PERCEIVED IMPORTANCE AND OBJECTIVE MEASURES

OF BUILT ENVIRONMENT WALKABILITY OF A UNIVERSITY CAMPUS

by

XUAN ZHANG

(Under the Direction of LAN MU)

ABSTRACT

The built environment plays an important role to shape physical activities. On such a premise, the obesity gene in the uninviting neighborhood structure could cause environmental-induced inactivity, particularly in walking. Existing walkability measurements only consider facilities features and potential destinations, but fail to count for built environment design aspects, people's preferences or other walking purposes. This study designed a walking preference survey to identify and measure the perceived importance upon built environment factors. Survey results were analyzed with modified Analytic Hierarchy Process (MAHP) and varied statistics and geographic information systems (GIS) methods. The research combines the perceived importance and objective measures into a factor-weighted index to quantify walkability. A case study at a university campus illustrated the detailed variation in the walkability. Survey results speak for people's walking preferences, such as sidewalk availability, flat slope and green space in amenities. The limitation and extension of the research are also discussed.

INDEX WORDS: Walkability, Health, Geographic Information Systems (GIS), Modified Analytic Hierarchy Process (MAHP), Walk Score®

PERCEIVED IMPORTANCE AND OBJECTIVE MEASURES

OF BUILT ENVIRONMENT WALKABILITY OF A UNIVERSITY CAMPUS

by

XUAN ZHANG

BS, Wuhan University, China, 2014

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2016

PERCEIVED IMPORTANCE AND OBJECTIVE MEASURES

OF BUILT ENVIRONMENT WALKABILITY OF A UNIVERSITY CAMPUS

by

XUAN ZHANG

Major Professor:	Lan Mu
Committee:	Jerry Shannon
	Xiaobai Yao

Electronic Version Approved:

Suzanne Barbour
Dean of the Graduate School
The University of Georgia
May 2016

DEDICATION

To all the people that want to walk out a way to better life.

ACKNOWLEDGEMENTS

Two years are not long but not too short. Everything happened and everyone with me during that period, have given me supports, love, inspirations or some lessons to learn. I want to offer my grateful thanks to everyone who was there with me.

First I would like to thank my advisor, Dr. Lan Mu, who brought me into the walkability world and constantly provided assistance all the way through. You make my life here more like home. To tell a secret, you changed my thought about whether going further in my research or not, and you are the person I want to be. Appreciations to my committee members: Dr. Jerry Shannon, for bearing me ask unclear or illogic questions, for the assistance when I was in the dark, for making statistics and coding fun, and understanding that English is my second language; Dr. Xiaobai Yao, for teaching me how to think spatially, and helping me make this blurred idea into a detailed thesis research. I also appreciate the planning and design perspectives that I was exposed to in the classes of Dr. Stephen Ramos and Dr. Umit Yilmaz (College of Environment and Design).

I would also thank my friends who is/was spatially correlated with me: Linli Zhu, for being a great friend and senior to help me out and comfort me when I was nervous, and for the happiness that you brought to us; Wuyang Cai, for being energetic, interesting and a foodie friend; Dorris Scott, for connecting me to the real American life and culture; Katy Kane, for being my supportive language partner and solution provider to Athens-related questions; Wenjing Xu, for showing me a different life style a Chinese girl could have; Kelly Harris, for all the conversions before and after class; Mingshu Wang, for those new ideas and actions; Qinjin Fan, for the experience sharing and technical support; Dorri Oh, for the Korean food and game; Julia Connell, for the bike lane data; people I met in the DEVELOP, for the learnings and fun.

Thanks for Sarah Turula at the UGA Writing Center for revising my grant proposal and make the whole thing better. Thanks for the Office of Architecture to generously provide the GIS data of UGA. Also want to spread my appreciation to the Office of Sustainability for the 2016 Sustainability Grant and support to reach out for more people to know and participate; AAG EPBG (Environmental Perception & Behavioral Geography) specialty group for the travel grant. Thanks for UGA Geography Department and our staffs' assistance: Emily Coffee, for putting out the flyers over the building, Amy Bellamy, for her kindness and beautiful smile; and Jane Kenney Worley, for helping me use the grant money wisely. Also need to be grateful for everyone's forward and attention to my survey email, because without their help, the survey was not able to have more than 400 participants.

Sweet thanks for my soul mate (hopefully), Xiaodong Jiang. Thanks for being supportive to me, being passionate about learning, enduring my volatile emotions, being great in cooking, and loving for animals. Thanks for seeing the world and going to places with me (especially driving me on campus day and night for millions of times to collect the field data). You let me mature but still keep my simplicity.

I also own acknowledgement to the anonymous participants who took their time to involve in my survey and make my research meaningful. You are the ones that care about making a difference, and this study wants to speak for you.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Page

CHAPTER 1

INTRODUCTION AND PROBLEM STATEMENT

Overweight and obesity are among the severest health problems in the U.S., and more than one-third of adults are obese (Ogden, Carroll, Kit, & Flegal, 2014). As the second leading cause of preventable death, which may soon overtake tobacco as the top one, overweight and obesity are associated and contribute to other diseases including coronary heart disease, high blood pressure, type 2 diabetes and more (National Institutes of Health, 2012; New York State Department of Health, 2014; West Virginia Health Statistic Center, 2002). Research has proved that physical activities benefit people's health by reducing the possibility to be overweight, obesity, and especially in the primary and secondary prevention of several chronic diseases (Warburton, Nicol, & Bredin, 2006). The society has noticed the problem and kept underscoring the importance of getting active through all kinds of campaigns and events that promote healthier choices towards healthier lives. For example, there is a popular campaign called "Let's Move!" which was launched by the First Lady Michelle Obama in 2010. It aims at combating the epidemic of childhood obesity and encouraging a healthy lifestyle among children. Other examples include Active For Life[SM] campaign for individuals and groups, Go4Life® which provides activities guidelines for older adults, Healthy Eating Active Living (HEAL) Cities Campaign which helps make residents to engage in health behaviors. Those ongoing events and campaigns aims to advocate people to make right choices about their lifestyle towards healthier food and moderate physical activities every day. However, some characteristics in the “toxic” neighborhood built environment play a strong role in prohibiting people to be physical active. In 1999, the term “obesogenic environment” was coined to describe “an environment that promotes gaining weight and one that is not conducive to weight loss” within home or workplace (Swinburn, Egger, & Raza, 1999).

The obesogenic environment idea has been supported by many other researchers (Berke, Koepsell, Moudon, Hoskins, & Larson, 2007; Booth, Pinkston, & Poston, 2005; Galvez, Pearl, & Yen, 2010; Papas et al., 2007). Several review articles concluded that most articles showed a statistically significant positive association between some aspects of built environment and Body Mass Index (BMI), others showed the influence of built environment covers childhood obesity and older people obesity. To find out the obesogenic problems lying under the environment design and fabric, first we need to measure and compare the built environment. How to measure and further improve the environment’s walkability becomes a hot topic in multiple fields such as GIScience, City Planning and Public Health (Frank et al., 2010; Vargo, Stone, & Glanz, 2012). Researchers have done plenty of studies on walkability measurements, most of which agreed on a measurement called walkability index (Dobesova & Krivka, 2012; Frank et al., 2010). Besides, several websites describe a place’s walkability by giving an overall value, such as Walk Score®, Walkonomics®, and Walkshed©. Among them, Walk Score® is now widely used as an indicator of how friendly a place (an address, a neighborhood, or a city) is for walking in the United States, Canada, and Australia. Some researchers also regarded Walk Score® as a good and convenient tool to measure certain aspects of neighborhood walkability that can be used in academic research (Duncan, Aldstadt, Whalen, & Melly, 2013).

Several groups of researchers have done works to validate the methodology behind Walk Score® for various locations using similar methods (L. J. Carr, Dunsiger, & Marcus, 2011; Lucas J. Carr, Dunsiger, & Marcus, 2010; Duncan et al., 2013; Duncan, Aldstadt, Whalen, Melly, & Gortmaker, 2011a). The validations make this measurement quite reliable for all places and feasible for further academic and scientific applications. However, the methodology applied to the Walk Score® and all validation projects have some serious limitations such as lack of consideration for sidewalk or differentiation between varied amenities, which can skew the measurement. Additionally, the available validation cases were only performed in big cities or populous areas, and the walkability in less populous or undeveloped places remains to be uncertain.

Meanwhile, contemporary popular planning concepts and directions, such as new urbanism, smart growth, and sustainability planning, all advocate walkability, or walkable communities as an important guiding principle for its benefits on not only health but also sustainability, economy, and equity (Zhu, Lu, & Yu, 2013). Waking activity can also bring good effects on social network, community involvement and social capital development for the neighborhood (Kevin M. Leyden, 2003). Physical activities, including walking, can people healthier, and can be used as strategies to help with serious mental illness (Richardson et al., 2005). As we know more about walking benefits, some places, especially universities, have already taken actions to reach the goad of walkable environment. Recently, the Princeton University released a new Campus Plan for 2016, which has the idea of walkable campus baked into it (Office of the University Architect, 2015). In 2012, the University of Alabama published a Campus Master Plan to support and lead to a more walkable campus with a comprehensive network of streets, walkways and bicycle lanes (Campus Master Planning Committee, 2012).

Although people care about the walking environment, the existing measurements are not ideal from following aspects. First, the current methods haven’t consider the urban design part such as sidewalk conditions, walking buffer and more, which are the important factors that influence people’s walking behavior. Second, in evaluating the walkability, it is critical to understand the neighborhood’s function and more importantly, local people’s preferences on the walking environment. People have different walking needs and expectations in commercial area, residential area and a university campus. Walkability measurement needs to reflect detailed and localized walking capacity for specific areas. Third, current researches or measurements do assess the walking environment using scores. However, more future work could be done to investigate the underlying factors which city planners and urban designers can use to make the place more walkable. Last, walking can be more than a mode of transportation. There is no destination needed if people just walk around to enjoy the weather, to exercise and for other purposes. The walkability assessment may perform better without the emphasis on the predetermined destinations which are most often applied (i.e., destination-oriented) in such studies.

This study is trying to fill up those gaps and develop a new walkability measurement to capture both perceived importance and objective measures of the built environment. It aims to answer the following research question: how to assess walkability by incorporating both perceived importance and objective measures of built environment factors?

To answer that research question, we have following objectives:

1) Incorporate more urban design factors (sidewalk conditions, walking buffer, sidewalk share situation and more) into the walkability assessment and design; and launch an online survey to collect people's walking preferences on the built environment and other considerations in their walking decision making process.

2) Develop and apply the modified Analytic Hierarchy Process (MAHP) to analyze the survey results on the preferred-level aspect of walkability assessment.

3) Integrate people's perceived importance and objective measures of the built environment into the new walkability measurement for a specific area with specific functions -- UGA campus to identify the "where, what and how" to improve the walking environment.

For the community at large, the findings from this study, including survey results and campus walkability map, will provide insights on future campus planning or design.

CHAPTER 2

LITERATURE REVIEW

Previous work on this topic could be divided in to the following three groups of knowledge. First, the research focused on proving that the built environment shapes people's physical activities and health behaviors, and further influences their health status. Researchers have looked into people's travel behaviors from different perspectives such as transportation, public health, city planning and more (Cervero & Kockelman, 1997; Frackelton, 2013; Krizek, 2003). From city planning perspective, early studies have already shown associations between built environment in the area of residence and people's health behavior (Ellaway, Anderson, & Macintyre, 1997; Morland, Wing, Diez Roux, & Poole, 2002). Saelens and Hardy (Saelens & Handy, 2010a) reviewed articles regarding the correlation between built environment and walking and concluded that the built environment is associated with walking. They also provided evidence that different attributes of the built environment are associated more with walking for exercise than with walking as a mode of transportation (Saelens & Handy, 2010b). Many studies also proved the statistically significant positive association between some aspects of built environment and obesity situation(Papas et al., 2007). The influence of built environment covers people from different age groups (Berke et al., 2007; Booth et al., 2005; Galvez et al., 2010).

Second, researchers defined and explored the obesogenic environment. As a version of built environment, the obesogenic environment, which contributes to the obesity, is the reason why the neighborhood environment discourages people from active transportation choices. Automobile-oriented or car-oriented planning strategy is one causing factor of obesogenic environment. The pervasion of automobiles allows people enjoy the convenience and proficiency, but have less chances to be physically active. As the dominated strategy used in American cities, automobile-oriented planning has been criticized a lot because it satisfies the automobiles' daily use but neglect the needs of local residences as pedestrians, cyclists or the bus takers (Forsyth & Southworth, 2008; Jackson & Kochtitzky, 2001; Park, 2008). Litman (Litman, 2014) addresses the auto-oriented planning problems in urban areas by asking: Land for Vehicles or People? An automobile-oriented world will have sufficient lanes, traffic lights, traffic signs as well as large parking lots or decks, yet without concerns about whether people can walk around the place without potential danger. The walking-unfriendly built environment will but maybe unconsciously influence people's choices on the travel mode (Duncan et al., 2013). The walking-unfriendly built environment results in a huge dependence on automobiles and also contributes to health issues such as overweight and obesity (Rundle et al., 2009; Slater et al., 2013). The obesogenic environment is handicapped in providing efficient walking environment to support walking. How can the environment support people's walking choice? How can we make the environment more inviting for walking? It is time for us to tackle the problem and find the essential parts for a walkable place.

The third group involves finding how the obesogenic environment fails to support walking activities by constructing and using the walkability for evaluation. However, current walkability analyses are not comprehensive enough. Walkability is defined as a neighborhood's capacity to support lifestyle physical activity (L. J. Carr et al., 2011). The neighborhood walkability will influence local people's social interactions and health status such as obesity rate (Dobesova & Krivka, 2012; Salois, 2012; Van Dyck et al., 2010). As Saelens and Hardy (2010b) mentioned, the built environment consists of three parts: land use patterns, transportation system and urban design. Nevertheless, only two of the three parts, land use patterns and transportation system, are considered in most existing studies in the form of destination distributions and the connectivity, with the lack of evaluations for urban design part (Figure 1: grey indicate the parts have been considered, and yellow indicate the parts have not been considered).

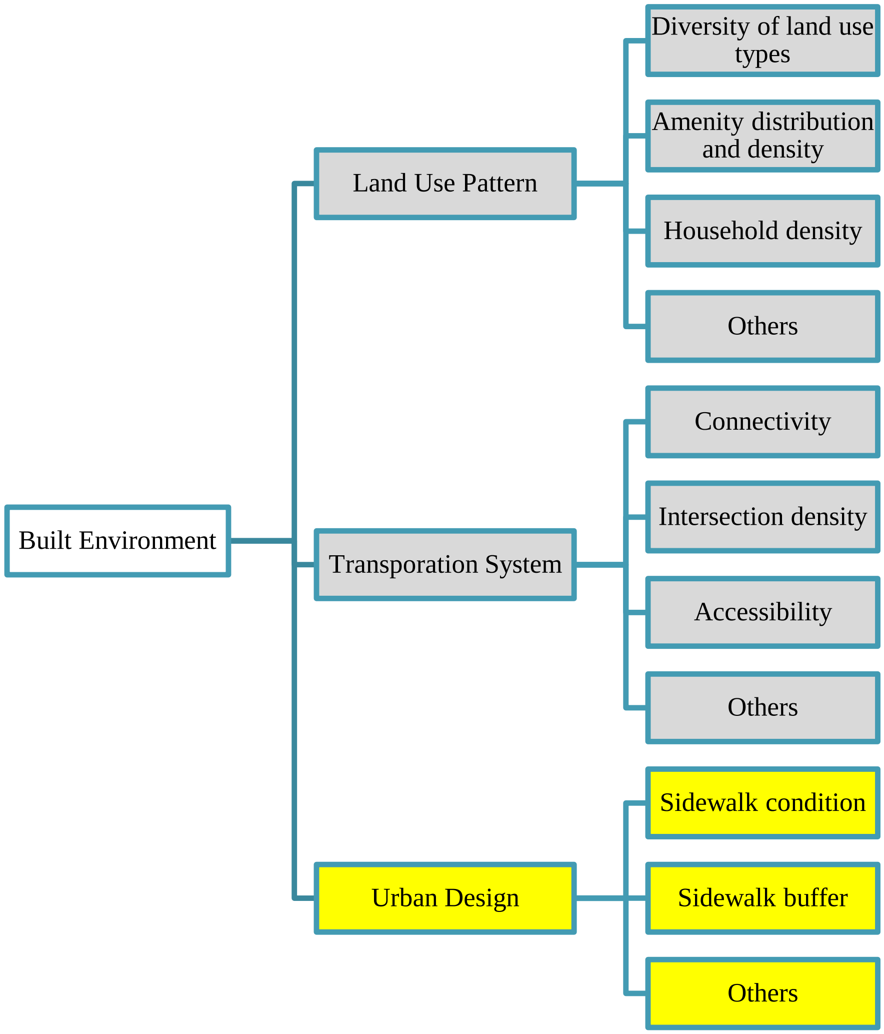


Figure 1 Built Environment Components
(Grey indicates the parts have been considered, and yellow indicates the parts have not been considered)

The same problem exists in the two commonly used walkability measures. The first popular walkability measurement is called the Walkability Index, which consists of Connectivity index, Entropy index, Floor area ratio index and Household density index (Frank et al., 2010). This index conceptualizes a more walkability place with high residential density, smaller setbacks and less parking, high density of intersections and high diversity of land use types (Dobesova & Krivka, 2012; Jun & Hur, 2015). The other measurement is a general group of walkability measurements. It emphases on the distribution of possible destinations, in which way skews walkability to a proxy of amenity availability (Duncan et al., 2013; Fan, Wen, & Kowaleski-Jones, 2014; Forsyth & Southworth, 2008). Both method can be improved if consider walkability from the view of the pedestrians who are actually walking in the area, or from the “ground”. For example, whether a sidewalk is existent and adequate to support walking, whether pedestrians need to share the sidewalk with bikers, and whether the traffic speed limit aside the sidewalk makes the pedestrians feel safe. The urban design part will cover those characteristics that support walking activities but haven’t included in the previous studies. Besides, In addition to a mode of transportation, walking can be an entertainment, physical workout, social event choice or even aimless activity for local people and tourists (Lo, 2009). However, most of the current walkability analysis studies concentrate on walking as a transportation mode with predetermined destinations, without walking for all possible purposes. The existing measurements would not be ideal to mirror the real walking environment capacity because of those conceptual omissions.

A small group of people studied and validated specific walkability measurements. The one that caught most attention is called Walk Score®, but it can still be improved based on their research. As one of the existing walkability measurements, Walk Score® is now widely recognized and applied as an indicator of walkability in both commercial and academic areas. Although it was originally developed for real estate purpose, it is the most popular walkability proxy tool currently. As some validation studies commented, Walk Score does represent some perspective of walkability in the neighborhood. However, there are obvious and serious limitations including weighting all categories of the destination equally, emphasizing too much on the number and density of nearby walkable destinations rather than walking routes characteristics (Lo, 2009), assuming every walking journey has a predetermined destination, and using straight-line distance rather than road network distance (Duncan et al., 2013). Several studies validated the methodology behind Walk Score (L. J. Carr et al., 2011; Duncan et al., 2013; Duncan, Aldstadt, Whalen, Melly, & Gortmaker, 2011b; Ewing & Handy, 2009) in some populous and developed cities or areas, such as New York City, Boston in Massachusetts, Providence in Rhode Island, and four metropolitan areas in the United States (U.S.). There is still a gap for the unknown situation in less populous urban or rural areas, such as campus-based towns.

As abovementioned problems in the current built environment and walkability research, it is worthwhile to look at other aspects of the neighborhood, rather than only the spatial distribution and features of all available potential destinations within certain travel time or distance. In addition to the objective measures upon the built environment factors, pedestrians' walking preferences upon the built environment are also important to understand people's physiological recognitions towards the built environment and the walking decision making process. To my knowledge, there is no research takes both people's perceived importance and objective measures of built-environment into consideration to measure the walkability. A sidewalk accessibility index to evaluate the performance of the infrastructure of sidewalks and public spaces was proposed based on the expectations and perceived needs of wheelchair users (Ferreira & Sanches, 2007). Although this article specifically concentrated on the people in wheelchair, the detailed scenarios and sidewalk condition categories can still be applied in walkable environment evaluation. At the Active Living Research Conference, Broach and Dill (Broach & Dill,

2015) stated that pedestrians make systematic route choices, which means that pedestrians' behaviors can be predicted and changed if their preferences and decision making process are clear enough.

Under the assumption that pedestrian's preferences are pretty consistent, the perceived importance can be obtained through surveys or interviews, and the results can identify and measure the built environment factors that influence walking activities. There is a common recommendation that specific behaviors should be studied in specific environments (Saelens & Handy, 2010a). A study with more specific environment and behavior will help identify the particular environmental characteristics that might prompt or maintain habitual physical (Owen, Humpel, Leslie, Bauman, & Sallis, 2004). Therefore, it would be better to conduct the built environment and walkability studies in a specific environment and for a specific behavior to understand local pedestrians' reasoning, predict behaviors and make changes.

CHAPTER 3

DATA AND METHODS

This chapter will introduce the data and methods used in the study in following flow chart (Figure 2). After built environment factors identified and selected based on literature review and the study area situation, those factors were used in the online Walking Preferences Survey (Appendix B) and their GIS layers were obtained and validated. One the one hand, the survey data were processed into perceived importance through the modified Analytic Hierarchy Process (MAHP), and produced other findings through information summary and statistical analysis. On the other hand, the GIS layers were processed into built environment objective measures by Exploratory Spatial Data Analysis, and calorie map and calorie matrix were created based on shortest path analysis. Finally, the perceived importance was used in interpreting the objective measures into a new walkability measurement.

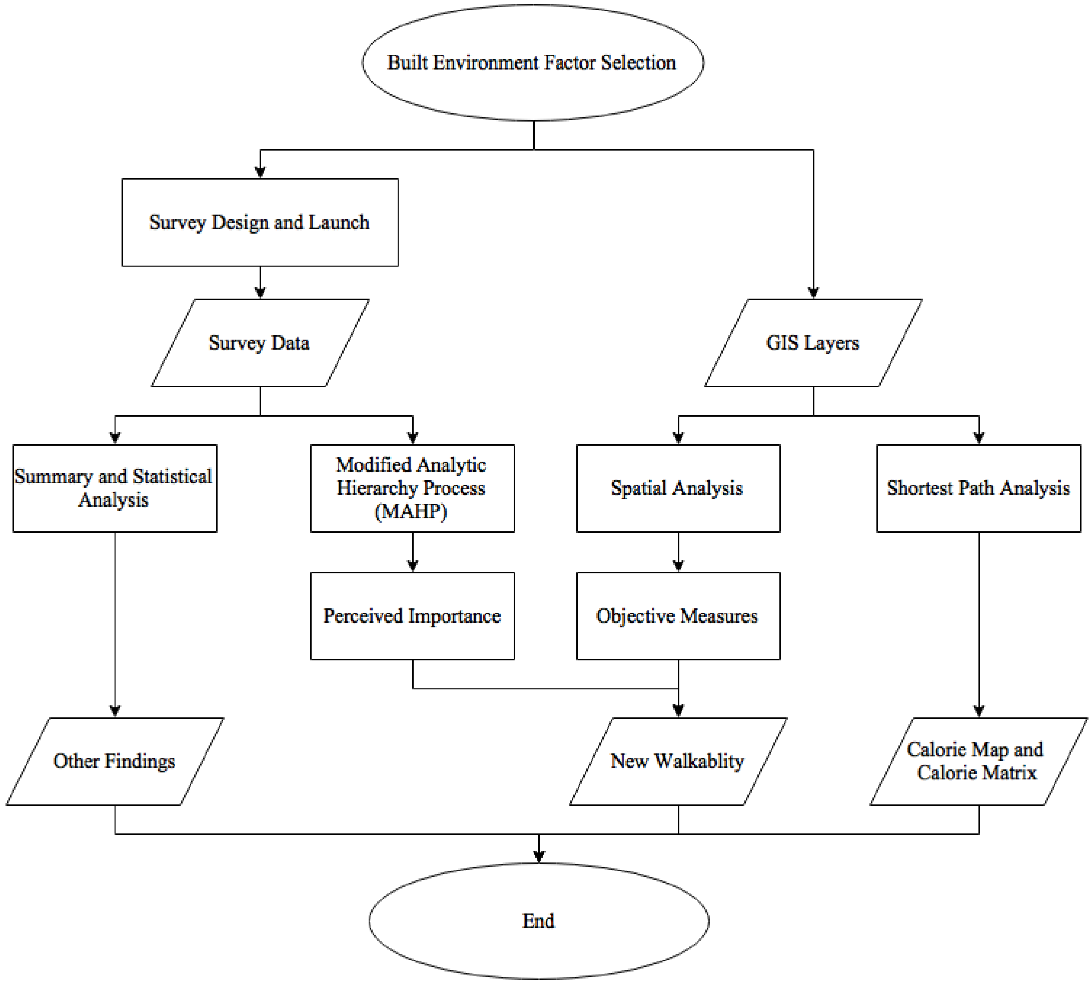


Figure 2 Flow Chart

3.1 Study Area

The University of Georgia (UGA) main campus (shown in Figure 3) was selected as the study area of a specific built environment to frame walkability. UGA is located in Athens, Georgia, approximately 70 miles from Atlanta. Founded in 1785, UGA is the first state-chartered public university in the U.S. and is the flagship institution in the University System of Georgia. The main campus covers 605 acres (2.45 square km) and includes 313 buildings, and is the primary study or work place for the majority of more than 36,000 students and 10,000 faculty and staff of UGA (UGA, 2015). UGA's main campus lies within the humid subtropical climate zone, with hot, humid summers and mild to moderately cold winters. Light to moderate snowfall can occur in winter. Because the City of Athens sits on a series of anomalous hills which are unique to the Piedmont region, there are some hilly areas in the main campus. With good vegetation coverage, mild climate, scenery and interesting terrain, UGA main campus is suited for people to walk all year round. Although the main campus is quite compact and well designed, a lot of students would still take the crowded Campus buses no matter whether they are in a hurry. The UGA main campus serves a perfect starting point for this study with a very feasible total area for the analysis. From 1996 to 2008, there was a clear trend that the overall body fat increased and fitness level decrease among college students (Pribis, Burtnack, Mckenzie, & Thayer, 2010). It is one of our motivations and intents that addressing and measuring the obesogenic problem in a campus environment would help mitigate the health issue.

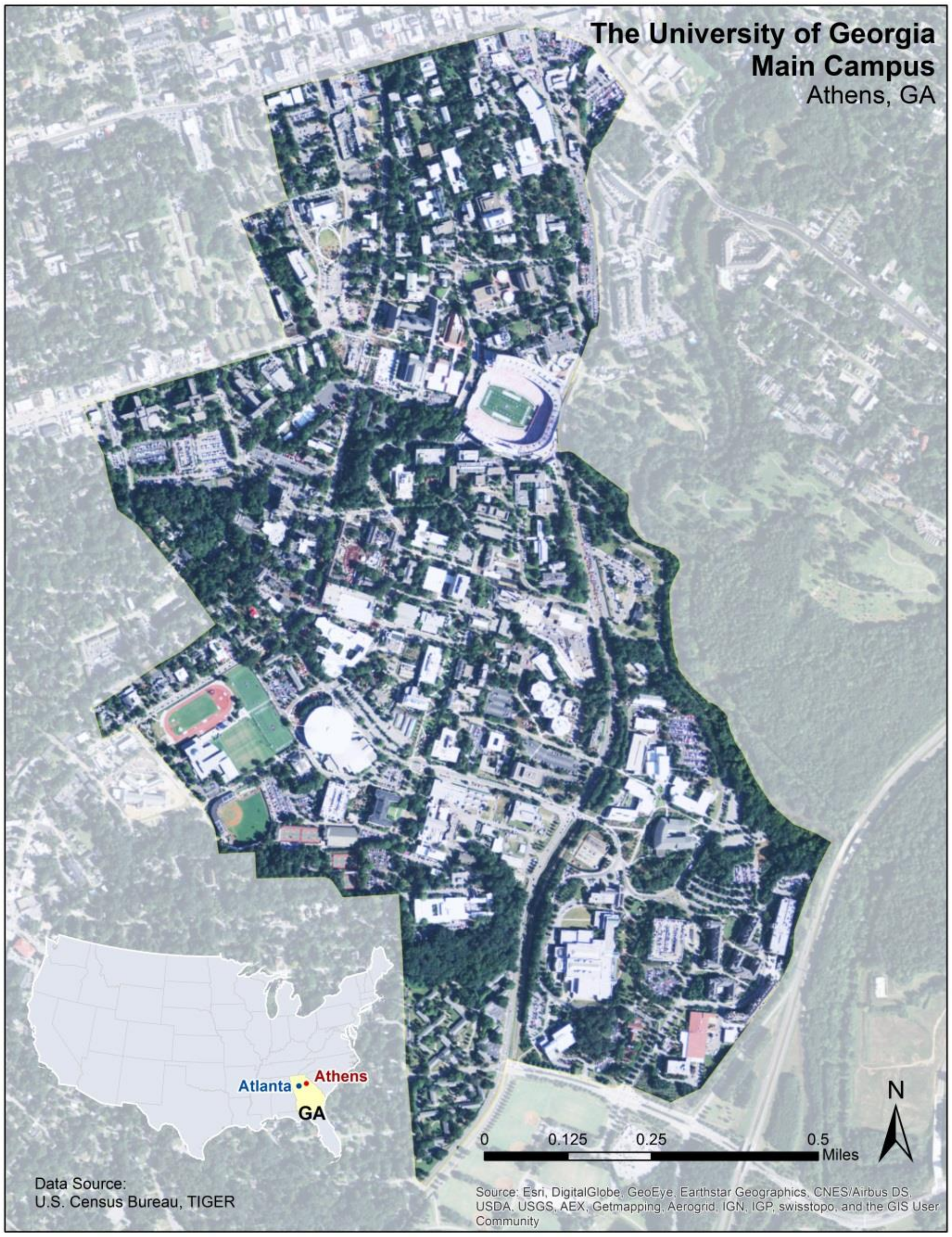


Figure 3 Study Area

3.2 Built Environment Factors

Perceived importance is used as weights to interpret the objective measures on the walking environment. Objective measures consider the current objective situation of built environment factors, such as the speed limit, or whether there is a sidewalk or not, to record the objective situation of the built environment. Perceived importance concentrates on pedestrians' preferences toward the involved built environment factors. For example, people may prefer to walk with the walking buffer to separate them from the running traffic than without it. For the walkability assessment, both objective measures and perceived importance evaluate all the built environment factors.

Based on the literature review, and the current conditions of UGA main campus, the concept of walkability is presented with four conceptual hierarchy tiers and focus for both perceived importance and objective measures (Figure 4).

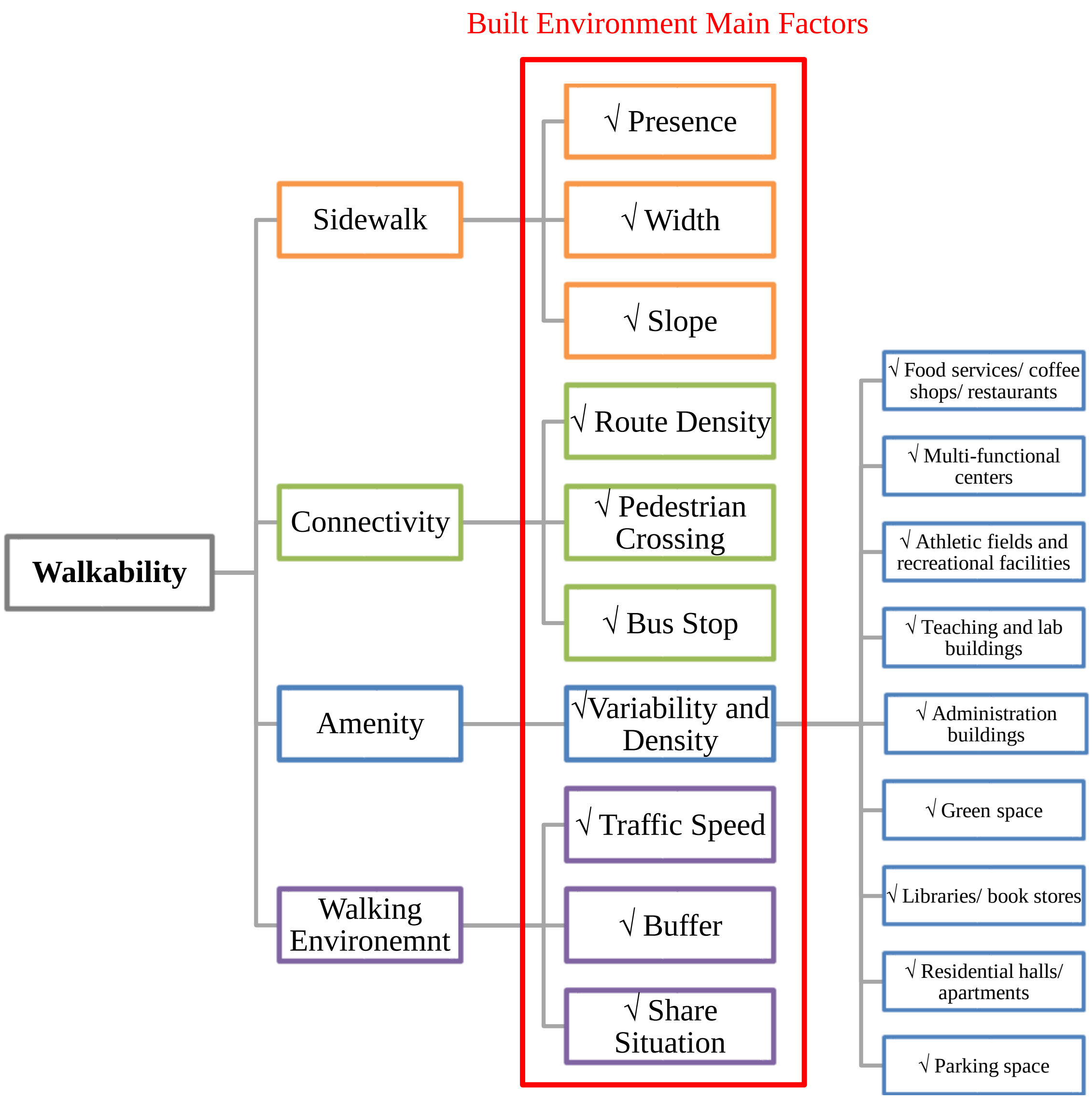


Figure 4 The Four Tiers of Walkability

(Factors with a checkmark were used in the new walkability calculation)

Both objective measures and perceived importance will cover 1) sidewalk condition such as presence or not, width, and slope; 2) connectivity condition such as the availability of routes, pedestrian crossing, and bus stop for other transportation modes; 3) amenities variability and density; and 4) walking environment such as traffic speed, buffer, and sharing situation. Those ten factors were considered as ten built environment main factors. Under the Amenity Variability and Density measure, nine amenity types are considered here to understand the detailed difference upon the possible destinations on campus.

Some other common used factors such as sidewalk pavement and sidewalk evenness will not be included in the survey because all UGA campus sidewalks are in very good conditions with minor differences.

3.3 Walking Preference Survey

Survey is one of the most straightforward and intuitive methods for obtaining first-hand data and assessing the built environment. A walking preference survey was designed to obtain pedestrians' preferences on walkable settings on campus. The survey is used to identify and measure the built environment factors that influence people's walking choices and decisions on UGA main campus.

Most of the questions are designed and presented in seeking participants' agreement on a statement in a Likert scale format from 1 to 9, strongly disagree to strongly agree. This detailed scale can capture slight differences in agreement, and can be easily applied in a modified multiscale analysis to be discussed later. Likert scale is usually used for ordinal data, similar method has been used in previous study (Lai, Wong, & Cheung, 2002). Additionally, the survey collects participants' gender, birth year and occupation for group analysis. It also requests participants' other walking considerations, walking motivations, the most walkable/ non-walkable places on UGA campus, and their usual and most preferred transportation modes. A copy of the survey is attached in Appendix II.

The survey aims to recruit at least 100 participants in order to have a reasonable representation of the pedestrians on UGA main campus and for the sake of sound samples in statistical methods too. This study requires training and approval of Human Subjects and the requirement has been met.

3.4 GIS Data

The built environment data utilized in the walkability calculation were acquired from the Office of University Architects at the UGA in October, 2015. The campus GIS data include sidewalk, building, parking, recreation buildings and areas, road network and others.

The Digital Elevation Model (DEM) data was acquired from the Geospatial Data Gateway from the Natural Resources Conservation Service of United States Department of Agriculture (USDA). The available finest elevation dataset is in 10-meter resolution, and the surface covering UGA main campus was mosaiced from two DEM images.

More ancillary data was collected by field work. Since there is no speed limit data available in any shapefile, map or document, field work was done to collect the data from speed limit signs. Bike lane data was obtained from other students' previous work which was based on the existing bike lane map made in 2010 by a local non-governmental organization (NGO) called BikeAthens (BikeAthens, 2010), and more field work was done to valid the bike lane information.

3.5 Spatial Analysis

The spatial analysis was performed on available GIS data (from the Office of University Architects of UGA and USDA) to have the preliminary results for the objective measures before the survey results being collected. Figure 5 shows the general information about the distribution of the sidewalk, buildings, parking space, recreation area, road and railroad within the boundary of study area.

Figure 5 Facilities Distribution at University of Georgia Main Campus

3.5.1 Sidewalk Condition

The sidewalk availability (on neither side, one side, or both sides) was obtained based on the spatial data and completed and validated through field trips. In Figure 6, the campus sidewalk availability is color coded. A score (0-1.00) is assigned to each road segment: if the sidewalk is available on both sides, it will receive the score of 1.00; if one or none sidewalk available, the road segment will receive 0 or 0.5 for the sidewalk availability factor.

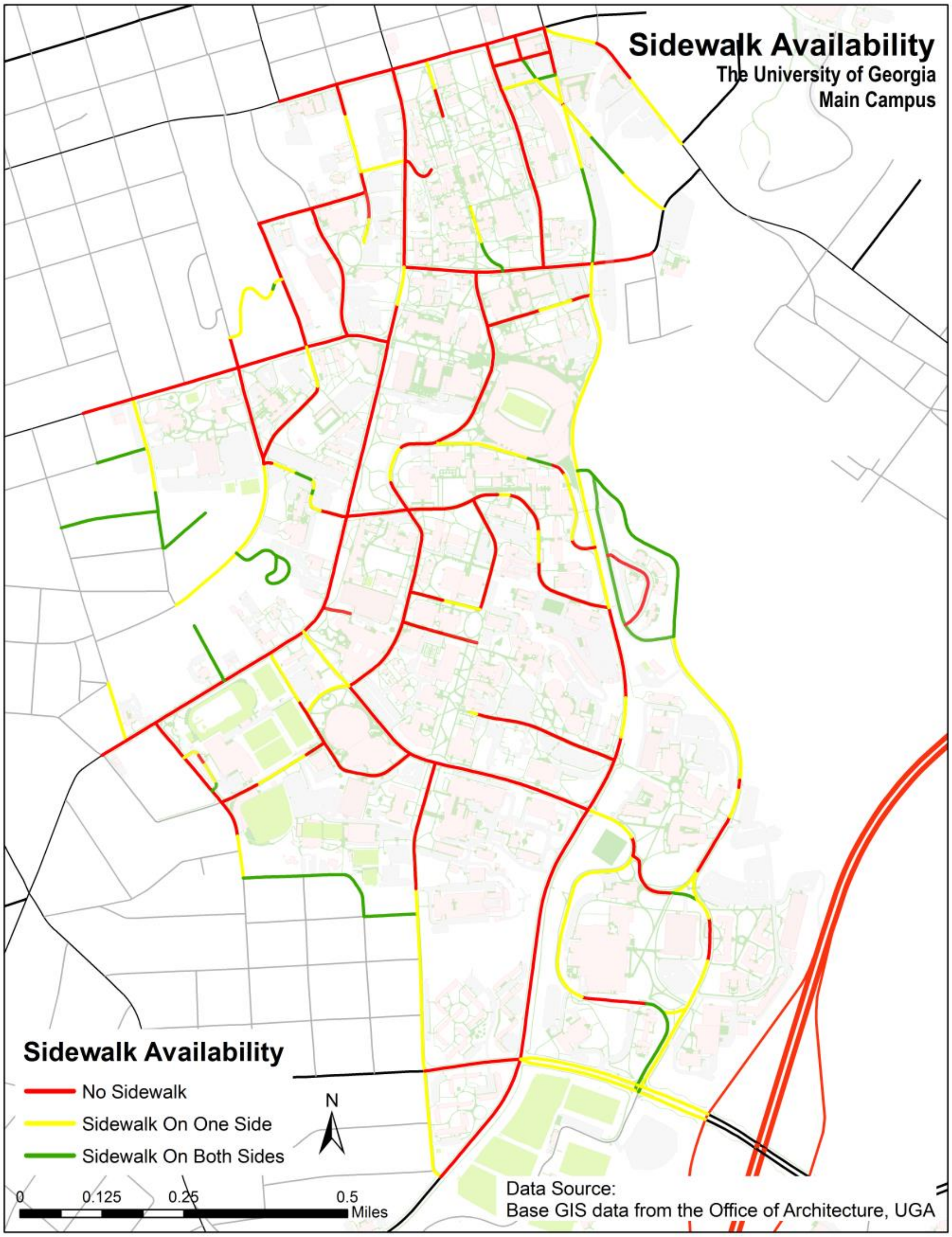


Figure 6 Sidewalk Availability at the University of Georgia Main Campus

Through more spatial data exploration and field work, we found out the sidewalk width is pretty adequate to provide walking spaces, except several road segments on the campus edges. In this case, the sidewalk width would be assigned score of 1.00 for all road segments.

The slope, or physical terrain, surface was calculated out from 10 meter DEM data (Natural Resources Conservation Service, Geospatial Data Getaway). In Figure 7, the slope was projected on the hill shade to show the changing of elevation over the space. The slope was categorized into 3 classes: <5 (flat), 5-10 (slightly hilly) and > 10 (hilly) degree. For each road segment, the slope class was assigned by the class that covers the most area of the road segment.

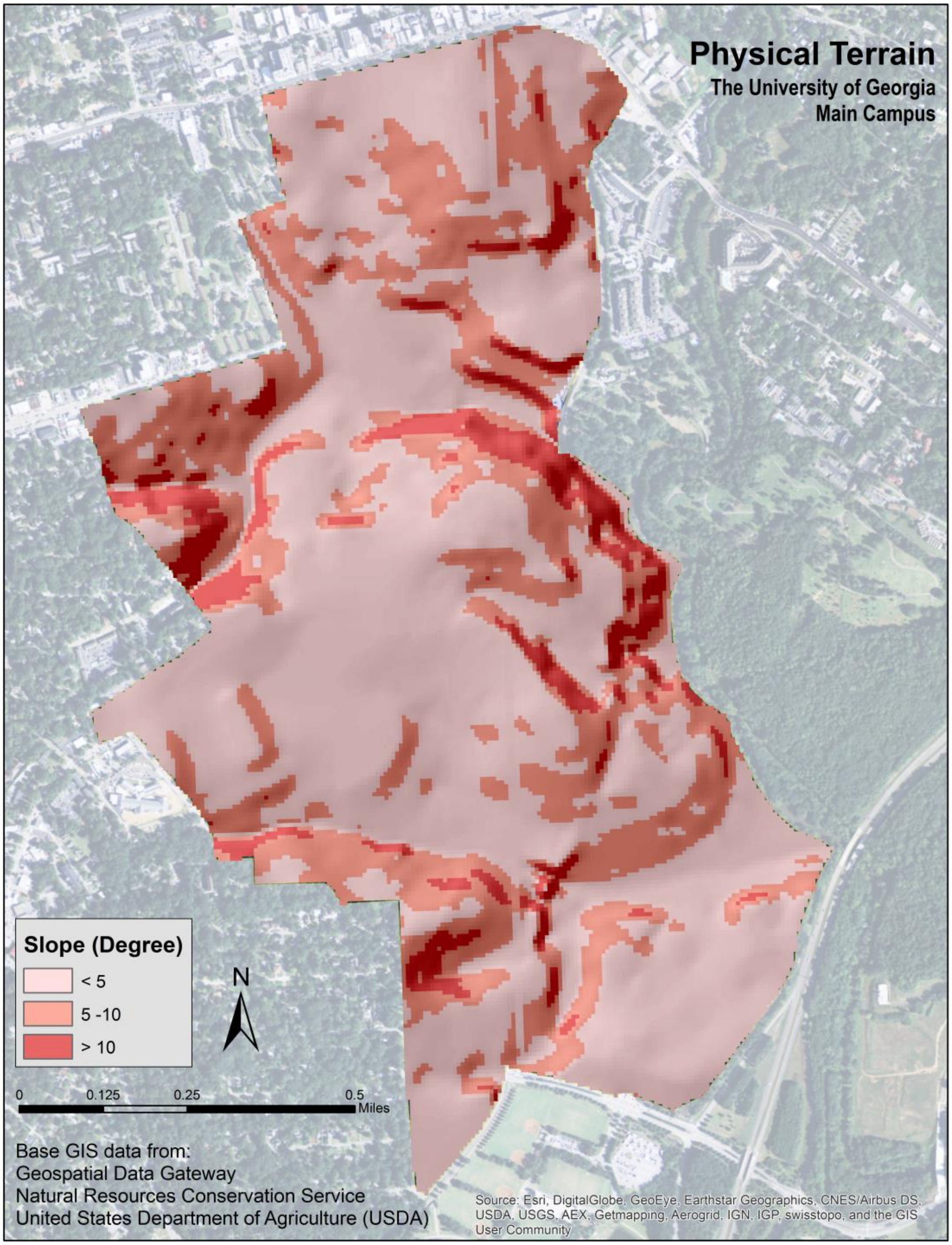


Figure 7 The Slope Variation at University of Georgia Main Campus

3.5.2 Connectivity Condition

For individual road segment, the walking route score depends on the available sidewalk coverage within the 50 m buffer of the segment. From the data exploration, Figure 8 shows that walking route covers 20 m^2 or more, the sidewalk will be continuous and sufficient for the pedestrians. Within the buffer area, if walking route covers 20 m^2 or more, the road segment receives 1.00, in other cases, the score equals to the percentage of the walking route coverage divide 20 m^2.

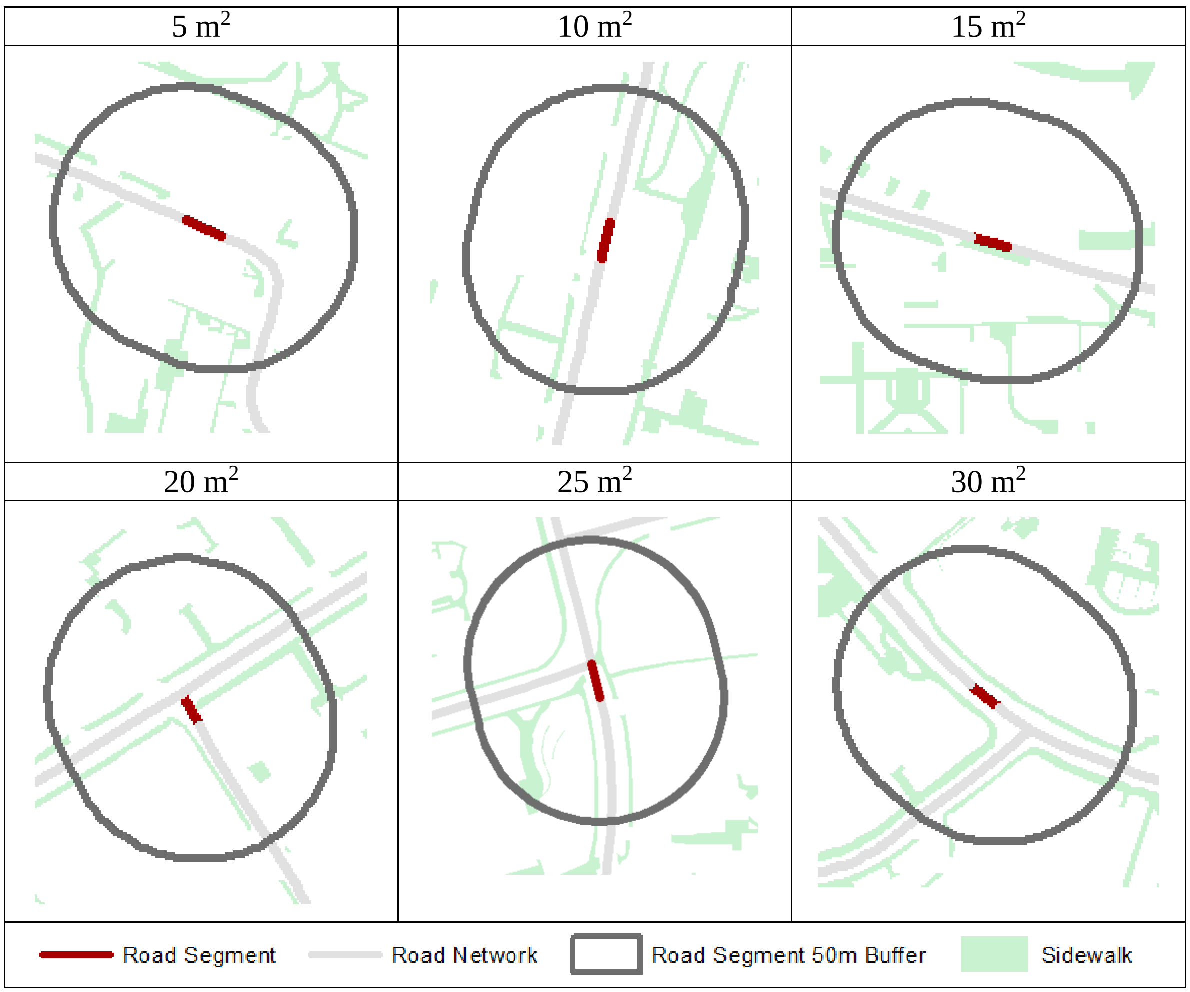


Figure 8 Walking Route Density Illustration
(Road segment in red, road network in grey, 50 m buffer in black and walking space in green)

Pedestrian crossings were digitized based on Google Map and Google Street View. After data collection and compilation, some data were validated by field work. The pedestrian crossing connectivity condition first provides information on available pedestrian crossings within a nearby distance (20 m). The scores of the connectivity are assigned as 0, 0.5 and 1 for situations of no crossing available, one available and two and more available respectively.

The bus stop data were obtained and digitized from campus and regional transit map. Just as pedestrian crossing connectivity, the same method applies to the bus stop, or bus stop, connectivity.

3.5.3 Amenity Condition

As illustrated in Figure 4, nine amenity categories were considered including (1) food services/ coffee shops/ restaurants/ bars, (2) multi-functional centers, (3) Athletic fields and recreational facilities, (4) teaching and lab buildings, (5) administration buildings, (6) green space, (7) libraries/ book stores, (8) resident halls /apartments and (9) parking space. Most data were classified from the buildings and recreation spatial data provided by the Office of Architecture at UGA, green space data were digitized from campus map for large contiguous green space that people can walk or have a rest there. For categories 2, 7 and 8, the amenity score is assigned as 0 or 1 depending on whether there is such a facility nearby. For the other six categories, score 0, 0.5 and 1.00 were given corresponding to 0, 1 and 2 or more amenities available within a nearby distance.

3.5.4 Walking Environment

Field work was done to collect speed limit data by observing speed limit signs along the roads. There are about 19% road segments within our study area having no visible speed limit signs posted. According to the "Athens-Clarke County Code of Ordinances" , the maximum lawful speed limit in Athens-Clarke County school zones shall be 25 miles per hour except where a different speed is established, designated and marked. Therefore 25 mph was given to those road segments without speed limit signs. (Figure 9)

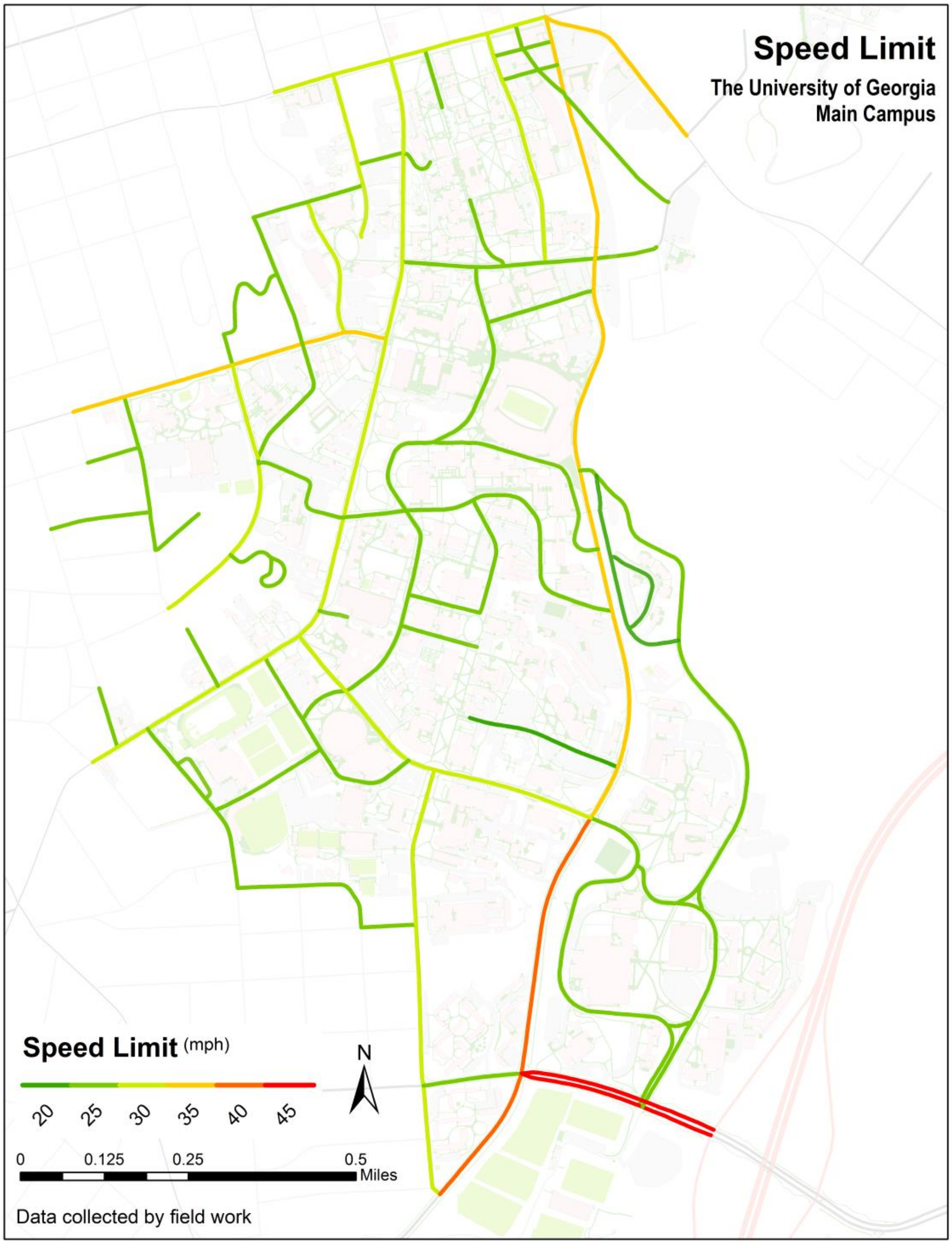


Figure 9 Speed Limit at the University of Georgia Main Campus

Walking and Bicycling Suitability Assessment (WABSA) evaluates the walkability and bikeability of urban streets. The WABSA project provided a validated method to assess the walkability (Emery, Crump, & Bors, 2003) in a general neighborhood. Speed limit, or posted speed, was also considered in their walkability assessment method. The WABSA method categories the speed limit into three classes: <30, 30-44 and 45 or more for their target neighborhoods. To fit the university campus situation, we modified the speed classes to <=25, 25<speed<35 and more than 35 mph (Figure 10) with the value of 1.00, 0.5 and 0.

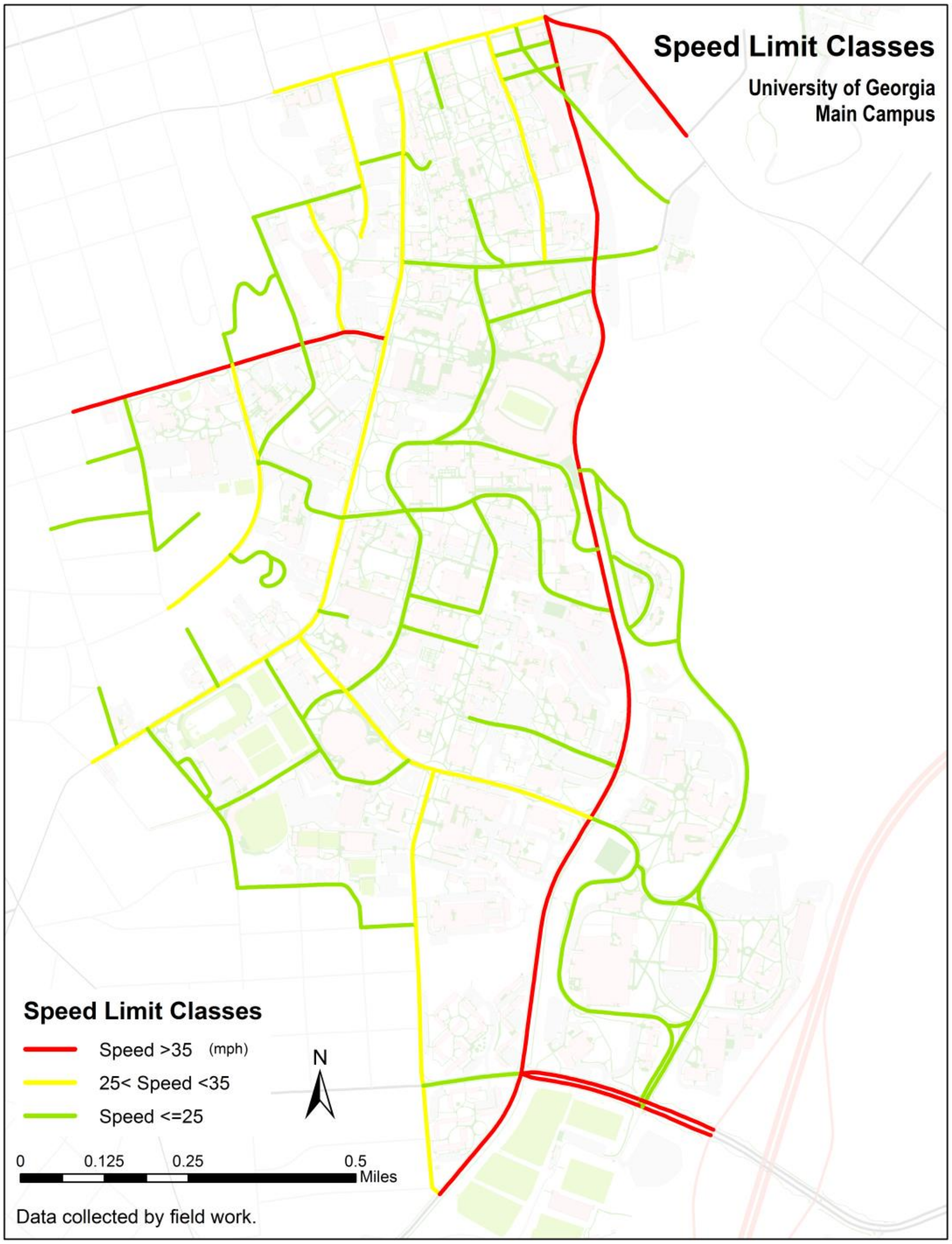


Figure 10 Speed Limit Classes

The walking buffer (green space, parking along the sidewalk, railing and others) is not always available on campus. Just as the sidewalk availability, the walking buffer could be not available, available on one side or both. Their scores were assigned as 0, 0.5 and 1.00 as well, according to the road situation (Figure 11).

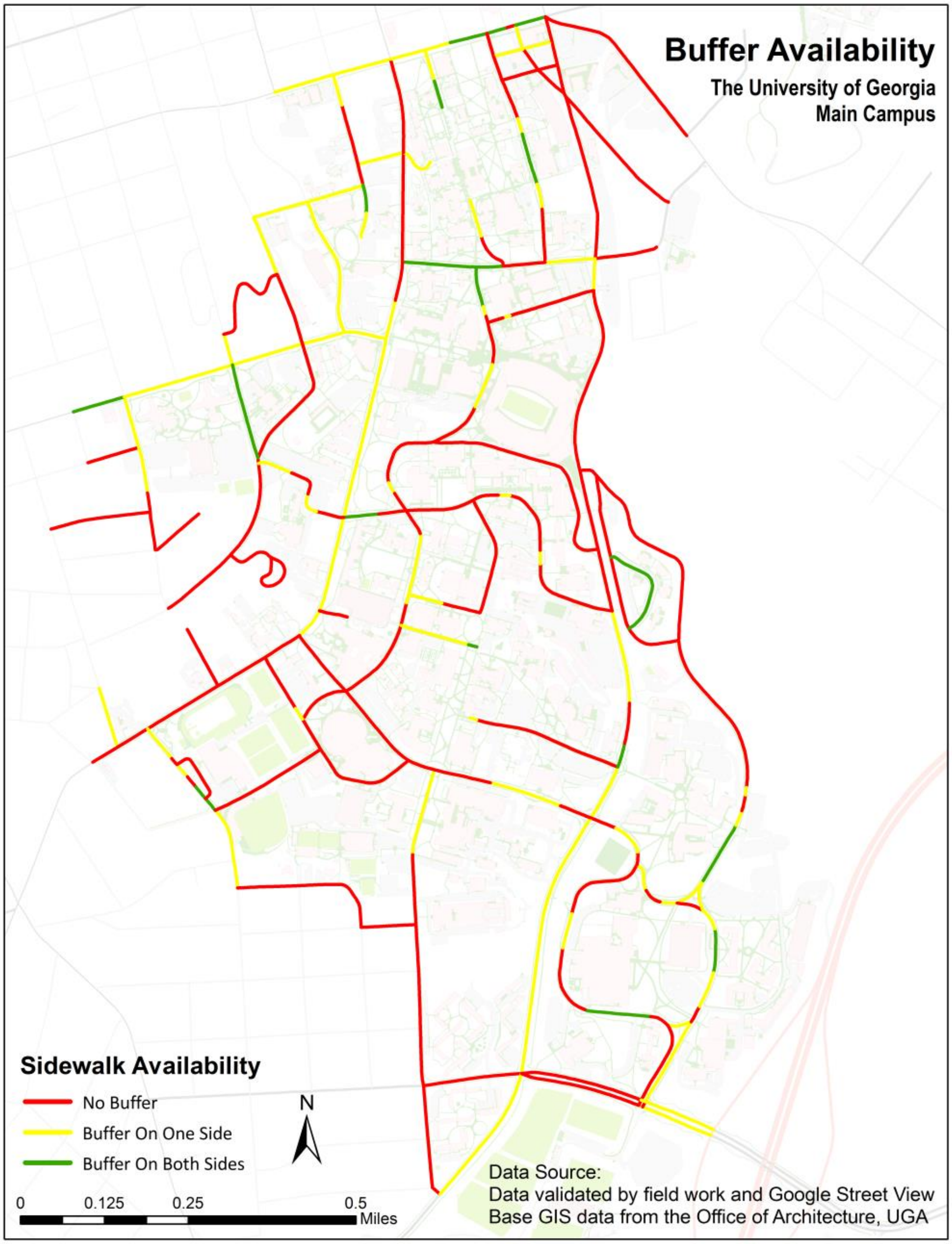


Figure 11 Walking Buffer Availability

The bike lane data were compiled based on the 2010 Athens Bike Map (BikeAthens, 2010), and other contributor’s recent update. Field trip was done to validate some areas. With the bike lane, there is less possibility that bikers would share the sidewalk with the pedestrians for biking purpose, so it would be safer for both bikers and pedestrians (Figure 12). As the bike lane is usually designed for both sides of the road, the road segment receives 1.00 or 0 for with or without bike lanes.

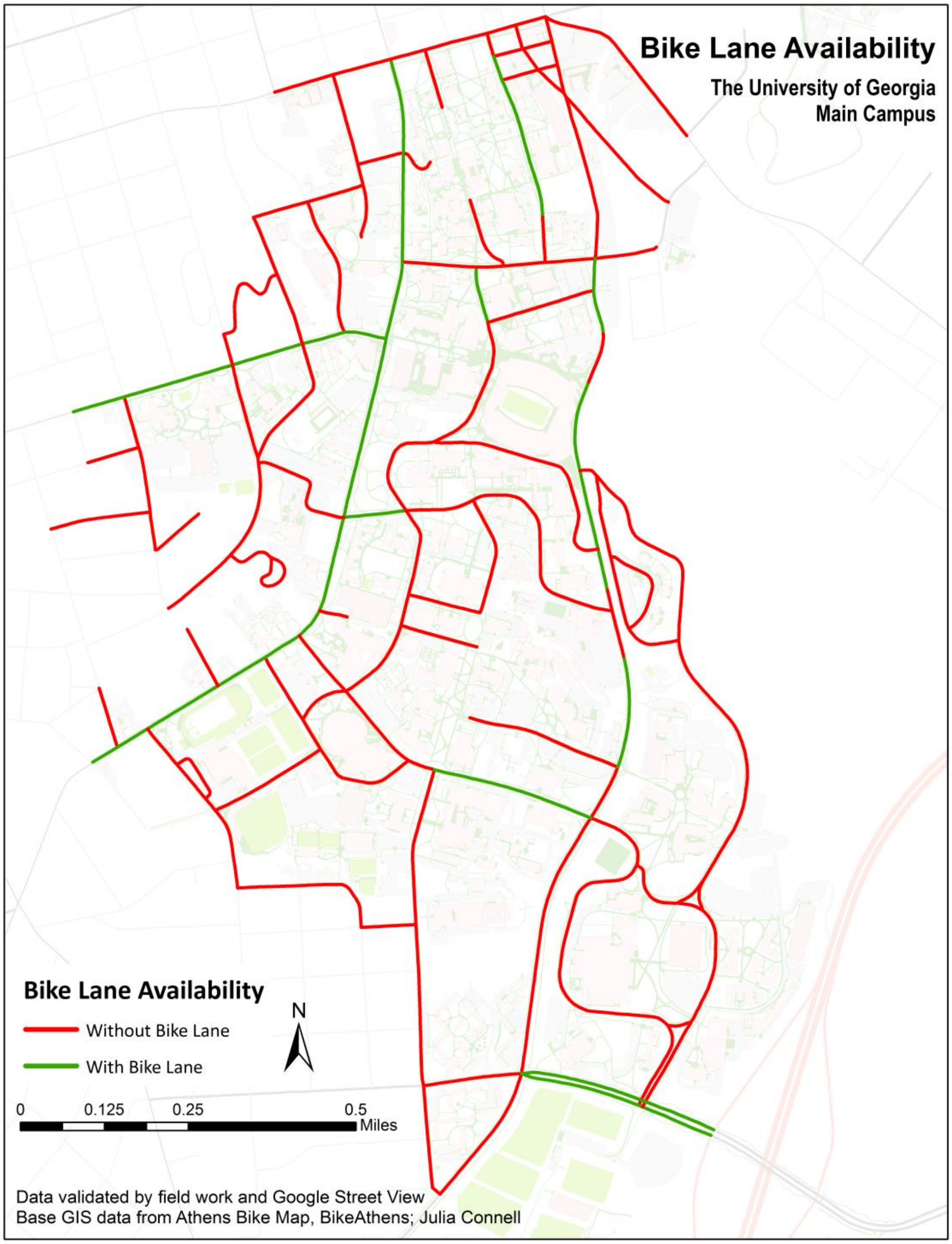


Figure 12 Bike Lane Availability

3.6 Modified Analytic Hierarchy Process (MAHP)

Initialed by Saaty in 1970s, Analytic Hierarchy Process (AHP) is a structured technique using pair comparison to analyze complicated decisions, based on mathematics and psychology. This method constructs a set of pairwise comparison matrices to find out the relative importance between the variables. Then, based on the priorities obtained from the comparisons, the weights can be assigned to the variables with a total value of 1. As shown in Table 1, for individual factor, the pair comparison uses the scale of 1 to 9 for the relative importance. 1 indicates the equal importance, and 9 indicates extreme more importance over the other factor (Saaty, 2008).

Table 1 The Fundamental Scale of Absolute Numbers

Intensity	*Definition*	*Importance*
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities

Saaty provided an example in his 2008 piece as well. Table 2 shows how the scale is used to compare the relative consumption of drinks in the USA by answering the question: how many times more is the drink on the left side consumed than the one at the top in the US? With more mathematic processing, the derived weights will be calculated out based on the matrix in Table 2.

Table 2 AHP Example: Relative Consumption of Drinks

Which drink is consumed more in the USA?							
An example of examination using judgements							
Drink consumption in US	*Coffee*	*Wine*	*Tea*	*Beer*	*Sodas*	*Milk*	*Water*
Coffee	1	9	5	2	1	1	1/2
Wine	1/9	1	1/3	1/9	1/9	1/9	1/9
Tea	1/5	2	1	1/3	1/4	1/3	1/9
Beer	1/2	9	3	1	1/2	1	1/3
Sodas	1	9	4	2	1	2	1/2
Milk	1	9	3	1	1/2	1	1/3
Water	2	9	9	3	2	3	1

The classic AHP needs to compare the factors pairwise. If *n* factors are considered in the AHP, C(n,2) = $\frac{n!}{(n-2)!*2}$ questions need to be asked for pair comparison.

However, in the modified Analytic Hierarchy Process (MAHP), it will only ask n questions directly related to individual factors in order to capture the characteristics of individual factors by certain values, and then those values will be used in comparing two factors. For the abovementioned example "*Which drink is consumed more in the USA?*", the factor number n equals to 7. The classic AHP needs to ask 7*(7-1)/2 = 21 questions. In the MAHP, the question may be framed differently as "*How many times is the drink consumed within one a certain time frame?*" Only seven questions will be asked towards individual drinks. The relative consumption will be calculated out (Table 3), and further be used to calculate individual weights.

Table 3 MAHP Example: Relative Consumption of Drinks

How many times is the drink consumed within one week?							
	Coffee	*Wine*	*Tea*	*Beer*	*Sodas*	*Milk*	*Water*
	a	*b*	*c*	*d*	*e*	*f*	*g*

⇩

Relative Consumption of Drinks							
	Coffee	*Wine*	*Tea*	*Beer*	*Sodas*	*Milk*	*Water*
Coffee	1	a/b	a/c	a/d	a/e	a/f	a/g
Wine	b/a	1	b/c	b/d	b/e	b/f	b/g
Tea	c/a	c/b	1	c/d	c/e	c/f	c/g
Beer	d/a	d/b	d/c	1	d/e	d/f	d/g
Sodas	e/a	e/b	e/c	e/d	1	e/f	e/g
Milk	f/a	f/b	f/c	f/d	f/e	1	f/g
Water	g/a	g/b	g/c	g/d	g/e	g/f	1

In my own study, the survey participants give the Likert scale agreement from 1 (strongly disagree) to 9 (strongly agree) to the individual factors, and then the pairwise ratio can be used to indicate the relative importance of any two factors, which match the original AHP method.

The MAHP also emphases on the multiscale hierarchy that more factors are considered under the major factors categories (see Figure 4). For example, under the amenity, there are nice categories of amenities will also be weighted through AHP. According to the weights derived from median perceived importance of all participants, the weights could be used as perceived importance, which represent the campus pedestrians' preferences at the study site.

3.7 Walkability Calculation

The road will be divided into segments according to the walking pace for ordinary people (about 1.4 m per second) and 10 second time slot is small enough to capture the detailed walkability variation. The 14-meter road segments will be used as the analysis unit in the calculation of new defined UGA campus walkability. For road segment *i*, the preferred weight (p_{ij}) and objective measure (o_{ij}) will be obtained for each considered built environment factor *j*. The *walkability* value will be the sum of the product of each factor's perceived importance (p_{ij}) and the factor's objective measures (o_{ij}) of the road segment, as showed in equation (1).

$$Walkability_i = \sum_j (p_{ij} * o_{ij}) * 100 \tag{1}$$

For individual road segment, p_{ij} will be in the range from 0-1 to indicate low - high in the perceived importance for certain built environment factor *j*. o_{ij} will be in the range from 0-1, but it will be in different forms based on the road segment real condition and the built environment factor *j* that it looks at. For example, o_{ij} would be 0, 0.5 or 1 as a dummy variable for the buffer absence, existence on one side, or on both sides. For route density, o_{ij} would be in the range of 0-1 to show the coverage level of walking route within a 5-minute walking buffer zone. For all factors considered, o_{ij} will be in the range of 0-1, as an indicator of presence or not, and the percentage of its coverage.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Human Subjects

This research involved human participants for obtaining local people's walking preferences. Before launching the survey, the approval was needed for the Human Subjects research application from the Institutional Review Board (IRB) at the UGA. Required by IRB, my advisor Dr. Mu and I completed Collaborative Institutional Training Initiative (CITI) training in September 2015, and the IRB application (ID: STUDY00002627) was approved in October 2015. After receiving the Sustainability Grant, this project was modified in the Human Subject application (ID: MOD00002698) to include the survey incentives, and it was approved again in late February.

4.2 Objective Measures

Objective measures were based on the preprocessed results of spatial analysis in abovementioned 3.4. Table 4 summarizes all the values that are assigned to the objective measures with possible entries of 0, 0.5 and 1 (color coded in blue, green and orange). Three value assignment schemes are listed and applied to the factors (except for sidewalk slope, which will be assigned with the perceived importance).

Table 4 Value Assignment Scheme of the Objective Measures

Three Value Assignment Scheme (Not feasible for sidewalk slope*)		0	0.5	1
		0		1
		1		
Sidewalk	Availability	On neither side	On one side	On both sides
	Width	1		
	Slope (degree)*	<5 Flat	5-10 Slightly hilly	> 10 Hilly
Connectivity	Route Density	<20 m^2		>=20 m^2
	Pedestrian Crossing	Not available	One available	Two and more
	Bus Stop	Not available	One available	Two and more
Amenity	Variability and Density	Not available		One available
		Not available	One available	More than two
Walking Environment	Traffic Speed (mph)	>= 35	25<speed<35	<=25
	Buffer	Not available	One side available	Both sides available
	Share Situation	Not available		Available

4.3 Perceived Importance

4.3.1 Walking Preference Survey

The perceived importance were processed from the walking preference survey results. The online survey was first distributed among a small group of people for the sake of seeking possible improvements based on the original version. The survey was then revised and finalized according to the feedback and input. The revised survey was then sent out to all possible participant groups on campus. With the survey incentives available in late February 2016, some flyers were distributed on campus notice boards and bus stops at various locations. Besides, more recruiting emails were sent out to mailing lists of UGA students, faculty and staff.

The original goal of collecting at least 100 survey results was achieved. Till April 20th when the survey ended, 413 people have participated in the survey. The following results and discussion focus on the data collected from the first four months (November 20th 2015 - March 20th 2016). 307 participants did the survey within that time frame. However, a small portion of the surveys are incomplete for important variables, and cannot be used in future analysis. The 284 valid surveys (92.51%) covered a good age range from 19-65 years old, with more young people participated, which is a good reflection of campus population. (Figure 13)

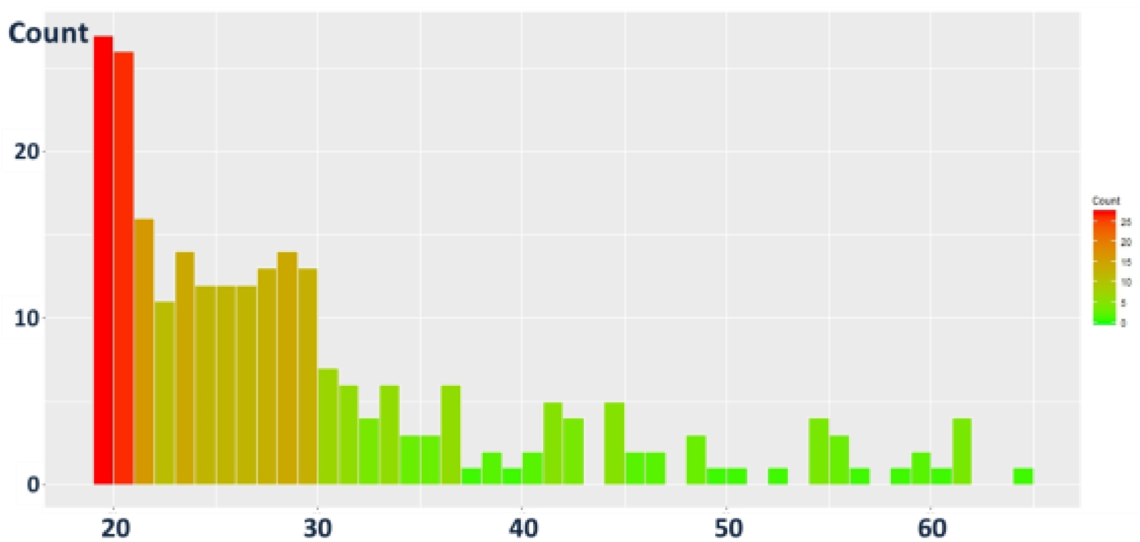


Figure 13 Survey Participants' Age Distribution

The participants include undergraduate, graduate and faculty and staff (Figure 14, left). Regarding the gender information reported in the survey, there are more female participants than male (Figure 14, right).

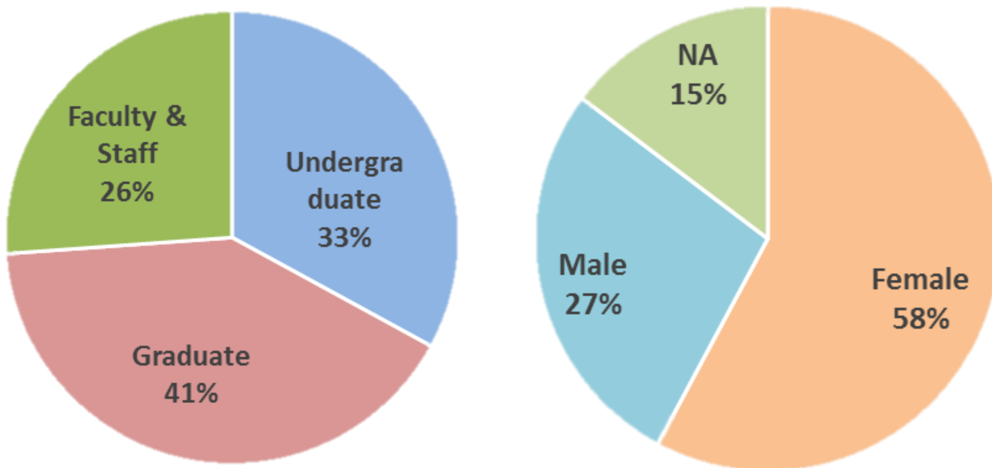


Figure 14 Survey Participants' Group and Gender

4.3.2 Perceived Importance

For the ten built environment main factors, the following histogram chart (Figure 15) was created in R studio. Using Likert scale, 1 indicates the built environment factor is not needed at all for people's decision on walking while 9 means this factor is extremely important in such a decision.

The histograms can be very informative for understanding the importance of individual factor in people's walking behaviors. They illustrate that people have strong preferences over sidewalk availability and adequate sidewalk width. The majority people are neutral about factors such as sidewalk slope, walking route connectivity or bus stop connectivity. For the other main factors, survey participants are thinking those are slightly more important to have than to not.

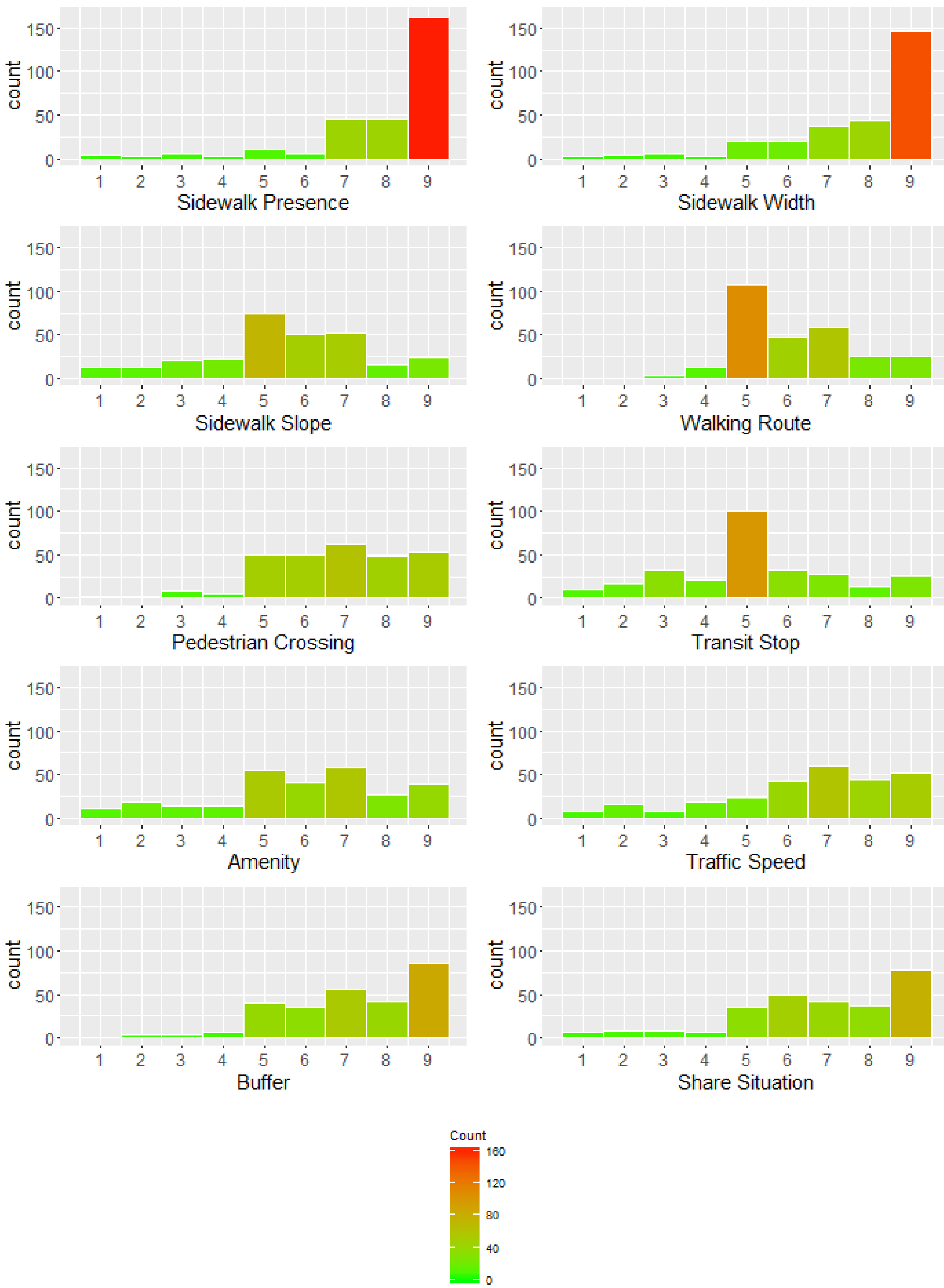


Figure 15 Preferences' Histogram for Individual Factors

For those ten factors, MAHP was applied to calculate the relative importance by using the preference median value of each factor in pair comparison (Table 5, symmetric part of the matrix shown in yellow). Then the classic AHP was applied to normalize the matrix and calculate individual weights, which are shown in Figure 16. The colors in this figure match those in Figure 4. The sidewalk availability and width are with the highest weights while bus stop connectivity is lowest weighted. It makes sense that people feel safer and more comfortable to walk there if there is sufficient and assigned walking spaces. Compared to other factors, the transit stop appearance won't influence people's walking experience, efforts, and motivations as much as other factors. For the feasible walking distance, the campus buses and several Clarke County buses cover the campus and adjacent areas well with good frequency. However, for the infeasible walking distance, the Clarke County transits for distant area have low frequencies (an hour). That could be the reason why people consider transit stops as least important.

Table 5 Relative Importance Matrix

	Sidewalk			Connectivity			Amenity	Walking Environment		
	Availability	Width	Slope	Route Density	Pedestrian Crossing	Bus Stop	Variability & Density	Traffic Speed	Buffer	Share Situation
Median	9	9	5.5	6	7	5	6	7	7	7
9	1	1	1.636	1.500	1.286	1.800	1.500	1.286	1.286	1.286
9	1	1	1.636	1.500	1.286	1.800	1.500	1.286	1.286	1.286
5.5	0.611	0.611	1	0.917	0.786	1.100	0.917	0.786	0.786	0.786
6	0.667	0.667	1.091	1	0.857	1.200	1.000	0.857	0.857	0.857
7	0.778	0.778	1.273	1.167	1	1.400	1.167	1.000	1.000	1.000
5	0.556	0.556	0.909	0.833	0.714	1	0.833	0.714	0.714	0.714
6	0.667	0.667	1.091	1.000	0.857	1.200	1	0.857	0.857	0.857
7	0.778	0.778	1.273	1.167	1.000	1.400	1.167	1	1	1
7	0.778	0.778	1.273	1.167	1.000	1.400	1.167	1	1	1
7	0.778	0.778	1.273	1.167	1.000	1.400	1.167	1	1	1

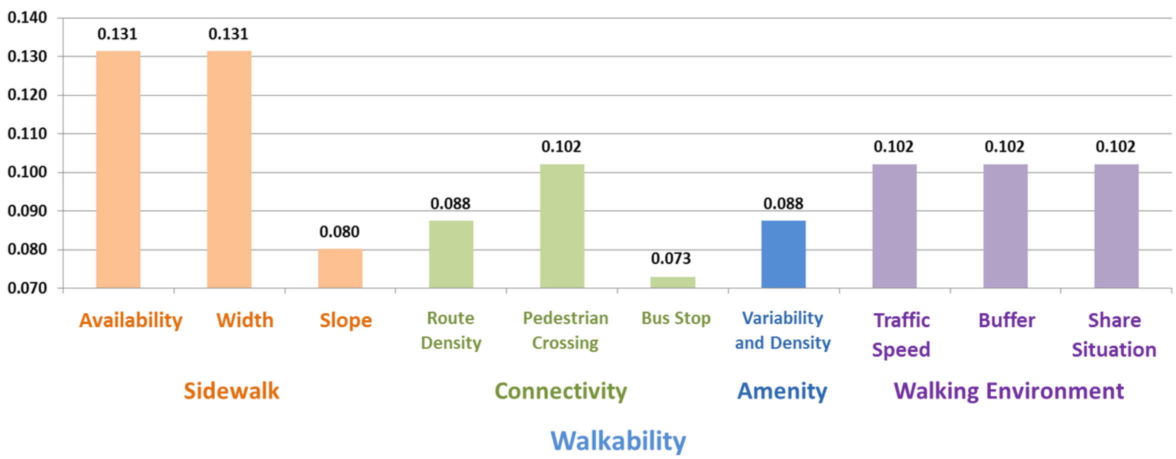


Figure 16 Weights for Individual Factors

Under the Amenity main factor, MAHP method was applied to the nine amenity categories. Green space, food amenities and book amenities stand out with the highest (0.16) or second highest (0.12) weights, while the other six categories all have relative low weights of 0.10 (Figure 17).

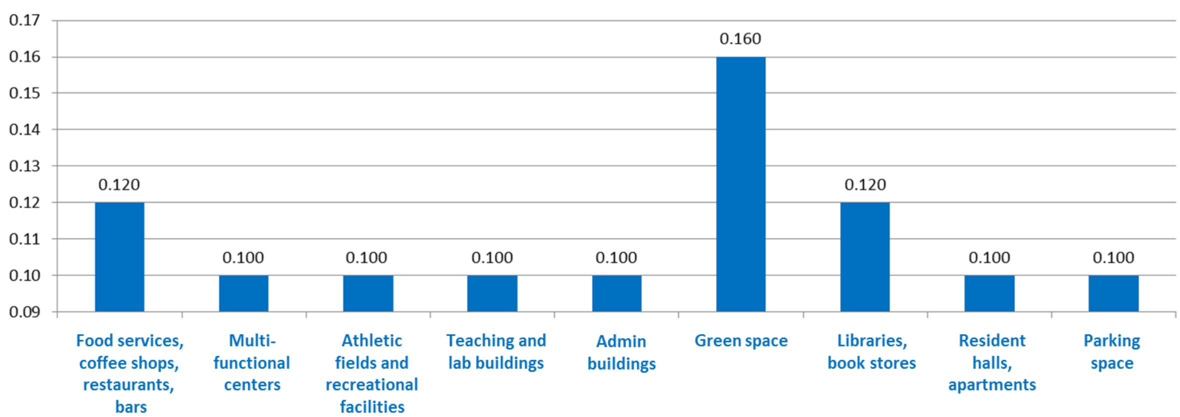


Figure 17 Weights for Amenity Categories

For the sidewalk slope factor, survey participants gave the preferences (Figure 18) that most people (54%) prefer flat area, 39% people prefer slightly hilly, while only 7 % people prefer hilly slope to walk on. Therefore, the flat sidewalk was given the weight of

1.00, 0.7222 for the slightly hilly, and 0.1296 for the hilly, all based on their preference proportions from the survey results.

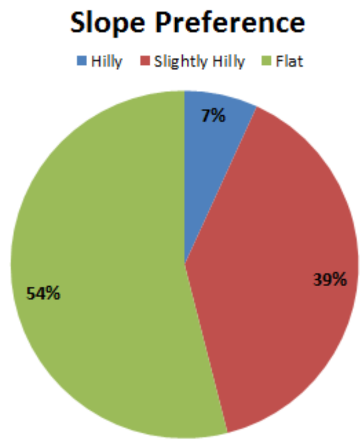


Figure 18 Participants' Slope Preferences

4.4 Walkability Calculation, Visualization and Validation

With all objective measures and perceived importance, walkability can be calculated based on the equation (1). For a possible range of 0 to 100, UGA main campus walkability is within a range from 25.3 to 88.94 and it is color coded in Figure 19. The low walkability places stand out at the east side (East Campus Road, east side circle) while most of the other low walkability areas are at the boundary or outside of campus parcels. If we look into the walkability calculation for the both roads (Figure 20), we will see that following reasons lead to low walkability. For the East Campus Road: 1) the north part of the road (about half of the road) doesn't have a sidewalk buffer; 2) 16.6% of the road is hilly (bigger than 10 degree), and 30.6% of the road is slightly hilly, however, the road segments flat slope are weighted higher; 3) along a 1.732 mile (2.787 km) road, there are only eight places have the pedestrian crossing with five places have the bus stop; 4) there are much less amenities on the east side of the north half of the roads; 5) the traffic speed there is 35 mph or 40 mph, which is among the highest speed class; 6) more than 65% of the road doesn't have bike lanes. For the east side circle area: 1) both sidewalk and sidewalk buffer exist only for 25% of the road; 2) there are much less sidewalk area available compare to the other places on campus; 3) there is neither bus stop, pedestrian crossing nor any bike lane; 4) there are river and forestry area one the east side of the road without any amenities. Many factors contribute to the low walkability and those are the things that we can investigate and change in the future planning process.

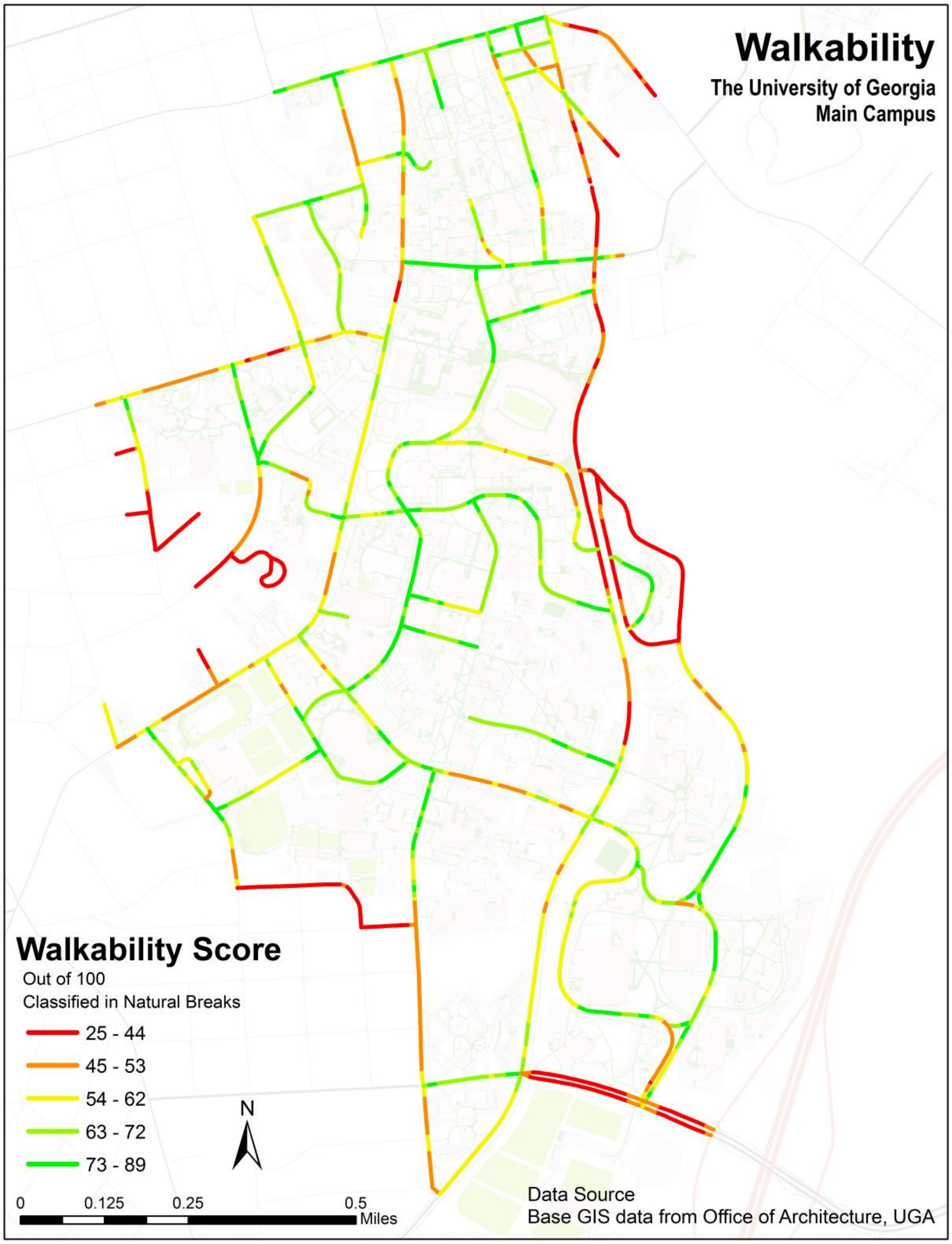


Figure 19 Walkability Map

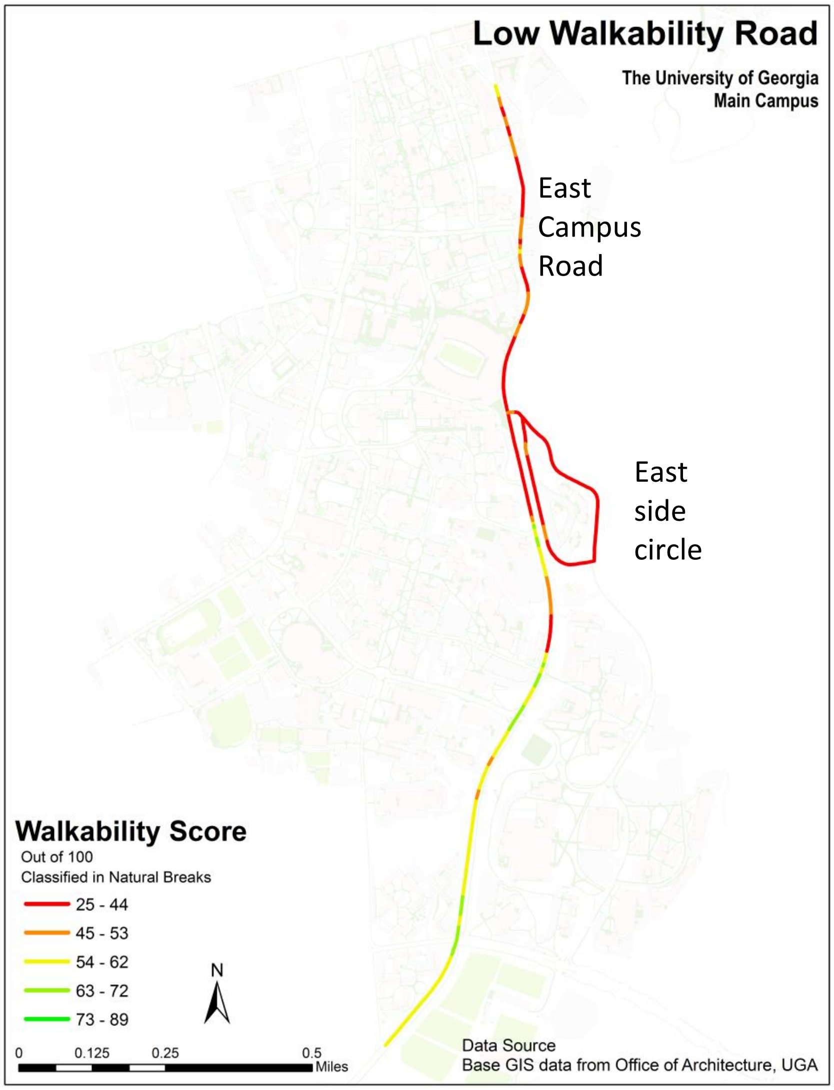


Figure 20 Low Walkability Places

One survey question is about the most unwalkable place on main campus. Figure 21 shows the places that are mentioned for more than once. The area, road and building/intersection are all mentioned here, and they were presented in different colors (the ones being mentioned for the most times are in relatively darker color). East Campus Road, Lumpkin Street, Sanford Dr, Ramsey Center and East Campus Village stand out as the top 5 most unwalkable places. From the new walkability map (Figure 21), the majority of the mentioned road and building/intersection are truly in yellow to red colors for low walkability.

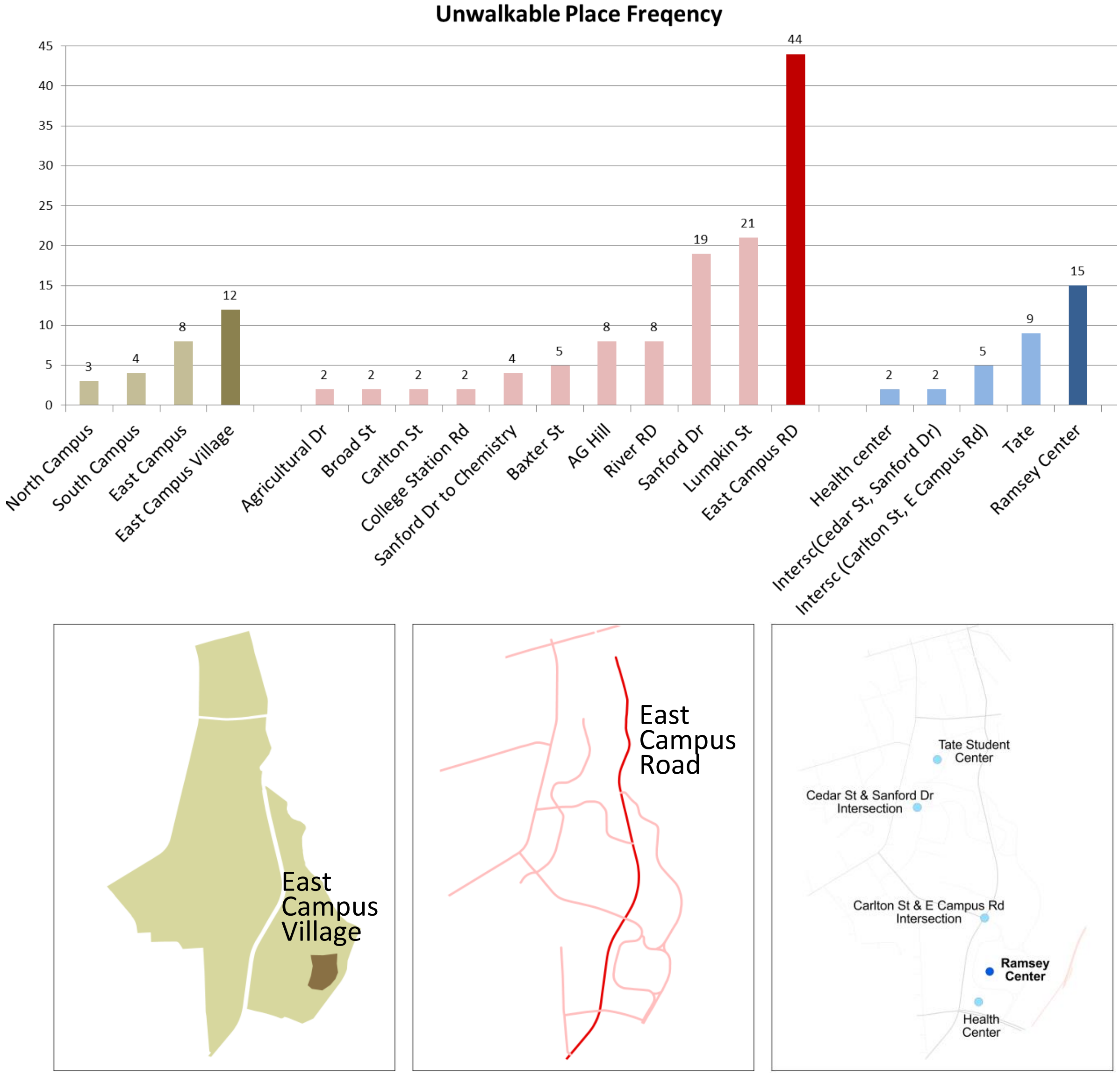


Figure 21 Unwalkable Places and Locations

4.5 Calorie Map and Calorie Matrix

After all the walking routes digitized, a calorie map was designed to measure the calorie burned starting from the UGA Arch (the landmark of UGA main campus) to possible destinations all over the campus through the shortest path. Based on the average male weight (164 lbs.) and average slope (5 degree), the calories burned by walking were calculated and then visualized by UGA coke cans (one can represent 100 calories). This map (Figure 22) is trying to show the walking benefits that people receive outside of the gym, between classrooms and dorms. The calculation and estimation are rather ballpark, and such an approach is mainly applied to promote walking, raise awareness of health, and broaden the impact of this study.

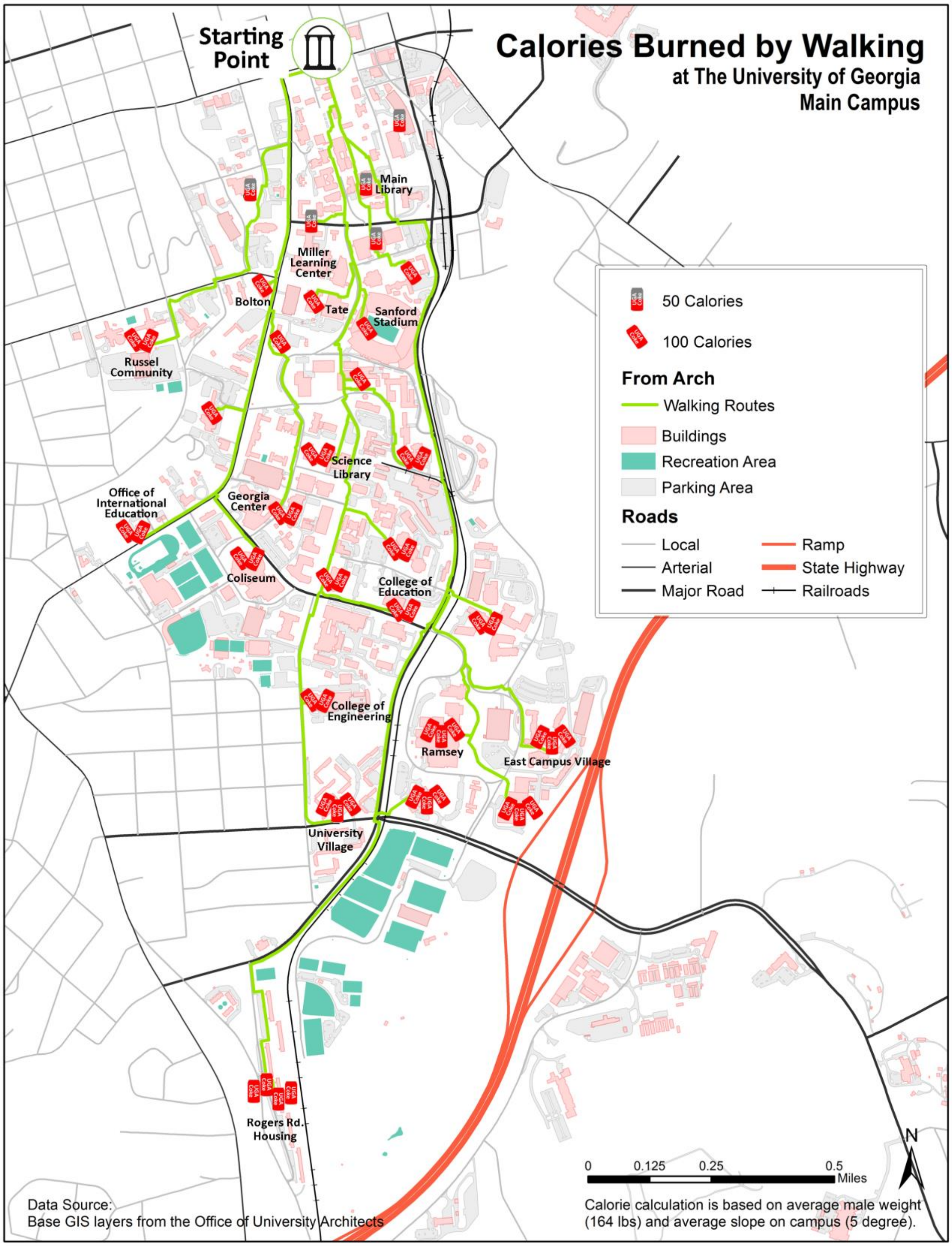


Figure 22 Calorie Burned by Walking Map

Using the same method to find the shortest path, a calorie matrix (Table 6) was also created between 11 popular places (including the teaching building, landmark, undergraduate dorm, graduate housing, libraries and more) which are visualized in Figure 23 in blue.

Table 6 Calorie Matrix between Places (from blue to red shows the calorie burned levels)

Approximate Calorie Burned	Calorie calculation is based on the average male weight (164 lbs.) and average slope on campus (5 degree) without considering downhill situation.										
1 Aderhold Hall											
2 Arch	224										
3 Georgia Center	75	177									
4 Main Library	196	45	152								
5 Ramsey Center	69	271	141	239							
6 Rogers Road Apts	207	414	274	382	176						
7 Russell Hall	168	142	107	126	232	366					
8 Science Library	81	154	35	126	139	282	104				
9 Tate Student Center	155	104	91	76	211	354	86	85			
10 Health Center	96	303	164	271	40	138	256	171	243		
11 University Village	103	275	121	246	87	160	212	131	205	50	
	1 Aderhold Hall	2 Arch	3 Georgia Center	4 Main Library	5 Ramsey Center	6 Roger Road Apartments	7 Russell Hall	8 Science Library	9 Tate Student Center	10 Health Center	11 University Village

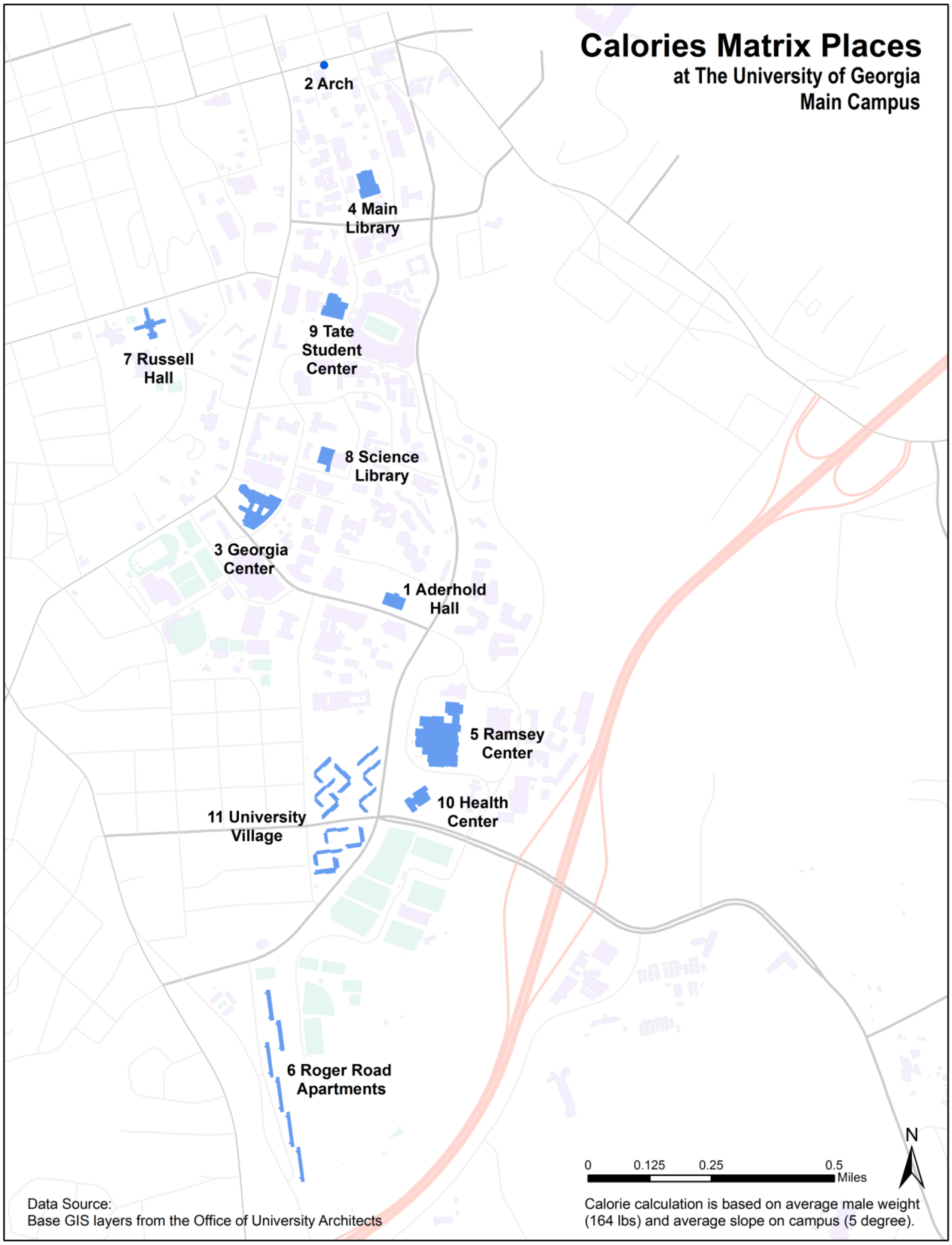


Figure 23 Calorie Matrix Places

4.6 Group Characteristics and Other Findings

With demographic information from the survey, statistic tests are used to find out the variation among groups. The differences between undergraduate, graduate and faculty & staff for bus stop connectivity are particularly interesting (Table 7). For transit stop availability, faculty & staff group has statistically significant difference or marginal significant difference with undergraduate or graduate students, while such a difference is not significant between these two student groups. The result is easy to explain because faculty & staff, who have the highest priority to have a parking permit, primarily commute to and within campus by driving their own cars, so that the bus stop connectivity influences them less than the students, who primarily use the public transportation (UGA shuttle or Athens Transit), biking and walking.

Table 7 Two-Sample Two-Tail t-test For bus Stop Connectivity Preferences between Groups

Undergraduate			
Graduate	Not significant (p=0.348)		
Faculty & Staff	Significant (p=0.011)	Marginal significant (p=0.091)	
	Undergraduate	Graduate	Faculty & Staff

In the survey, one question is about other important amenities that influence people’s walking decisions. The result, generated by Word Cloud Generator - Jason Davies (Davies, 2012), is surprising but thought-provoking (Figure 24). People consider bathroom and water fountain a lot when making the walking decision.

Figure 24 Other Amenities That Influence Walking Decisions

The survey also asked what make people avoid walking at a place on campus. The following word crowd (Figure 25) highlights factors such as dark, crowds, traffic and unsafety, and offers an idea that what the planning and design department could change and improve to promote more walking and provide better walking experiences.

Figure 25 Things That People Avoid to Walk There

4.7 Comparison with Walk Score®

Figure 26 shows the new calculated walkability overlaying with widely used Walk Score map® for our study area. In the original Walk Score map, Walk Score smoothly covers the whole area. The high score clustered in the northwestern side of the study area, where lots of possible destinations locate. It makes sense because the method is destination-oriented, and its algorithm calculates Walk Score based on distance to and density of 13 categories of amenities (e.g., grocery stores, coffee shops, restaurants, bars, movie theaters, schools, parks, libraries, bookstores, fitness centers, drugstores, hardware stores, clothing/music stores) (Duncan et al., 2013) which are most located in the downtown area (north side of Broad St.). Walk Score of most main campus area fits into the categories that Somewhat Walkable (some errands can be accomplished on foot) and Car-Dependent (most or almost all errands require a car) ("Walk Score Methodology," 2016). In comparison, the new calculated walkability has high and low walkability areas spread out all over the campus, and it captures more detailed walkability variation, especially the southwestern side of the campus.

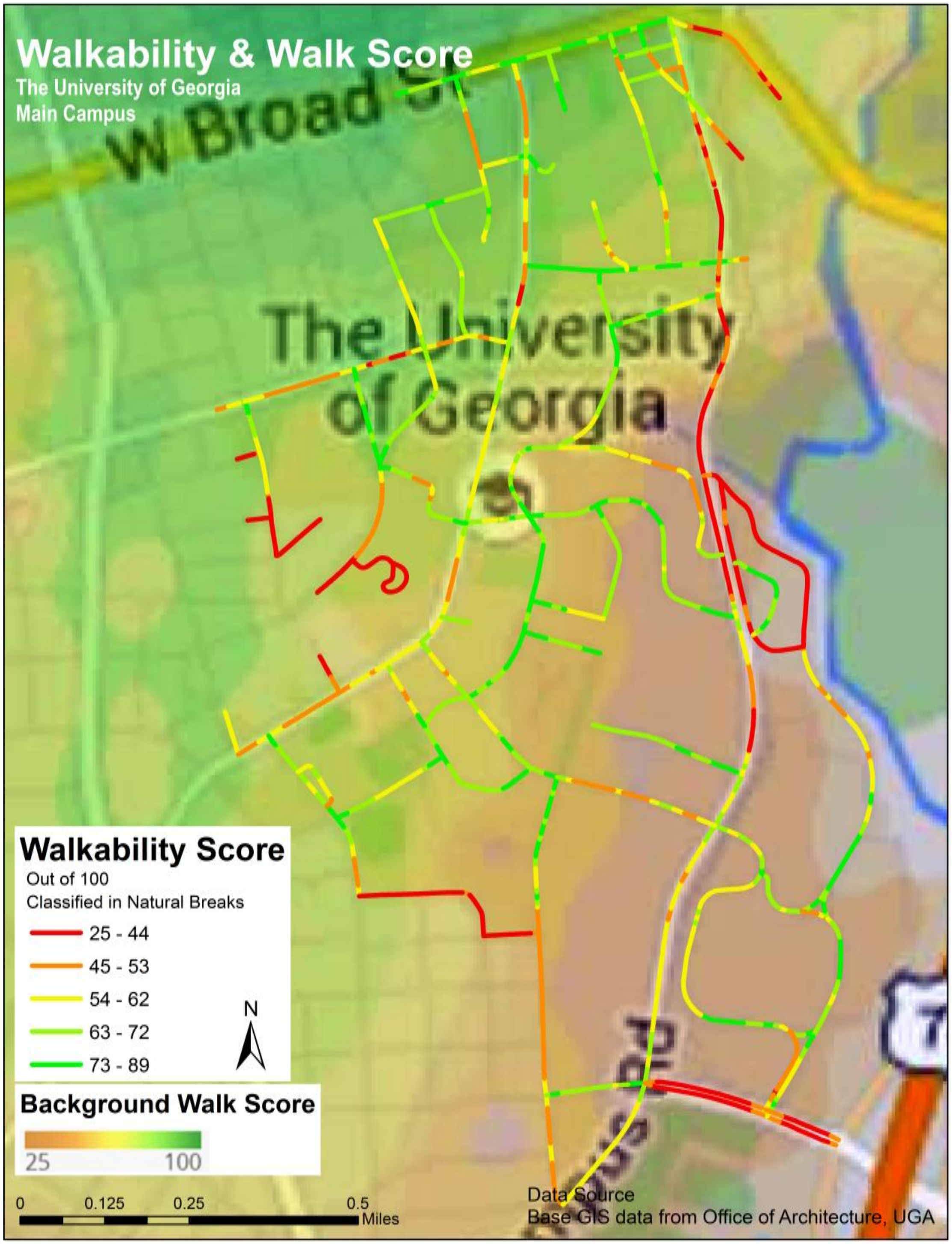


Figure 26 Comparison of New Walkability and Walk Score

CHAPTER 5

SUMMARY AND CONCLUSION

Corresponding to the research objectives outlined in the introduction, the major findings and contribution of this study are as following. First, more urban design perspectives were included in the walkability assessment. Beyond the traditionally considered factors in the land use and transportation, the proposed method takes other important built environment factors such as sidewalk conditions, walking buffer, sidewalk share situation, traffic speed and more into consideration. The online walking preference survey also successfully obtained people's walking preferences on the built environment and other considerations in their walking decision making process. The walking preference survey is a straightforward method to capture the detailed perceived importance and their variation among campus pedestrians. To my knowledge, this study provides the first walkability method that considers people's preferences by using well-designed survey. Survey is an ideal tool to make the walkability more intuitive and human-oriented.

Second, the modified analytic hierarchy process (MAHP) was developed here to simplify the process of obtaining inputs for complicated questions. With many factors in varied scales, aggregation levels and categories, it is hard to obtain direct pair comparison results from participants as the classic AHP does. This modification could let more factors be evaluated and by a large group of people that more than just several expert as in AHP.

Third, it successfully combines people's perceived importance and objective measures of the built environment into the new walkability measurement. Instead of working in a generic environment, this measurement is tailored to the UGA main campus. For a specific area with specific needs, it is possible to visualize and identify the "where, what and how" to improve the walking environment.

The new walkability assessment still has some limitations. First, this method sets the environment as a university campus, which differs from commercial, residential or any other places. Participants that are all affiliated to the university could have different preferences than residents in an urban or rural neighborhood or the tourists in a shopping area. Second, the method only considers the walking space along the roads rather than all the walking space accessible to the pedestrians such as those between the buildings and within a quad. People may have different thoughts for those area than the walking space along the road. However, if those walking spaces are connected and considered, the walkability could be different from current results. Third, this method counts for the built environment factors that city planners and urban designers could improve in the future plans, but does not consider the natural conditions (weather) or other unquantifiable or hard to quantify parts of the walking environment (aesthetic feeling, safety, tree shade and more), which could also be very important in the walking decision making process. Fourth, although the built environment factors are weighted by the perceived importance, there could still be some factors that are crucial but not considered here. It would be ideal that using some test survey or interviews among a small group of local people to identify the built environment factors that should be included before walking preference survey reaching more participants.

Future work of this research will investigate those areas where should have high walkability but currently don't, and then find out how and what the planning department can do to better support walking activities on campus. The Calorie Map and Calorie Matrix will be printed out into pamphlet to promote more walking on campus. More efforts, such as making an online app, will be done to make the research results accessible and attractive to bigger audience. Methods in this research can also be applied to bigger scale to benefit more people. For example, similar surveys and methods can be used to improve walkability in bigger areas, such as cities, or for specific groups, such as elderly people, handicapped people and more. The survey questions can be redesigned according to the various needs of the area and the group. It would also be interesting and meaningful to see whether there is significantly difference between male and female, or age groups.

As an upgrade of existing walkability calculation methods, the new walkability measurement in this study includes pedestrian's perceived importance and more built environment factors. For a university campus setting, where pedestrians are mostly students, faculty and staff, this walkability measurement obtains more detailed information from these groups and the area. The findings, along with some survey outcome insights, could help the campus planners and designers to make our campus more walkable, and further make people enjoy more walking on campus. If this method could consider the different factors from various settings, this method can be applied for other places to find the problems in the auto-oriented planning and built environment.

REFERNCES

Administration, U. (2015). UGA by the Numbers. Retrieved from http://www.uga.edu/profile/facts/

Athens-Clarke County Code of Ordinances. (1993). Retrieved from https://www.municode.com/library/ga/athens-clarke_county/codes/code_of_ordinances?nodeId=PTIIICOOR_TIT3PUSA_CH3-3PAMOVETR_S3-3-17SPLIGE

Berke, E. M., Koepsell, T. D., Moudon, A. V., Hoskins, R. E., & Larson, E. B. (2007). Association of the Built Environment With Physical Activity and Obesity in Older Persons. *American Journal of Public Health*, *97*(3), 486–492. http://doi.org/10.2105/AJPH.2006.085837

BikeAthens. (2010). Athens-Clarke County Bike Map. Retrieved from http://bikeathens.com/

Booth, K. M., Pinkston, M. M., & Poston, W. S. C. (2005). Obesity and the Built Environment. *Journal of the American Dietetic Association*, *105*(5), 110–117. http://doi.org/10.1016/j.jada.2005.02.045

Campus Master Planning Committee. (2012). The University of Alabama Campus Master Plan. Retrieved from http://www.uafacilities.ua.edu/planning/information/2012 Master Plan Update/2012 Master Plan Update.pdf

Carr, L. J., Dunsiger, S. I., & Marcus, B. H. (2010). Walk Score™ as a global estimate of neighborhood walkability. *American Journal of Preventive Medicine*, *39*(5), 460–463. http://doi.org/10.1016/j.amepre.2010.07.007

Carr, L. J., Dunsiger, S. I., & Marcus, B. H. (2011). Validation of Walk Score for estimating access to walkable amenities. *British Journal of Sports Medicine*, *45*(14), 1144–1148. http://doi.org/10.1136/bjsm.2009.069609

Cervero, R., & Kockelman, K. (1997). Travel Demand And The 3ds : Density , Design And Diversity. *Transportation Research Part D: Transport and Environment*, *2*(3), 199–219. http://doi.org/10.1016/S1361-9209(97)00009-6

Davies, J. (2012). Word Cloud Generator - Jason Davies. London, UK. Retrieved from https://www.jasondavies.com/wordcloud/

Dobesova, Z., & Krivka, T. (2012). Walkability Index in the Urban Planning : A Case Study in Olomouc City. *Advances in Spatial Planning*, *3*, 179–196.

Duncan, D. T., Aldstadt, J., Whalen, J., & Melly, S. J. (2013). Validation of Walk Scores and Transit Scores for estimating neighborhood walkability and transit availability: A small-area analysis. *GeoJournal*, *78*(2), 407–416. http://doi.org/10.1007/s10708-011-9444-4

Duncan, D. T., Aldstadt, J., Whalen, J., Melly, S. J., & Gortmaker, S. L. (2011a). Validation of Walk Score® for Estimating Neighborhood Walkability: An Analysis of Four US Metropolitan Areas. *International Journal of Environmental Research and Public Health*, *8*(12), 4160–4179. http://doi.org/10.3390/ijerph8114160

Duncan, D. T., Aldstadt, J., Whalen, J., Melly, S. J., & Gortmaker, S. L. (2011b). Validation of Walk Score® for Estimating Neighborhood Walkability: An Analysis of Four US Metropolitan Areas. *International Journal of Environmental Research and Public Health*, *8*(12), 4160–4179. http://doi.org/10.3390/ijerph8114160

Ellaway, a, Anderson, a, & Macintyre, S. (1997). Does area of residence affect body size and shape? *International Journal of Obesity and Related Metabolic Disorders : Journal of the International Association for the Study of Obesity*, *21*, 304–308. http://doi.org/10.1038/sj.ijo.0800405

Emery, J., Crump, C., & Bors, P. (2003). Reliability and Validity of Two Instruments Suitability of Sidewalks and Roads, 38–47.

Ewing, R., & Handy, S. (2009). Measuring the Unmeasurable: Urban Design Qualities Related to Walkability. *Journal of Urban Design*, *14*(1), 65–84. http://doi.org/10.1080/13574800802451155

Fan, J. X., Wen, M., & Kowaleski-Jones, L. (2014). An ecological analysis of environmental correlates of active commuting in urban U.S. *Health & Place*, *30*, 242–250. http://doi.org/10.1016/j.healthplace.2014.09.014

Ferreira, M. a G., & Sanches, S. D. P. (2007). Proposal of a sidewalk accessibility index. *Journal of Urban and Environmental Engineering*, *1*(1), 1–9. http://doi.org/10.4090/juee.2007.v1n1.001009

Forsyth, A., & Southworth, M. (2008). Cities Afoot—Pedestrians, Walkability and Urban Design. *Journal of Urban Design*, *13*(1), 1–3. http://doi.org/10.1080/13574800701816896

Frackelton, A. (2013). Pedestrian Transportation Project Prioritization Incorporating App-Collected Sidewalk Data.

Frank, L. D., Sallis, J. F., Saelens, B. E., Leary, L., Cain, K., Conway, T. L., & Hess, P. M. (2010). The development of a walkability index: application to the Neighborhood Quality of Life Study. *British Journal of Sports Medicine*, *44*(13), 924–933. http://doi.org/10.1136/bjsm.2009.058701

Galvez, M. P., Pearl, M., & Yen, I. H. (2010). Childhood Obesity and the Built Environment: A review of the Literature from 2008-2009. *Current Opinion in Pediatrics*, *22*(2), 202–207. http://doi.org/10.1097/MOP.0b013e328336eb6f.Childhood

Jackson, R. J., & Kochtitzky, C. (2001). Creating A Health Enviroment: The Impact of the Built Environment on Public Health. *Washington, DC: Sprawl Watch Clearinghouse Monograph Series*.

Jun, H.-J., & Hur, M. (2015). The relationship between walkability and neighborhood social environment: The importance of physical and perceived walkability. *Applied Geography*, *62*, 115–124. http://doi.org/10.1016/j.apgeog.2015.04.014

Kevin M. Leyden, P. (2003). Social Capital and the Built Environment: The Importance of Walkable Neighborhoods -- Leyden 93 (9): 1546 -- American Journal of Public Health, *93*(9), 1546–1551. http://doi.org/10.2105/AJPH.93.9.1546

Krizek, K. J. (2003). Operationalizing Neighborhood Accessibility for Land Use-Travel Behavior Research and Regional Modeling. *Journal of Planning Education and Research*, *22*(3), 270–287. http://doi.org/10.1177/0739456X02250315

Lai, V. S., Wong, B. K., & Cheung, W. (2002). Group decision making in a multiple criteria environment : A case using the AHP in software selection, *137*, 134–144.

Litman, T. (2014). Land for Vehicles or People?

Lo, R. H. (2009). Walkability: what is it? *Journal of Urbanism: International Research on Placemaking and Urban Sustainability*, *2*(2), 145. http://doi.org/10.1080/17549170903092867

Morland, K., Wing, S., Diez Roux, A., & Poole, C. (2002). Neighborhood characteristics associated with the location of food stores and food service places. *American Journal of Preventive Medicine*, *22*(1), 23–29. http://doi.org/10.1016/S0749-3797(01)00403-2

National Institutes of Health. (2012). What Are the Health Risks of Overweight and Obesity? Retrieved from http://www.nhlbi.nih.gov/health/health-topics/topics/obe/risks

New York State Department of Health. (2014). Obesity Prevention. Retrieved from https://www.health.ny.gov/prevention/obesity/

Office of the University Architect. (2015). The Legacy Of Princeton University's 2016 Campus Plan. Retrieved from http://walkableprinceton.com/2015/10/23/campus-2016-legacy/

Ogden, C. L., Carroll, M. D., Kit, B. K., & Flegal, K. M. (2014). Prevalence of childhood and adult obesity in the United States, 2011-2012. *Jama*, *311*(8), 806–814. http://doi.org/10.1001/jama.2014.732

Owen, N., Humpel, N., Leslie, E., Bauman, A., & Sallis, J. F. (2004). Understanding environmental influences on walking. *American Journal of Preventive Medicine*, *27*(1), 67–76. http://doi.org/10.1016/j.amepre.2004.03.006

Papas, M. a., Alberg, a. J., Ewing, R., Helzlsouer, K. J., Gary, T. L., & Klassen, a. C. (2007). The Built Environment and Obesity. *Epidemiologic Reviews*, *29*(1), 129–143. http://doi.org/10.1093/epirev/mxm009

Park, S. (2008). Defining, Measuring, and Evaluating Path Walkability, and Testing Its Impacts on Transit Users' Mode Choice and Walking Distance to the Station. *University of California Transportation Center, UCTC Disse*(150), 239. Retrieved from http://www.uctc.net/research/diss150.pdf

Pribis, P., Burtnack, C. a., Mckenzie, S. O., & Thayer, J. (2010). Trends in body fat, body mass index and physical fitness among male and female college students. *Nutrients*, *2*, 1075–1085. http://doi.org/10.3390/nu2101075

Richardson, C. R., Faulkner, G., McDevitt, J., Skrinar, G. S., Hutchinson, D. S., & Piette, J. D. (2005). Integrating physical activity into mental health services for persons with serious mental illness. *Psychiatric Services*, *56*(3), 324–331. http://doi.org/10.1176/appi.ps.56.3.324

Rundle, A., Neckerman, K. M., Freeman, L., Lovasi, G. S., Purciel, M., Quinn, J., … Weiss, C. (2009). Neighborhood Food Environment and Walkability Predict Obesity in New York City. *Environmental Health Perspectives*, *117*(3), 442–447. http://doi.org/10.1289/ehp.11590

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, *1*(1), 83. http://doi.org/10.1504/IJSSCI.2008.017590

Saelens, B. E., & Handy, S. L. (2010a). Built Environment Correlates of Walking: A Review, *40*(206). http://doi.org/10.1249/MSS.0b013e31817c67a4.Built

Saelens, B. E., & Handy, S. L. (2010b). NIH Public Access, *40*(206). http://doi.org/10.1249/MSS.0b013e31817c67a4.Built

Salois, M. J. (2012). Obesity and diabetes, the built environment, and the "local" food economy in the United States, 2007. *Economics & Human Biology*, *10*(1), 35–42. http://doi.org/10.1016/j.ehb.2011.04.001

Slater, S. J., Nicholson, L., Chriqui, J., Barker, D. C., Chaloupka, F. J., & Johnston, L. D. (2013). Walkable communities and adolescent weight. *American Journal of Preventive Medicine*, *44*(2), 164–8. http://doi.org/10.1016/j.amepre.2012.10.015

Swinburn, B., Egger, G., & Raza, F. (1999). Dissecting obesogenic environments: the development and application of a framework for identifying and prioritizing environmental interventions for obesity. *Preventive Medicine*, *29*(6 Pt 1), 563–570. http://doi.org/10.1006/pmed.1999.0585

Van Dyck, D., Cardon, G., Deforche, B., Sallis, J. F., Owen, N., & De Bourdeaudhuij, I. (2010). Neighborhood SES and walkability are related to physical activity behavior in Belgian adults. *Preventive Medicine*, *50*, S74–S79. http://doi.org/10.1016/j.ypmed.2009.07.027

Vargo, J., Stone, B., & Glanz, K. (2012). Google walkability: a new tool for local planning and public health research? *Journal of Physical Activity & Health*, *9*(5), 689–97. http://doi.org/10.3109/17453054.2010.510445

Walk Score Methodology. (2016). Retrieved April 30, 2016, from https://www.walkscore.com/methodology.shtml

Warburton, D. E. R., Nicol, C. W., & Bredin, S. S. D. (2006). Health benefits of physical activity: the evidence. *CMAJ : Canadian Medical Association Journal = Journal de l'Association Medicale Canadienne*, *174*(6), 801–809. http://doi.org/10.1503/cmaj.051351

West Virginia Health Statistic Center. (2002). Obesity: Facts, Figures, Guidelines. Retrieved from https://www.wvdhhr.org/bph/oehp/obesity/mortality.htm

Zhu, X., Lu, Z., & Yu, C. (2013). Walkable communities: Impacts on residents' physical and social health, (July), 1–6. Retrieved from http://www.acsa-arch.org/docs/default-source/resources/aia_sus_tamu_rpt_digital_f.pdf?sfvrsn=2

Appendix A: List of Acronyms and Abbreviations

AHP: Analytic hierarchy process

BMI: Body Mass Index

CITI: Collaborative Institutional Training Initiative

DEM: Digital Elevation Model

GIS: Geographic information systems

IRB: Institutional Review Board

MAHP: Modified Analytic Hierarchy Process

NGO: Non-governmental organization

UGA: The University of Georgia

USDA: United States Department of Agriculture

Appendix B: Survey

The online survey: https://ugeorgia.qualtrics.com/jfe/form/SV_3dt6nZtHVno4hoh
(or tinyurl.com/walkableuga)
(The survey was built on Qualtrics, a professional research software company.)
The survey demo:

Walking Preference Survey for UGA Campus

Dear participant:

I am a graduate student, under the direction of Dr. Mu, in the Department of Geography at The University of Georgia. I invite you to participate in a research study entitled Perceived and Objective Measures of Built-Environment Walkability of a University Campus. The purpose of this study is to identify and measure the features which can promote walking activities for the University of Georgia.

Your participation will involve a one-time survey and will take less than 10 minutes. You must be 18 or older to participate. Your involvement in the study is voluntary, and you may choose not to participate or to stop at any time without penalty or loss of benefits to which you are otherwise entitled.

This survey asks about your preference when you are a pedestrian on UGA main campus. It won't ask sensitive or personal identifiable information. The findings from this project may provide information on improving the walkability and health promotion in the long run. There is no known risk associated with this research. By entering your email address at the end of survey, you have the chance to win one of ten $10 Jittery Joe's gift card (or cash)! If you do not wish to participate in the survey but would like to be entered into the drawing, you could send an email to xuan.zhang@uga.edu.

If you have any questions about this research project, please feel free to call me, Xuan Zhang, at (706)201-4195 or send an e-mail to xuan.zhang@uga.edu. Questions or concerns about your rights as a research participant should be directed to The Chairperson, University of Georgia Institutional Review Board; telephone (706) 542-3199; email address irb@uga.edu.

Thank you for your participation!

Sincerely,

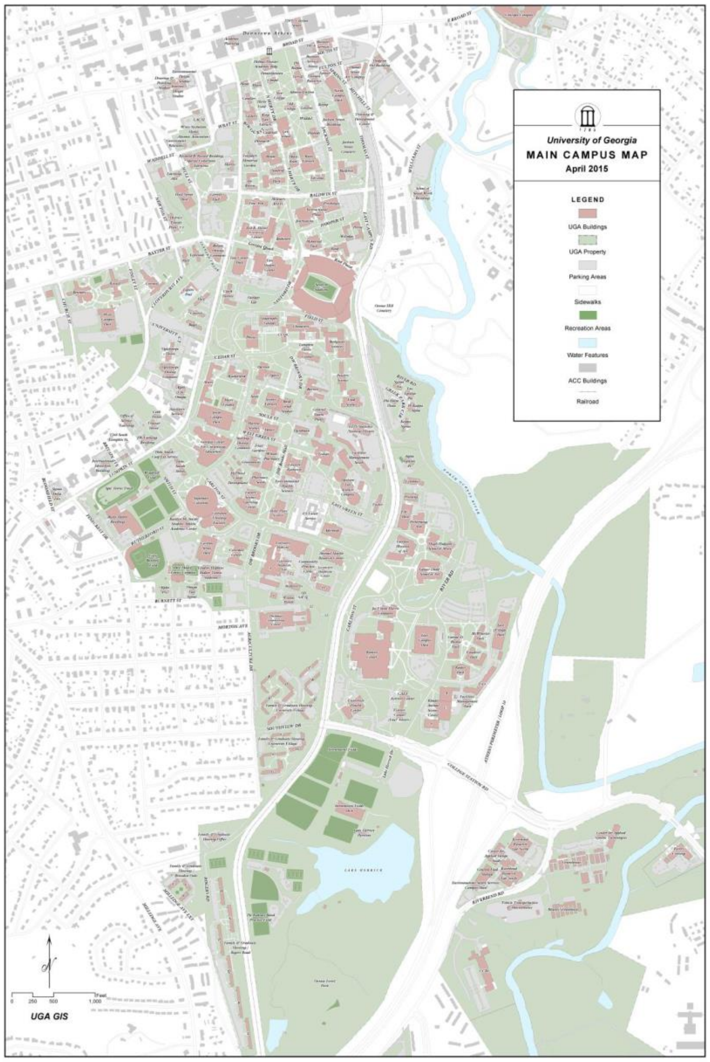
Xuan Zhang

By checking the following check-box, you are agreeing to participate in the above described research project.
I agree to participate in the survey.

☐ I agree to participate in the survey

Walking Preference Survey

This is a most recent UGA Main Campus map, which can give you the visual boundary of the main campus.



Data Source:
University Architects
www.architects.uga.edu

Thank you so much for your participation!

Sidewalk Condition

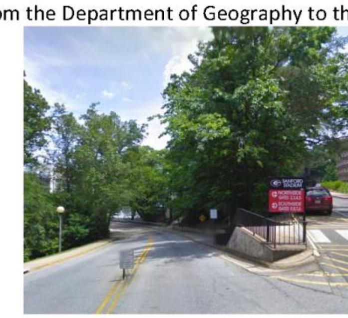
- I would choose a route with a sidewalk over a route without a sidewalk.
  Strongly disagree 1 2 3 4 5 6 7 8 9 Strongly agree

(The level of agreement increases from 1 to 9. And 5 means neutral. The following questions are all set in the same manner.)

- Adequate sidewalk width makes the walking more pleasurable.
  Strongly disagree 1 2 3 4 5 6 7 8 9 Strongly agree

- The vertical slope of a path is what I would consider when choosing a walking route.
  Strongly disagree 1 2 3 4 5 6 7 8 9 Strongly agree

- Which type of vertical slope do you prefer when walking?
  - ○ Hilly (bigger than 10 degree)
    As the Sanford Dr. from the Department of Geography to the Tate Center.



  - ○ Slight hilly (5-10 degree)
    As the Cedar Dr. from the Food Science/ Statistics to the Biology.

  - ○ Flatness (0-5 degree)
    As the Sanford Dr. from the Georgia Center to the Snelling Dining Hall.

Thank you so much for your participation!

Connectivity Condition

- I prefer to walk in a place with multiple route choices within sight (about 164 feet/50 m).
  Strongly disagree 1 2 3 4 5 6 7 8 9 Strongly agree

- I prefer to have pedestrian crossings nearby at any given place (about 67 feet/20 m).
  Strongly disagree 1 2 3 4 5 6 7 8 9 Strongly agree

- I prefer a walking route with a bus stop nearby, even if I don't plan on riding the bus.
  Strongly disagree 1 2 3 4 5 6 7 8 9 Strongly agree

Availability of Amenities

- How important is it that these types of amenities lie along your route?

	Extremely important 1				Neutral 5				Extremely unimportant 9
Food services/ coffee shop/ restaurants and bars	1	2	3	4	5	6	7	8	9
Multi-functional center (TATE/MLC)	1	2	3	4	5	6	7	8	9
Athletic field and recreational facilities	1	2	3	4	5	6	7	8	9
Teaching and lab buildings	1	2	3	4	5	6	7	8	9
Administration buildings	1	2	3	4	5	6	7	8	9
Green space	1	2	3	4	5	6	7	8	9
Libraries/ book stores	1	2	3	4	5	6	7	8	9
Resident halls /apartments	1	2	3	4	5	6	7	8	9
Parking space	1	2	3	4	5	6	7	8	9

- If you have other important amenities not included, please specify in the following line.

____

- I would walk more if a variety of amenities were nearby.
  Strongly disagree 1 2 3 4 5 6 7 8 9 Strongly agree

Thank you so much for your participation!

Perceived Feeling

- If the traffic speed is quite high near the sidewalk, you won't want to walk there.
  Strongly disagree 1 2 3 4 5 6 7 8 9 Strongly agree

- I prefer walking on a sidewalk with a buffer zone from the road (grass, trees or parking).
  Strongly disagree 1 2 3 4 5 6 7 8 9 Strongly agree

- I prefer walking on a sidewalk that no bike rider shares it with me (there is a bike lane aside the road).
  Strongly disagree 1 2 3 4 5 6 7 8 9 Strongly agree

- What else would influence you to avoid walking at a place?
  ____

- Where do you think is the most walkable place at UGA main campus and why? And what's the score (0-100) you will give regarding to its walkability?
  Please indicate a place, street, building or an area.
  ____
  ____

- Where do you think is the **most unwalkable** place and why? What's the score (0-100) you will give regarding to its walkability?
  ____
  ____

Thank you so much for your participation!

About you

- You are
  - An undergraduate student
  - A graduate student
  - A faculty or staff
  - A frequent visitor (such as long-term visiting scholar)
  - An occasional visitor to UGA

- What's your gender?
  - Female
  - Male
  - Do not want to answer

- Which year were you born in?

  ____

- What are your motivations of walking? (Check all that apply to you)
  - ☐ Exercise
  - ☐ Enjoying the time with friends
  - ☐ Going to some destination
  - ☐ Aimless
  - ☐ Entertainment
  - ☐ Others ________

- The transportation mode

	Bus	Car	Bicycle	Walking	Motorcycle
You use the most	○	○	○	○	○
You most prefer to use	○	○	○	○	○

- Do you have any comment or suggestion for the campus walking environment, the survey, or the whole project (to evaluate the walkable environment on the UGA campus for future better walking support)?

  ____

  ____

Thank you so much for your participation!