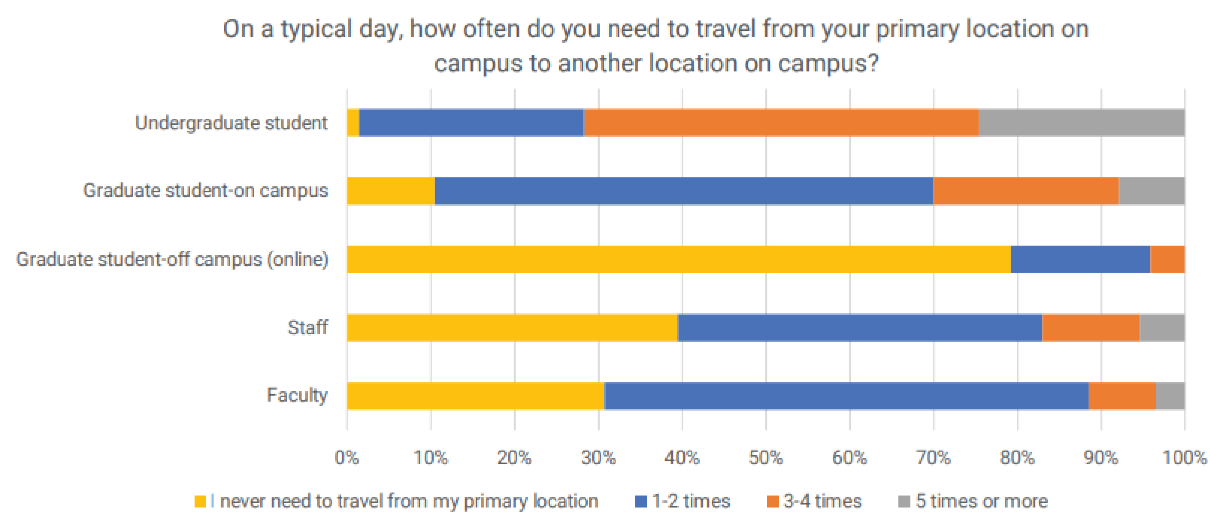

Figure 2 Frequency of travel within campus *Source: GT Commuter Survey 2022*

There are several locations along Ferst Drive that have the potential to pose serious safety risks for pedestrians and cyclists or motorists because there is either low visibility or high driving speeds from the part of motorists. Due to the hilly terrain of the campus, the road has a few curves that reduces visibility and pedestrians are prone to jay-walk at those locations because it is closer to their destination than walking up the hill to the next mid-block crossing.

The survey results discussed in this section from UMB were a select few that could be applicable for Georgia Tech as well, but there are many other results from accident studies and questions specific to comfort level and experience of bicycle and scooter users that help provide context to the travel patterns on the UMB campus. UMB developed several recommendations based on their analysis, which are useful to note as next steps that can be incorporated at Georgia Tech as well. One recommendation that was made was overall prioritization of roadway space for vulnerable users, which aligns with implementing temporary road closures and limited access for vehicles during high pedestrian traffic periods so that non-motorists can travel safety and confidently through the campus without worrying about the potential for a collision. Another strategy is to move or create bicycle lock stations closer to the curb so that the facilities do not have to impede pedestrian traffic by crossing over sidewalks, and this idea can be folded in as an element of a mobility hub that provides direct access to bike lanes from bike racks for cyclists that does not get in the way of other mode users. A third recommendation that could also be implemented on Georgia Tech's campus is that of signage and clear education strategies to make the public aware of who has the right of way throughout the campus.

University of Utah

The university of Utah has published a campus mobility hub study that provides best practice strategies for implementing mobility hubs on campus, that are used to select locations on campus that have the potential to become mobility hubs (University of Utah 2020).

Some key best practice strategies that are mentioned in this document include a cohesive design that is not simply a bus stop that has a bike share stand, but it also connects modes in a seamless manner. The design can determine if a person feels comfortable using another mode and can access it using clear direction and wayfinding tools. Another strategy uses curbside management to make use of the curb to create seamless and safe transitions from sidewalks to transit stops and provide enough space for loading and offloading without impeding the way of other modes of transportation. There still needs to be parking available for people who drive as it is still the most common mode that is used, but the mobility hubs can be used to incentivize more sustainable transportation options such as electric vehicles, carpool, and low-emission two-wheeler vehicles. To promote the use of alternative transportation modes, parking facilities for those should be created as well, such as short- and long-term bicycling parking, or locked bicycle and scooter rooms to provide extra security and reassurance for cyclists and scooterists. While increasing parking costs for motorists may be considered as a strategy to reduce the number of people driving to and around campus, it can create challenges for people who do not have adequate access to other modes of travel from their origin points. Thus, a more practical solution could be providing discounted rates for people who carpool for people who do have the ability to rideshare to campus.

Georgia Tech already provides many parking pass options so that people do not have to overpay if they only need the parking pass for few instances, and there are discounted passes for carpooling. However, this is not widely used as people may not have the ability to carpool and other transportation options are not accessible or widely available. If scooters and bicycles were encouraged on campus more than regulated, and proper infrastructure was set in place, people could be incentivized to use that instead.

Mobility hubs also provide the opportunity for placemaking, and act as a third place that is welcoming and safe. To accomplish this, it is important to reduce the visibility of concrete structures, for multiple purposes, by cooling down the temperatures and preventing the structures from retaining the heat. This can be accomplished through art installations, green landscaping, lighting, and seating options to encourage people to not only use the mobility hub as a transfer center, but also as a location to wait and gather as they wish. Providing wayfinding tools will make it clear for students, staff, and visitors to navigate the different mode options available and find data such as real-time transit schedules, and other bike and scooter lock stations across campus.

A key factor of mobility hubs that should be considered is ADA compliant accessibility, which goes further than physical structures for those with diverse mobility needs and provides audio or video wayfinding tools. Having digital wayfinding kiosks that provide information in multiple languages can also help to accommodate non-English speakers. The University of Utah also specified that their approach to the implementation of mobility hubs would be categorized into three tiers or phases so that different hub types can be implemented from the short to long term. Some may not need as much time or development as others, so this will allow a staggered construction schedule, so it does not have to all occur at the same time.

Review of current GT policies and plans

Comprehensive Campus Plan

Georgia Tech currently is in the process of updating their Comprehensive Campus Plan (CCP), which includes plans for addressing transportation related mobility and accessibility issues on campus (Georgia Tech 2023). The current phase of the planning process has a thorough overview of the CCP team's ideas for the future of mobility at Georgia Tech. This includes an outline of the current conditions of the campus's transportation system, with encompasses transit, pedestrian, bicycle, and motorized vehicle networks. Following this review of existing conditions are recommendations for improving the networks in areas that have the opportunity for development. For instance, this includes where bike lanes should be further protected or connected, streamlining of existing transit routes, and locations of potential mobility hubs. The team developing the CCP have considered various factors when developing the plans for improvement.

The following set of maps are some of the outputs that identify the current conditions on campus, and a visualization of what future improvements to the network could look like. The first map identifies all the pedestrian walkways and paths located throughout campus. The paths shown in **Figure 3** include streets, sidewalks, and paths that have pedestrian access. One thing to note is that the streets on campus are primarily owned by the City of Atlanta, but they collaborate with Georgia Tech for maintenance and improvement projects. This will be the greatest challenge to implementing the type of mobility hubs that would be most effective on campus as it requires that majority of the right of way of the streets are reconfigured to meet the needs of multiple modes of transportation. In general, the pathways are quite disconnected outside of the campus core, which can cause pedestrians and micro-mobility users to take longer routes that take more time. This is why there are many 'desired paths' on campus where students cut across lawns, parking lots, and across streets at non-designated crossings. Implementing mobility hubs throughout the campus can provide a terminal through which footpaths can be connected, and people can get to their destinations in a more direct manner.

Figure 3 Pathways and Walkways on campus *Source: CCP 2023*

Georgia Tech has their own transit service (The Stinger) that primarily serves students and staff who either live in the surrounding neighborhoods of the campus or connect through the Midtown MARTA Station. This service is funded through a portion of student tuition cost, so there is no fee collected during boarding. As shown in **Figure 4,** the Stinger currently has eight service routes that provide service through the Home Park, Atlantic Station, and Midtown neighborhoods, in addition to the campus service. There is also a line that provides connections to Emory University for students and faculty that have cross registration or cross-appointment positions. The service has many different areas of coverage; however, the primary concern that riders have is the reliability and efficiency of the service. There is a transit app that has gone through a few updates to provide better real time information, but there are still several delays and inaccurate timing updates. Also, while there are many routes to cover the area, there is a lot of overlap that has significantly impacted the efficiency of the service. The majority of the routes overlap, and the intention is to provide different routes to meet the needs of different areas, but the overlap creates more delays and increased dwell times at each stop. The CCP team has developed a more efficient recommendation for the transit routes, as shown in **Figure 6**.

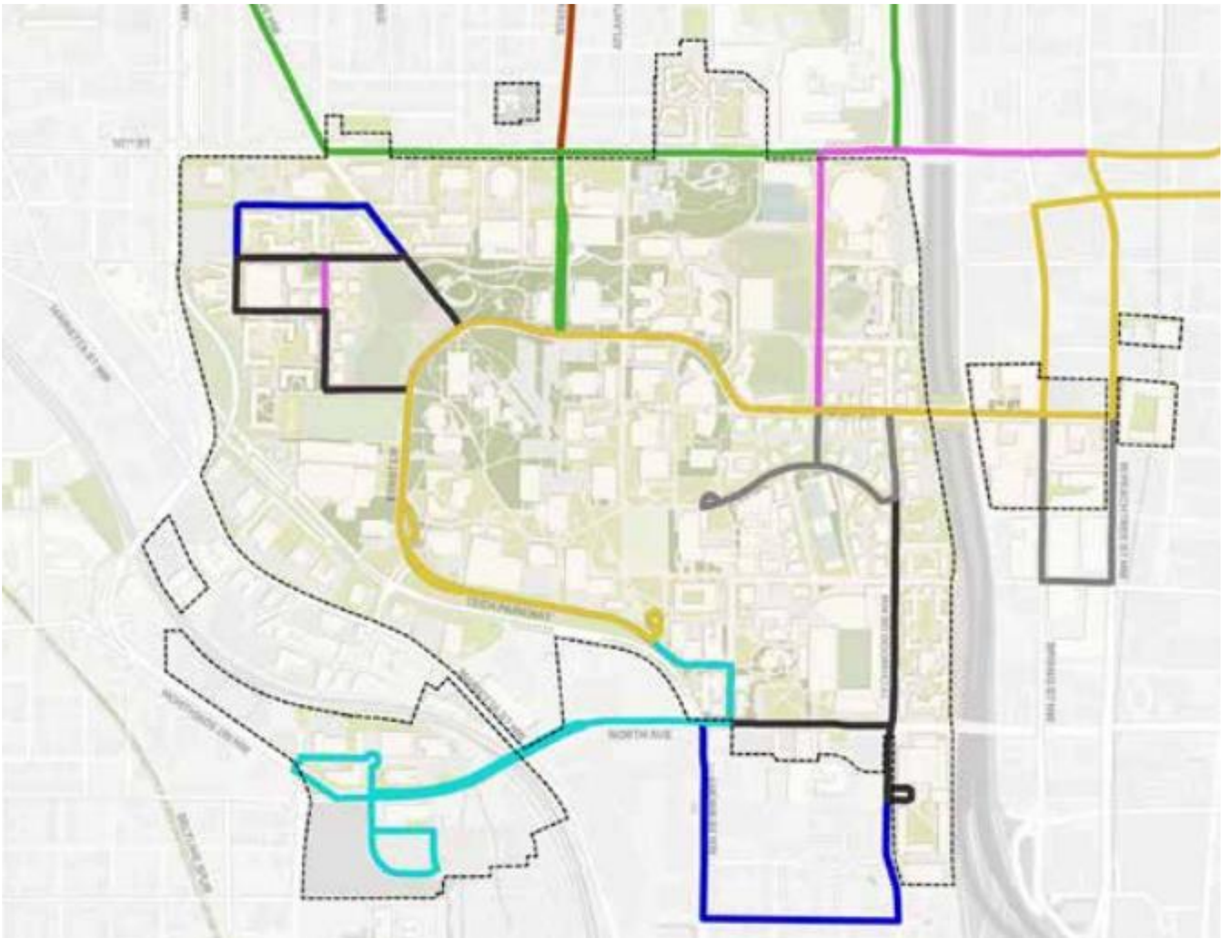

Figure 4 Existing Stinger transit routes on campus *Source: CCP 2023*

The current configuration of bicycle facilities predominantly provides medium- and low-protection pathways. The mid-protection lanes are along Ferst Drive and State Street, and the low-protection pathways are not necessarily designated bike lanes but shared use paths with pedestrians and other micro-mobility users. What sets apart a low and medium protection bike lane from a high protection cycle track is the use of vertical or physical barriers between roads and motorists. The only bi-directional cycle track is located on Tech Parkway, which connects from Marietta Street to Luckie Street NW. **Figure 5** depicts the existing bicycle infrastructure on and within campus, as well as plans for creating new facilities and improving existing facilities.

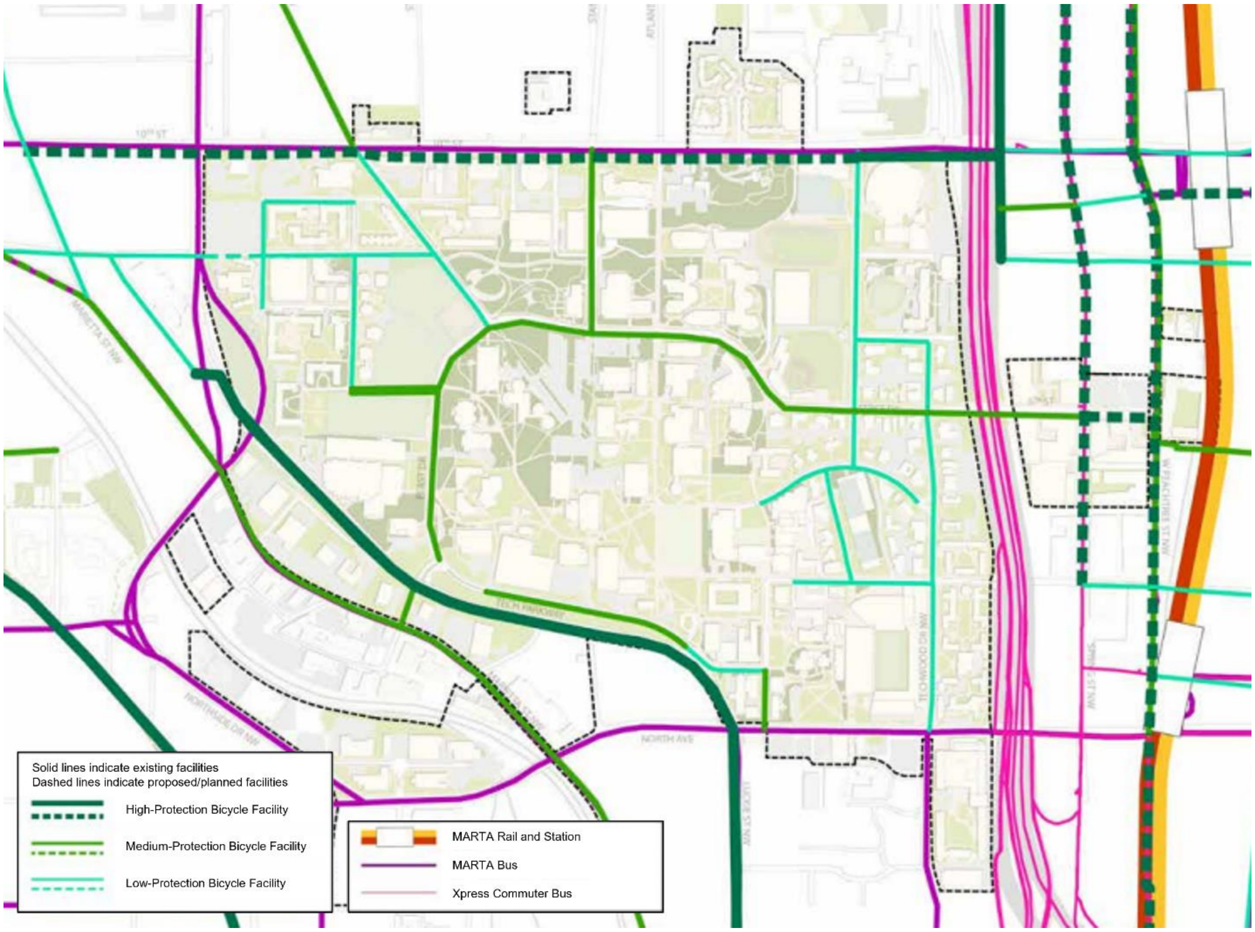

Figure 5 Existing and proposed bike infrastructure on campus *Source: CCP 2023*

The campus planning team identified 10 locations for building potential hubs **Figure 6** that are located where current surface lots and parking garages are located. Parking lots and garages provide a foundation for building a mobility hub and eliminates the initial challenge of having to find an available space and utilizes current space on campus without having a great impact on density. To maximize the effectiveness and efficiency of the mobility hubs, the first step needs to be identifying the points of intersection between all the modal networks as they currently are, as well as their plans for improvement. This will dictate which locations for mobility hubs will make the most sense and meet the goal of a car-free campus core.

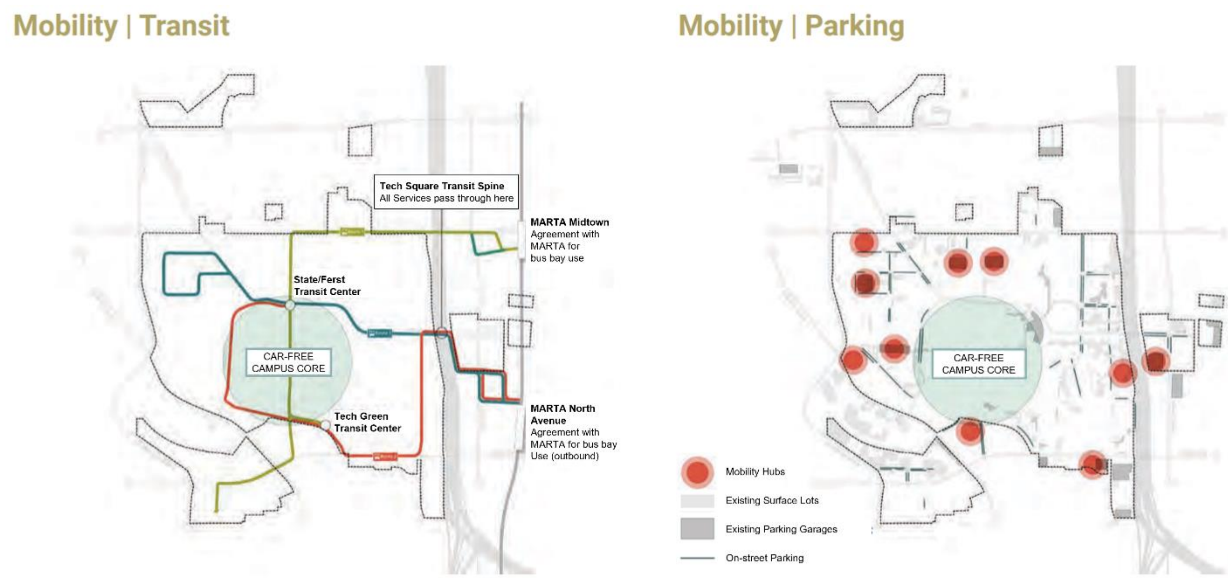

Figure 6 Proposed streamlined Stinger network (left) and proposed locations for mobility hubs (right) Source: CCP 2023

Figure 7 shows the mobility recommendations made by the campus planning team, as well as the locations for planned mobility hubs, that will be either implemented as new builds or repurpose of existing parking structures.

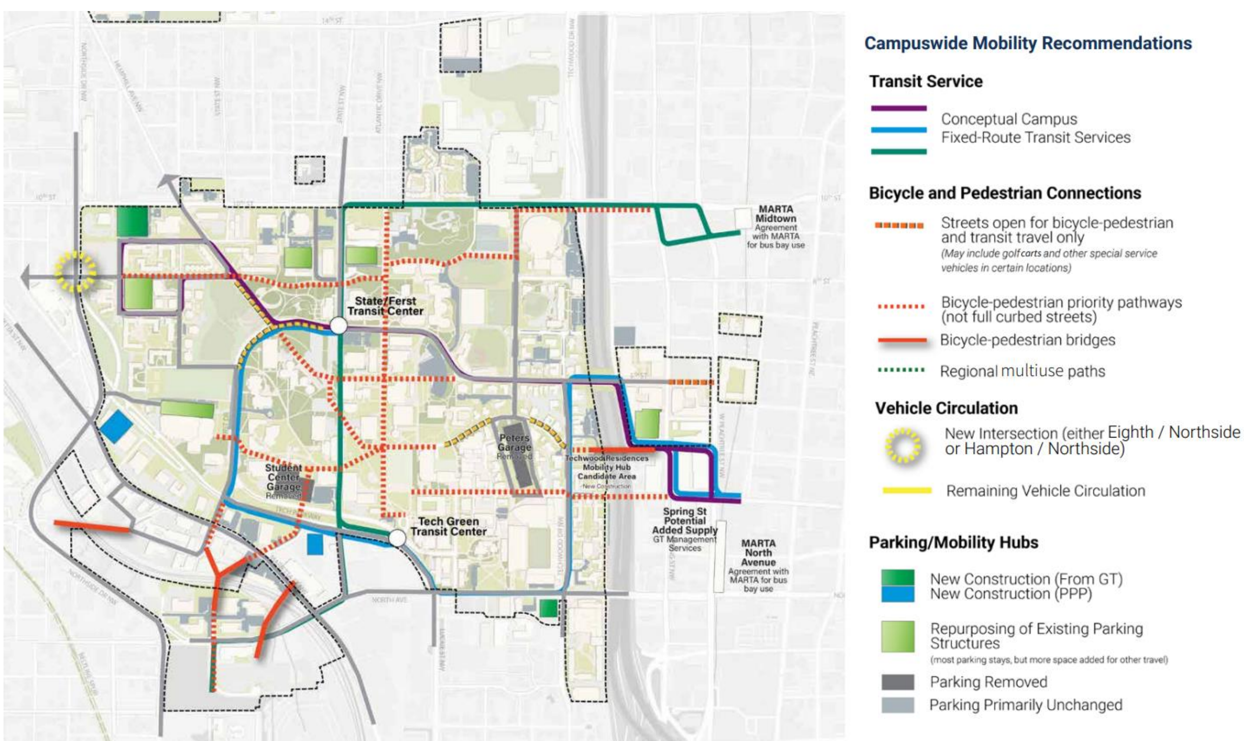

Figure 7 All mobility recommendations proposed by campus planning team *Source: CCP 2023*

The plans outlined and recommended by the CCP team is important to review to identify which hubs would be most critical to implement first to work towards the goal of integrating all modes and addressing the needs of the Georgia Tech community. These plans will be used as a basis for developing the climate considerations that will help reduce carbon emissions and have reduced impact on the environment during the construction phase.

Climate Vulnerability Assessment

Students enrolled in the School of City and Regional Planning Climate Change Studio at Georgia Tech have developed a Climate Vulnerability Assessment to determine the risks and vulnerabilities that Georgia Tech, as an institution and community, may face according to various climate hazards. For the purposes of this study, a review of the risks and vulnerabilities to heat were examined to determine the existing conditions of temperatures on campus and develop mitigation strategies that can be incorporated into sustainable mobility hubs. The section primarily addressed the temperature variations on campus, and locations of solar panels and cool roofs.

According to research, exposure to heat can be looked at locally in terms of urban heat islands. Urban heat island is when temperatures in an urban area, or parts of an urban area, are warmer than temperatures in a nearby rural area (EPA 2023). Differences in surface materials, trees, and greenspaces across cities determine the intensity of heat felt by individuals in those areas. A study by Mallen and colleagues identified areas of Georgia Tech's campus that experience greater urban heat island intensity than others, with cooler temperatures being associated with greater density of trees while warmer temperatures were associated with greater proportion of impervious surfaces such as concrete and buildings that absorb and retain heat (2020). **Figure 8** illustrates the maximum temperatures reported through temperature sensors between June and August 2017 (Georgia Tech Urban Climate Lab 2017).

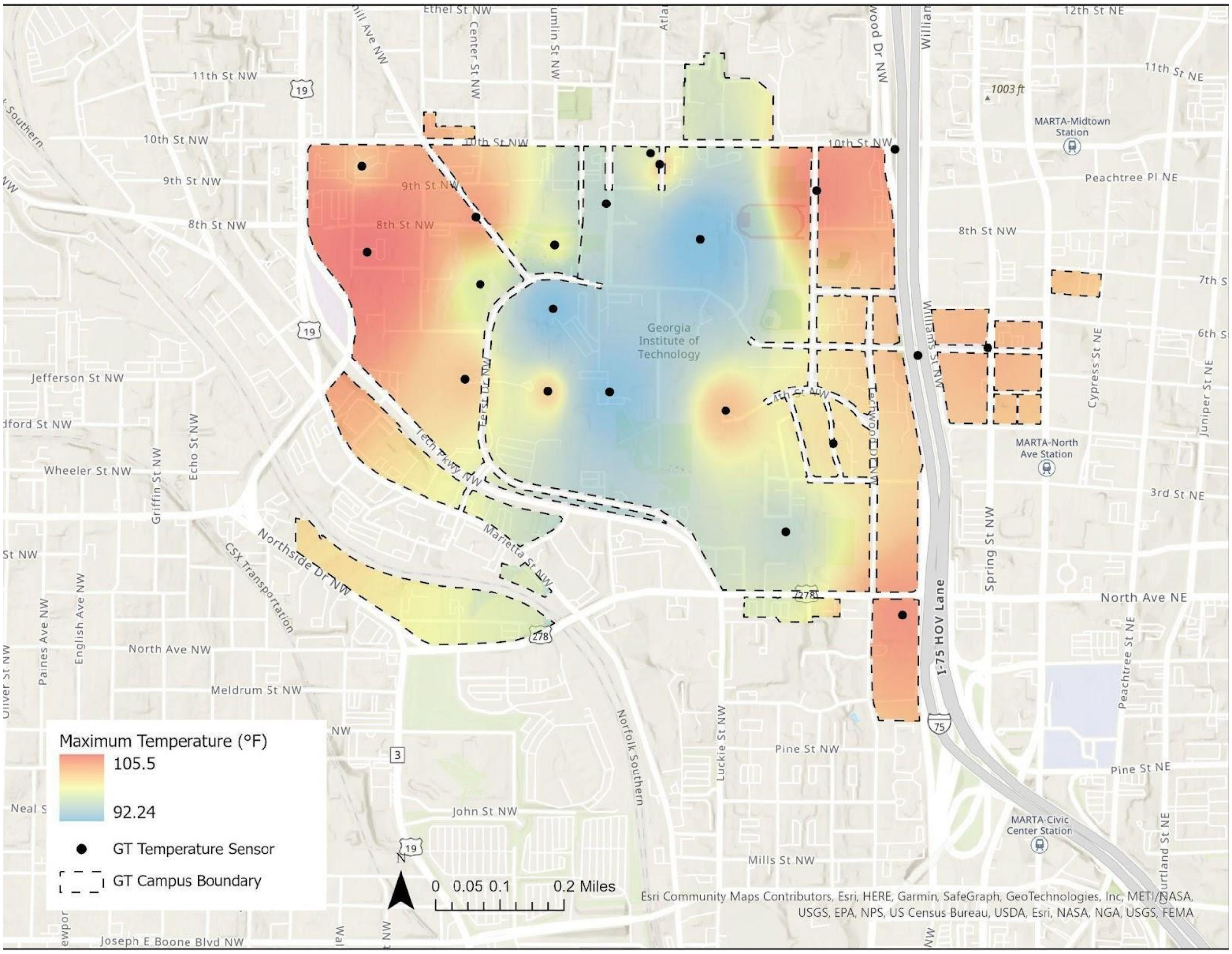

Figure 8 Maximum Temperatures on campus *Source: Georgia Tech Urban Climate Lab 2017*

Aside from risks to the individual, housing over 8,700 residents on campus requires substantial energy for cooling during days with high temperatures. Georgia Tech primarily sources its electricity from Georgia Power, which relies on an electrical grid. In the event of a loss of that supply, such as a power grid failure, the university's backup energy source is natural gas. However, the energy generated by natural gas is intended to provide lighting in hallways and for exit signs and is insufficient for heating and cooling loads (Clonts 2023). As the energy supplied from natural gas is not enough for cooling, this also means there are no designated cooling centers on campus where residents can go for relief if a power failure occurs during a heat wave.

The university does have some solar panel infrastructure in place and has assessed buildings and spaces on campus for potential to install additional panels. According to data provided by Georgia Tech's Infrastructure and Sustainability Office, as of

October 2023, there are 959 solar panels generating energy on Georgia Tech's campus and over one third (36.77%) of campus buildings assessed for candidacy were marked as potential candidates for solar installation (Clonts 2023). **Figure 9** is a map of buildings and parking spaces on campus indicating potential for solar panel installation and where the current panels are located.

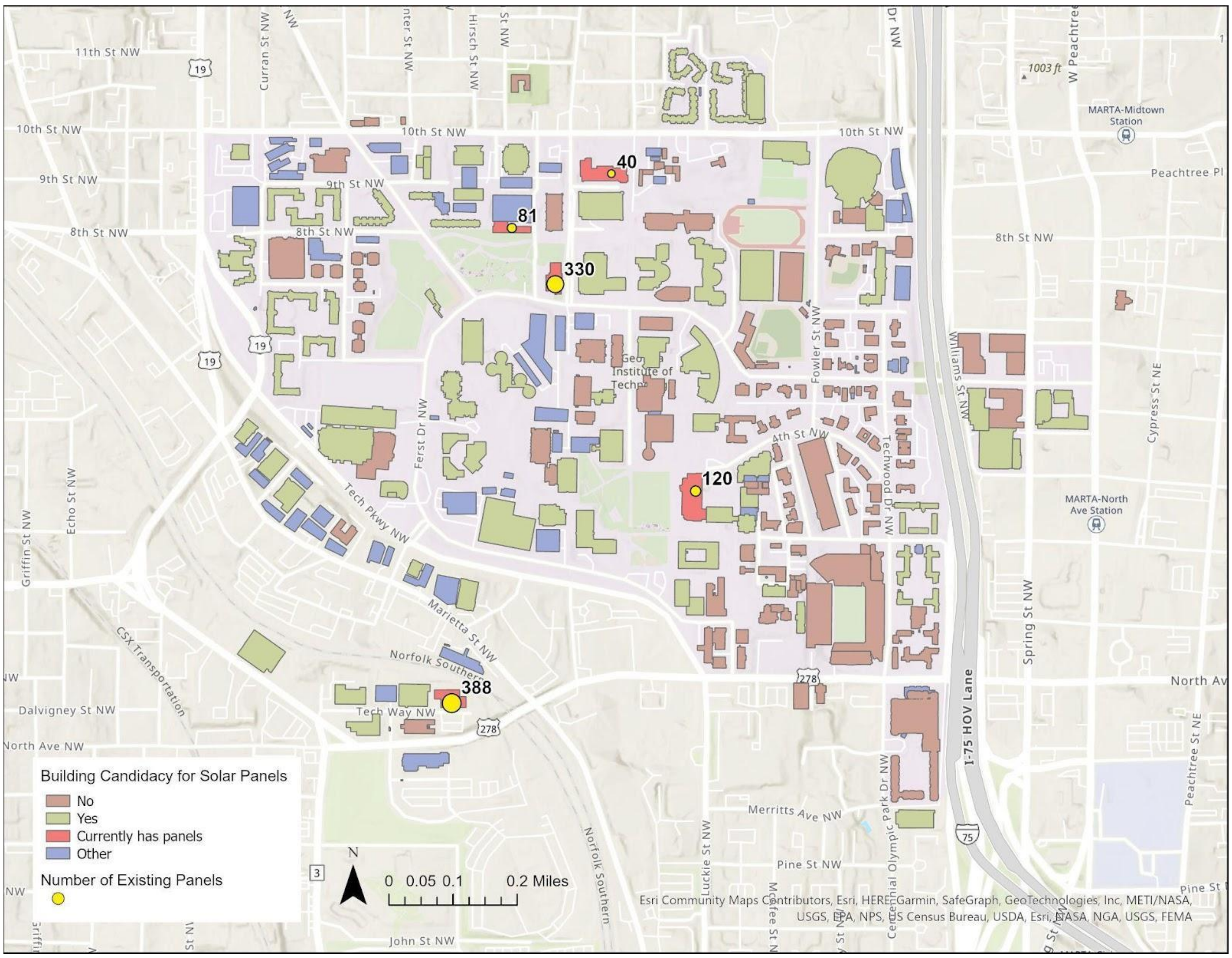

Figure 9 Solar panels on campus *Source: Georgia Tech Infrastructure and Sustainability 2023*

The increased energy demand during days with high temperatures and heat waves is exacerbated by inefficient buildings (U.S. Department of Energy, n.d.). Buildings that are not well-equipped to keep heat out and cool air in during high outdoor temperatures require more electricity to maintain a comfortable indoor temperature. High temperatures are a catalyst for a cycle of increased energy demand which means an increase in carbon emissions which contribute to continuing climate change which is causing temperatures to rise which increases energy demand. One mitigation strategy for reducing energy demand that some campus buildings have adopted is painting a building's roof white. The white color reflects light and reduces the heat absorbed by the building. **Figure 10** shows buildings on campus that have a white roof. Buildings with roofs light in color or with only sections of the roof painted white were not indicated on the map as having a white roof, so in reality the actual total surface area of white roofs on campus is slightly higher than illustrated by the map.

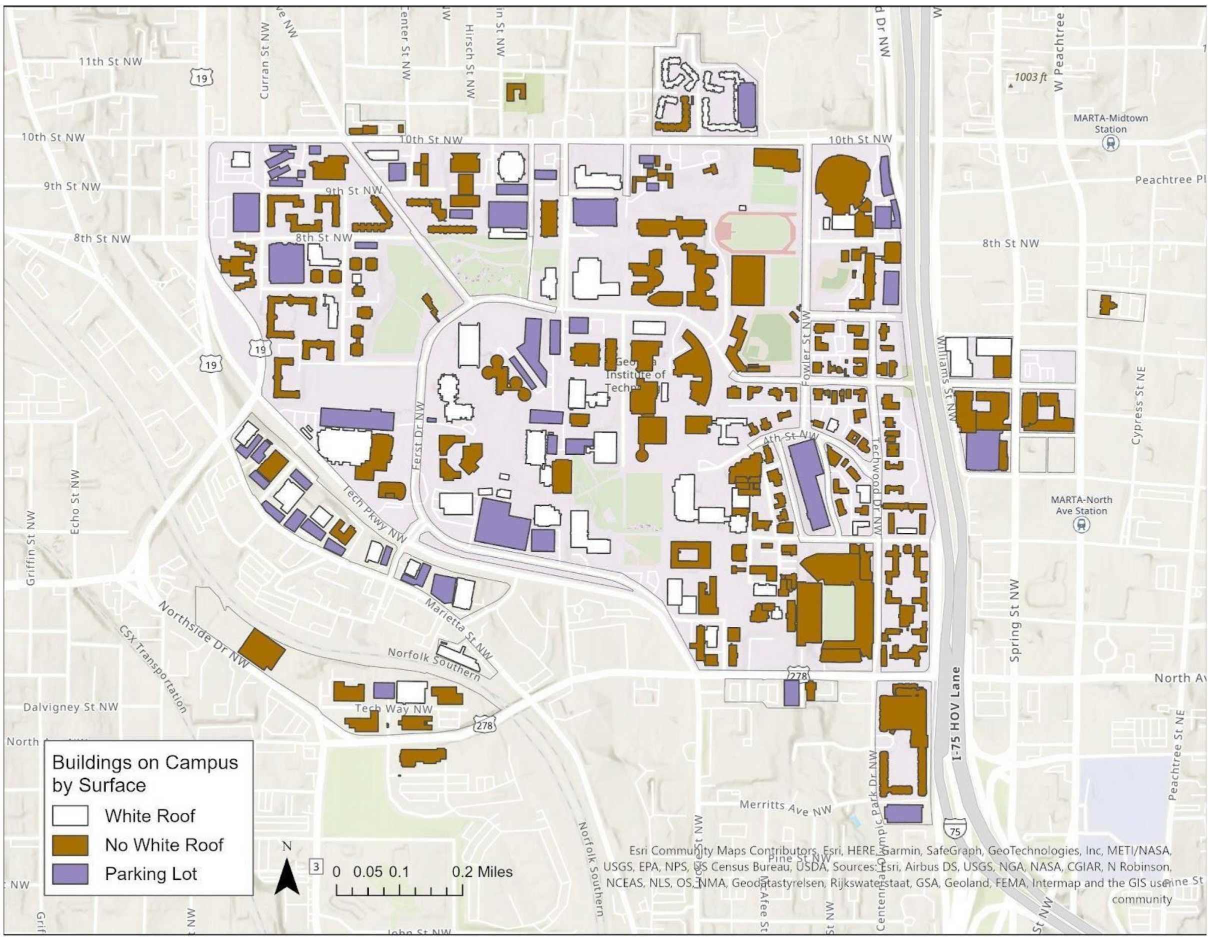

Figure 10 Cool roofs on campus *Source: Georgia Tech Infrastructure and Sustainability 2023*

Considering that 53% of Georgia Tech's emissions are caused by the transportation sector and 32% of total emissions come from faculty, staff, and student commute, it is imperative to consider strategies that can reduce this contribution (Georgia Tech Facilities 2023).

Methods: Considerations for Mobility Hubs at Georgia Tech

What to consider when implementing Mobility Hubs

User Education

There are many tools that can be used to ensure that the concept of a mobility hub and how to navigate it are clearly explained so that all users are able to use it comfortably and confidently. Some of the tools include digital wayfinding devices and signage that provide directions to users so that they can find access to the mode they need or facilities for bicycles and scooters. They can also provide real-time data on transit timing and delays, as well as information on where available scooters are parked throughout campus, which can be accomplished through collaborations with Transportation Network Companies (TNCs), and where other mobility hubs or bike and scooter locking stations are located through campus. Many digital wayfinding signs or kiosks are solar powered, which is a low-maintenance energy source that does not rely on the campus electricity system, and it acts as a light source at night which is an additional safety measure (IDS)

Space Constraints

One of the major challenges of implementing mobility hubs in an area that already has a set transportation network is that there may already be significant development that shapes the built fabric of the area. This can present potential barriers to design of the mobility hub, which may infringe on the hub's ability to provide the desired efficiency and access to the modes that should be accessible there. One solution to this is repurposing current structures, such as parking garages and surface lots, to maximize the space dedicated to mobility hubs. This does not necessarily mean parking spaces will be significantly reduced, but rather arranged more efficiently to present the alternative modes of transportation in an equally or more accessible manner. This could require curbside management strategies to utilize the curb space that may not currently be serving a desired purpose to install bike and scooter stations closer to pathways dedicated for these devices to allow for seamless transition. From a sustainability perspective, incorporating green infrastructure in areas that are exposed will ensure that the space dedicated for the mobility hubs utilize all opportunities for incorporating vegetation, while maintaining density. A more intensive approach with a long-term timeline for addressing space constraints is implementing road closures that only provide access to public transit or micro-mobility vehicles.

Adaptability to changes in mobility technology

When designing mobility hubs, one characteristic that should be prioritized is versatility or flexibility. Often when the built environment is developed, developers and planners may not consider the possibility of change in the future that could result in the need to alter the physical configuration of a given space. For instance, on Georgia Tech's campus, there are several parking garages and surface lots, many of which are located within the campus core, which is implemented with the assumption that the campus is accessible and will continue to develop around car-centric development. With the addition of public transit and shared-use mobility options, these alternatives are forced to be integrated into a car-centric environment, which makes it more difficult to truly incorporate these developments in an equal playing field.

Implementing mobility hubs will be an arduous and lengthy endeavor because the built environments like parking structures were not built with the potential for integration of alternative modes of transportation. Going forward, mobility hubs should be built with this idea in mind, in the event that new technology may emerge, and spaces should be built in a way that can allow for flexible transition to accommodate these potential new technologies. Digital wayfinding devices are a great way to promote this flexibility as the information that is presented on these devices can be updated for the purposes of the current era of technology. While solar powered charging technologies are still new concepts and under development, the EV and e-bike/e-scooter charging stations can draw power from solar energy that is integrated into the mobility hub. This can be incorporated through solar roofs and shelters, which can serve multiple purposes as technologies evolve and the use-case of the mobility hubs adapt over time.

Community engagement

Gaining insight from the community will ensure that the mobility goals of the campus to become less reliant on cars and more accessible for alternative modes of travel is prioritized. The experience of pedestrians, cyclists, drivers, and transit users are unique to each individual because of many factors, from distance, time, mode shift, mobility impairments, and affordability to name a few. The demographics that utilize spaces on university and college campuses come from diverse backgrounds that have informed their travel decisions and preferences, so it is important to accommodate these individuals while driving the goals of increased mobility and building sustainable infrastructure. The commuter survey is one way to engage the community, but many may not have the time or dedication to completing this survey, so coming up with creative approaches and physical demonstrations on campus to show people what the university plans to do to address their mobility needs may capture additional attention. While climate change is an important issue for many people, it can be a challenge to work towards sustainable travel decisions if the infrastructure is not conducive to that goal, so creating a space that meets the interest and needs of the community can lead to climate driven changes in travel behavior.

Methods: Climate Implications of Mobility Hubs at Georgia Tech

The climate benefits of mobility hubs have been studied extensively by researchers because while mobility hubs do serve the physical purpose of connecting different modes of transportation, the primary purpose of developing this connection point is to move away from car-oriented development and ultimately reduce car-use related emissions by using other modes. In this sense, mobility hubs are at its foundation a strategy for climate change mitigation and are an effective to actively alter travel patterns and travel behavior of individuals. This in turn alters the transportation fabric and framework that city planners and transportation professionals utilize for developing cities. The purpose of this section is to identify climate benefits of implementing mobility hubs, and then utilize the best practices outlined by other institutions and Georgia Tech's CCP to inform what elements should be present at the hubs to ensure there is a climate focus when implementing.

Seamless and convenient mode shift

The seamless and convenient mode shift opportunities facilitated by mobility hubs allow for more direct and straightforward ways to get around campus, with fewer barriers to come across and shorter distances. This will reduce the travel time required between places on campus, which helps to reduce overall travel-induced emissions. Having two types of mobility hubs can be beneficial on campus to develop the desired travel patterns of the campus community. If the goal is to maintain a car-free campus core, then parking lots that are on the periphery of campus can be transformed into mobility hubs that provide parking spaces for drivers to then connect to other modes to travel throughout campus, and for buses to connect people to the outside of the campus. Within the campus core or throughout the campus, a different type of mobility hub can be implemented that focuses primarily on active modes of transportation that allows for more compact mobility hub spaces and streamlined modal shift.

Reduced emissions using public transit (shuttle) and active modes

The streamlined Stinger transit route recommended in the CCP is critical to achieving reduction in carbon emissions. The overlap of routes causes longer dwell times, increased traffic, and longer travel times and route distances, which leads to more emissions being released into the atmosphere. Transit is a significantly more carbon efficient transportation alternative to single-occupancy vehicles (SOVs), but the configuration can also play an important factor in how much emissions are reduced (Griswold et al. 2017, 4). In addition to the streamlined transit route outlined in the CCP, mobility hubs should be strategically placed along these routes so that other modes can be accessed to compensate for any loss of service that results from the reduced transit service.

Greater availability of EV charging stations

While the general goal is to reduce car dependency through the implementation of the mobility hubs, enhancing electric vehicle (EV) infrastructure specifically contributes to the City of Atlanta's mission of working towards clean energy and carbon emission reduction (City of Atlanta 2023). As Georgia Tech is in a very central location of Atlanta, the institution can contribute to reaching these goals through providing EV charging infrastructure throughout campus. When parking lots are converted into mobility hubs, it can facilitate a connection for EV users to use transit or active modes of transportation to get around campus while their vehicle charges.

Promotes TOD

Implementing mobility hubs on a university campus that is central to the fabric of a metropolitan city like Atlanta can have impacts that reach outside the boundaries of the campus. From an institutional perspective, the goal is to provide greater access to campus buildings, reduce travel time, and promote density in development to ultimately reduce emissions. It is important to take into consideration the student and staff populations that live in the surrounding neighborhoods of campus. While the purpose of this study and the CCP is to address the needs of the campus, mobility hubs that are located on the periphery should be built in a manner that is conducive to future TOD in the event that Atlanta's public transit can be incorporated into those peripheral mobility hubs. It is also essential to have mobility hubs on campus that provide connections to services and amenities like grocery stores, shops, banks, and other places that people frequent to facilitate a smoother transition between the campus core to the external city environment. Creating these pathways that help students and staff to access places outside of campus will encourage them further to use the different modes of transportation made available on campus. If people rely more on these alternative modes, they can recognize micro-mobility as an option that can connect them to external destinations.

Proposal: Integration of Sustainable Infrastructure on Campus Mobility Hubs

By incorporating climate driven elements to Gorgia Tech's campus mobility plan, a bridge between the CCP's goals and the institution's Climate Action Plan (CAP) can be created. There are currently 10 potential mobility hub locations identified by the CCP, which are all located at existing parking garages and parking lots. Details about elements of these mobility hubs are not specified in the CCP, which is important for ensuring sustainability and accessibility measures are incorporated into the design and implementation process. After reviewing the locations of these hubs, 14 potential mobility hub locations have been selected that include a combination of elements from 11 that have been considered. The selected mobility hubs, as shown in **Figure 11** were categorized based on the definition of small, medium, and large-scale mobility hubs provided by the NCTCG (2023, 3).

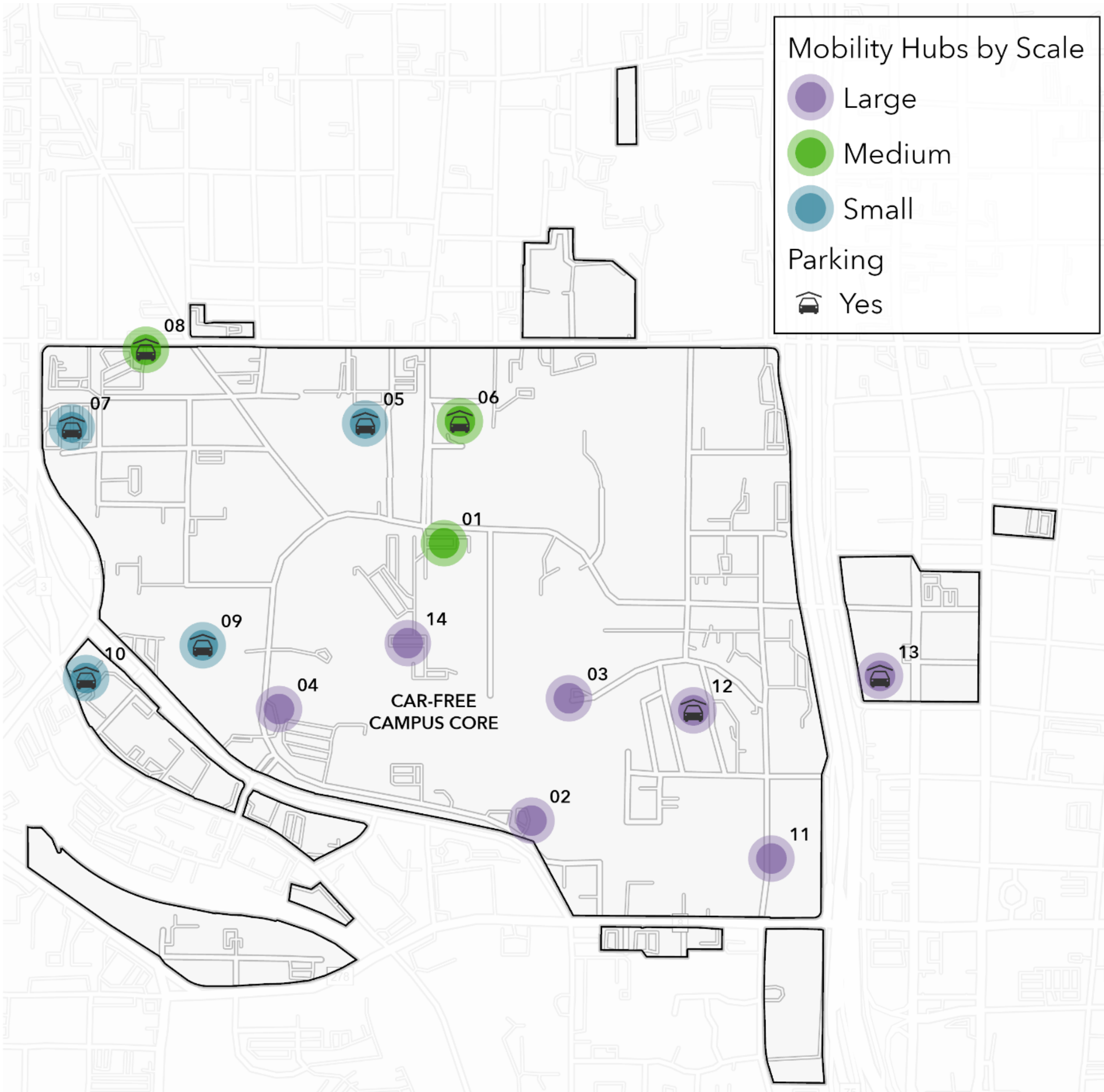

Figure 11 New proposed mobility hubs with climate focus *Source: Author 2023*

The 11 elements chosen to include at each location were developed based on the considerations and climate implications discussed in the methods section. To create mobility hubs that serve the need of each location, a combination of these elements can be implemented. **Table 2** outlines the elements that were selected and the purpose each of them serve at the three proposed scales.

Table 2 Elements incorporated into mobility hubs and description of purpose

	Purpose
Parking	Parking garages and surface lots on the periphery of the campus core allow access to campus by car and an existing structure to easily build out a transit connection and provide secure micro-mobility storage and charging infrastructure. Not all parking spaces were selected for mobility hubs, and not all surface lots were kept for parking spaces, for the purposes of this study.
Bike	Bicycle facilities that include racks, secure storage and charging stations at all locations on campus allow community members to feel confident in leaving their bike in storage for longer periods of time. Designated shared-use bicycle parking at several locations promotes proper use of pick-up and drop-off locations that do not physically obstruct pedestrian or vehicle right-of-way.
Scooter	Scooter facilities that include racks, secure storage and charging stations at all locations on campus allow community members to feel confident in leaving their scooter in storage for longer periods of time. Designated shared-use scooter parking at several locations promotes proper use of pick-up and drop-off locations that do not physically obstruct pedestrian or vehicle right-of-way.
Transit	Transit stops along the CCP's streamlined transit network that provide connections to other modes which compensates for any loss of service that results from the reduced transit service.
Lighting	Lighting is an important safety measure that should be included at all mobility hubs, regardless of scale.
Solar Power	Solar panels and solar powered charging infrastructure can greatly contribute to the use of alternative modes of transportation as the infrastructure to sustain them are available. This will ensure that the mobility hubs can be self-sufficient as it will not contribute to the City's electricity grid.
Greenspace	An urban tree canopy and vegetation are essential to reducing the impacts of many climate hazards on campus and can help achieve resiliency goals such as water management and heat reduction. The vegetation should especially be used for rooftops of parking garages and at the entrance of the mobility hubs.
Wayfinding	Digital wayfinding is versatile as it can be used to provide real-time transit data, information for visitors, and provide direction on where other mobility hubs and amenities are located throughout campus.

Charging	Charging infrastructure can be implemented to promote EV usage, as well as provide space for e-bike and e-scooter users to charge their devices as needed.
Seating	Seating is an accessibility measure for individuals who may require mobility assistance, as well as a tool for placemaking by creating a space to study, rest, and collaborate either in a recreational manner, or as a temporary stop while waiting for transit or rideshare pick-up.
Shelter	Shelters provide a safety measure against weather conditions, as well as a designated place to wait for transit.

Source: Author 2023

Certain criteria were used to determine which elements would benefit from being grouped together at each hub (**Figure 12**). In this proposal, bike and scooter facilities, lighting, greenspace, seating, solar power, and shelters are included at all hubs. The remaining elements were assigned at each location based on the potential space available and area of campus that is serviced.

	Parking	Bike	Scooter	Transit	Lighting	Solar Power	Greenspace	Wayfinding	Charging	Seating	Shelter
MH 01	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
MH 02	✗	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓
MH 03	✗	✓	✓	✗	✓	✓	✓	✓	✗	✓	✓
MH 04	✗	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓
MH 05	✓	✓	✓	✗	✓	✓	✓	✗	✓	✓	✓
MH 06	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
MH 07	✓	✓	✓	✗	✓	✓	✓	✗	✓	✓	✓
MH 08	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
MH 09	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓
MH 10	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
MH 11	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
MH 12	✓	✓	✓	✗	✓	✓	✓	✗	✓	✓	✓
MH 13	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
MH 14	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Figure 12 Summary of elements proposed at each location *Source: Author 2023*

Conclusions

The analysis completed for this study provides insight into the potential for mobility hubs to be incorporated into the transportation system at Georgia in a way that utilizes the current infrastructure and focuses on a climate driven approach. Without disrupting the flow of movement and drastically impacting commute and travel patterns for people using alternative modes of transportation, mobility hubs provide a practical solution to efficient, accessible, and inclusive transportation options. In recent years, many universities have begun to implement completely car-free campus cores, which began as street closures, then evolved into a redevelopment of streets into bike lanes and multi-use paths for active modes of transportation (UCSB 2019). This trend marks a change in the way university and college campuses are planned and is a gateway for understanding how mobility hubs can be integrated into the fabric of a city. What all the university mobility plans that were reviewed for this study indicate is that when people have better experience through alternative modes of transport, they can experience a change in travel behavior. If Georgia Tech can lead by example, there could be an opportunity for Atlanta to move in this direction as well, if mobility hubs are viewed as an enhancement of the current system that is feasible to pursue in the near future.

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