Linking Affect and the Built Environment using Mobile Sensors and Geospatial Analysis

by

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A REPORT

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Abstract

As urban development continues, it is imperative we understand how infrastructural policies impact well-being in order to design functional and healthy cities. The growth in wearable sensors and real-time data offer a way to assess the day-to-day influence of built infrastructure on health. The aim of this research is to determine if and how much characteristics of the built environment affect individual physiological responses. The purpose of this research is two-fold: 1) quantify and understand the linkages between form and function of the built environment on human affect and 2) identify practices for collecting and mining sensor data that can be used by planners.

Subjects ($n = 24$) were sent on a walk through downtown Manhattan, Kansas. The route was carefully designated to expose individuals to different architectural and environmental features such as: vegetation, infrastructure (broadly), building height and area, land use, trees and street conditions. The study explores the associations of nearly a dozen environmental characteristics with the real-time feedback from sensor data. The sensors used in this study measure electrodermal activity (EDA) and heart rate (HR) which were linked spatially using GPS. The results enable a spatio-temporal analysis to identify correlations between environmental characteristics and spatial representations of urban form. Differences of stress-related responses are identified through statistical analysis. The data and spatial analyses were also used by colleagues to develop a machine learning approach to explore methods for estimating stress. In addition to quantifying urban form additional subject information was collected, such as demographic information, fitness level, sense of place, feeling of community, and feeling of exposure in the built environment.

This work builds upon a previous study by Parker Ruskamp (MLA 2016). His qualitative results indicate that areas with lower lighting (at night) and higher-density infrastructure caused increased stress reactions. The efforts in this report, added additional participants and worked to spatially quantify urban form in order to conduct quantitative assessments to characterize the influence of environmental features against stress. Through the analysis it was discovered there is a relationship to biophysical measures and relationship to vegetation presence, building façades, building area or envelope, zoning and parking lots. In particular, the most influential characteristics were the amount of parking in close proximity to participants at night and the quality of the sidewalks during the day. While effects were discovered, further work should be done to confirm and generalize these findings. These initial results demonstrate how using biophysical measures can help planners evaluate the effectiveness of policies and built-environments toward improving the well-being of citizens. Further, this study provides a basis on how designs can be better informed by geospatial analysis, enhanced through an extensive environmental characteristic literature review, and statistical analysis to promote health and well-being through urban design.

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Definitions

Built Environment: human-made space in which people live, work, and recreate on a day-to-day basis (Roof, 2008). It can encompass all buildings, spaces, and products that are created or modified by people. It includes homes, greenspaces, schools, and transportation systems. It can extend overhead in the form of transmission lines, underground, and as highways (Department of Health and Human Services, 2004). The built environment includes land-use planning and policies that impact our communities in urban, rural, and suburban areas (Department of Health and Human Services, 2004).

Stress: “a relationship between the person and the environment that is appraised by the person as relevant to his or her well-being and in which the person’s resources are taxed or exceeded (Folkman & Lazarus, 1985).”

Biophysical Feedback: For the purpose of this study, biophysical feedback can be defined as “a procedure in which data regarding an individual’s biological activity are collected, processed, and conveyed back to the person so that he or she can modify that activity (Everly & Lating, 2013).”

Urbanization: “1. increase in the proportion of a population living in urban areas 2. Process by which a large number of people becomes permanently concentrated in relatively small areas, forming cities (United Nations, 1997).”

Core Affect: "…neurophysiological state consciously accessible as a simple primitive non-reflective feeling most evident in mood and emotion but always available to consciousness (Russell, 2009).” Examples of core affect include pleasure and displeasure, tension and relaxation, energy and tiredness (Ekkekakis, 2012).

“Peripheral physiological arousal” (arousal): “…implies increases above resting base rates of one or both of those arousal complexes, as indicated (Dienstbier, 1989).”

Land Use: “Diversity of uses and access to facilities (Ariffin & Zahari, 2013).”

List of Abbreviations

GSR – Galvanic Skin Response

EDA – Electrodermal Activity (uses synonymously with GSR)

HR – Heart Rate

Questionnaire Zone- Zones were delineated in GIS, based on where each image in the questionnaire survey was taken along the walking route, based on Ruskamp (2016). Used for Image Rating Analysis.

Random Zone- Zones randomly created geospatially. Used for Linear Regression Analysis.

Acknowledgements

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1.0 Introduction

The physical environment influences mental health (Abraham, Sommerhalder, & Abel, 2010a; Evans, 2003; R. Ulrich, 1983a, 1984a) yet, planners and designers still do not understand fully how specific built environment characteristics influence people's physiological response. Fortunately, studies have shown that having access to and maintaining a connection with the natural environment are very important for reducing stress and improving mental health (Abraham et al., 2010a; R. Kaplan & Kaplan, 1989a; S. Kaplan, 1995a; Maas, Verheij, Groenewegen, Vries, & Spreeuwenberg, 2006a; R. Ulrich, 1983a, 1984a). Although researchers are aware of the connection between nature and mental health, there is still much to understand between well-being and the built environment (Gary Evans & Cohen, 1987a). As urbanization increases globally (Frizell, 2014), there is a new pressure for rapid urban development. New advances in urban renewal and revitalization of city centers have increased developmental density (WHO, 2010). While encouraging new growth and expansion of cities, planners and designers are more pressed than ever to understand the types of environments they are creating, from a social and behavioral perspective. **The aim of this research is to determine if and how much characteristics of the built environment affect stress-related responses in users.**

The built environment is associated with human affect; or pleasure and displeasure, energy and tiredness (Ekkekakis, 2012). Urban environments have the power to negatively influence human health, yet natural elements in the built environment have the ability to improve mental and physical health (S. Kaplan, 1995a). Ideally then, planners and designers can use this information to ascertain what kinds of environmental characteristics are shown to cause or reduce stress from or caused by the built environment. Planners can then measure environmental characteristics using non-invasive sensors, such as an Empatica, to help find linkages between physiology and statistical analysis, or stated perceptions of safety. They can use this data to design a more comfortable environment and better plan policies. It is believed that the detection of arousal with the use of wearables and sensors can help researchers to investigate several issues in urban environments (Yates, Chamberlain, & Hsu, 2018), such as identifying specific characteristics and areas in the environment that are linked to a physiological response. Therefore, this research aims to: ***Quantify and understand the linkages between the form and function of the built environment on human stress or affect (Objective #1)*.**

This study will identify and utilize new practices to collect real-time feedback data using sensors and geospatial analysis. Many fields have utilized different forms of biophysical feedback tools to gain insight into human responses. These tools can be specifically applied to the design and planning field as well as many others that rely on quantitative data. Using biophysical feedback equipment with a geospatial approach can open new realms of research and data collection that relate to human perceptions and reactions to space. The geospatial analysis will analyze environmental variables compared to biophysical feedback data based on real- time results. It will provide models used in geospatial analysis which professionals can utilize for future research.

Using the results and participant information from this study in combination with an earlier study Ruskamp (2016), evidence will be developed to show that certain design characteristics play a role in perceived comfort, and comfort backed by biophysical data. These results can be presented when making design decisions as a tested way to show how and why certain features in an urban environment provide increased comfort, or discomfort. Whether these changes come in the form of additional vegetation, lighting, or more sidewalk space for pedestrians, the importance of this study is evident- to encourage and enhance the knowledge and creation of spaces that serve to enhance public well-being in the short and long term. This leads to the second objective of this research: ***Identify practices for collecting and mining sensor data that can be used for planners (Objective #2).***

This study provides planners and designers with an empirical and non-invasive method for investigating the relationship between environmental features in an urban environment and their impacts on citizens that live within those environments. This noninvasive data collection (using GPS and heart rate/EDA data) offers planners and designers a method to examine data and develop policy changes to improve citizen lives and design. Further, this report provides a group of geospatial models which planners can use to analyze data for their urban environments to understand how to create policies and design cities based on the biophysical responses of their citizens. Using the tools provided in this report, planners could characterize the built environment through spatial models that can then be used to evaluate how certain characteristics may influence citizens' affect. This study will provide a greater foundation on how public policy and design can be better informed to promote health and well-being through urban design.

2.0 Literature Review

Urbanization is not only a positive force for economic development, but also one that can create desirable social and health outcomes. Due to the greater access to social and health services, urban populations are generally better off than their rural counterparts- literacy rates are higher and life expectancy is longer (WHO, 2010). With the increase in urbanization comes the increase in downtown development.

A large number of downtown development expansions have increased demand for land and placed a greater pressure on the availability of outdoor spaces and amenities because they seem less valuable than the built environment, yet they are vital (Groenewegen, van den Berg, de Vries, & Verheij, 2006; Maas et al., 2006a). The vitality of amenities shows up in literature which suggests that the people using these highly urbanized areas may be negatively affected by the built environment (Jackson, 2003; Parsons, 1991; Parsons, Tassinary, Ulrich, Hebl, & Grossman-Alexander, 1998; R. S. Ulrich et al., 1991). The replacement of nature with built infrastructure can lead to stress and mental fatigue (R. Ulrich, 1981). Natural urban environments are shown to produce more beneficial changes in physiological stress responses relative to the built environment (Beil & Hanes, 2013). Common problems in cities are limited spaces, obstacles, noise, pollution, risks of accidents, and generally poor conditions (Gehl, 2013a), which all could have a negative influence on human health. The environment in which someone lives has the potential to influence mental and physical health, and it is found to be a source of several stressors that elicit reactions (Gary Evans & Cohen, 1987a). Certain characteristics of the environment have been shown to reduce, induce, or inhibit stress responses in people, both mental and physical; such as height of buildings (R. Ulrich, 1984a), vegetation (R. Ulrich, 1984a), lighting (Gary Evans & Cohen, 1987a), crowding (Gary Evans & Cohen, 1987a), infrastructure (R. Ulrich, 1981), walkability (Gary Evans & Cohen, 1987a), and noise (Gehl, 2013a).

Certain non-natural lighting has shown to have negative costs on human health and the environment (Evans, 1984), people feel safer when their urban environments are better lit (Ruskamp, 2016a). Another feature that has negative effects on people in urban environments is noise, which has continuously been mentioned to be one of the most undesirable conditions and is proven to cause stress (Borsky, 1979). People living in neighborhoods characterized by poorer features of the built environment, such as limited spaces, obstacles, pollution, and noise (Gehl, 2013b), were 29%–58% more likely to report depression in the past six months and 36%–64% more likely to report lifetime depression than respondents living in neighborhoods characterized by better features of the built environment (Galea & Vlahov, 2005).

Studies have shown the importance of having a connection to the natural environment, or places with little human influence, and the benefits of green space (Abraham et al., 2010a; Beil & Hanes, 2013; R. Kaplan & Kaplan, 1989a; S. Kaplan, 1995a; Maas et al., 2006a; R. Ulrich, 1981, 1983a, 1984a). Views of vegetation and water appear to sustain interest and attention more effectively than urban views (R. Ulrich, 1984a). Water has been described as a landscape element that evokes interest, aesthetic pleasantness, high levels of preference, and positive feelings, like tranquility (Childs, 2012; Civco, 1979; Penning- Roswell, 1979; Shafer et al., 1969; Hubbard et al., 1967; Ulrich, 1981; Ulrich, 1983; Zube, et al., 1975). In addition, urban forests, or ecosystems characterized by the presence of trees and other vegetation in association with human developments (Nowak et al. 2001), provide ecological, environmental, social, and economical benefits to the majority of urban populations (Yadong, 2003). Urban forests provide a number of ecosystem services (Board, 2005): air pollution removal, energy savings, carbon storage, enhanced real estate values, reduced heat island effects, recreational opportunities, wildlife habitat, visual and sound barriers, human stress reduction and aesthetic (Hull, 1992; Kaplan, 1989; Mole, et. al, 1989; Smardon, 1988; Ulrich, 1983; Yadong, 2003).

Research concerning human response to natural aesthetics has the possibility of being a key factor in the progression of understanding human interactions with the natural environment; it could prove to be essential in the development of complete theories of aesthetic response (R. Ulrich, 1983a). Aesthetic response to the natural environment relates to important questions in environmental planning and design (R. Ulrich, 1983a) of how humans identify with the spaces between buildings more than buildings themselves, and how to design for positive human interaction in an urban environment. Although most research has shown the benefits of exercise to physical health, exercise is also seen to enhance cognitive processing and reduce stress (Alghadir, Gabr, & Al-Eisa, 2016; Hogan, Mata, & Carstensen, 2013).

Favorable pedestrian environments are necessary for promoting walking (Jacobs, 1961; Parks & Schofer, 2006; Saelens, Sallis, Black, & Chen, 2003). Walkability can be categorized into how friendly an area is for a pedestrian to walk. Walkability provides economic benefits by reducing transportation cost, social benefits by increasing neighborhood interaction and community cohesion, and environmental benefits by reducing energy consumption (Ariffin & Zahari, 2013; Litman, 2017). Research concerning human response to walkability and the built environment states that typically grid networks with short blocks allow for direct routes, while long blocks and curvilinear streets lengthen pedestrian trips (Ariffin & Zahari, 2013; Parks & Schofer, 2006). Sidewalks are an essential component of good pedestrian design, particularly in areas where traffic is heavier. A lack of sidewalks requires pedestrians to walk in the roadway, decreasing their safety, or walk alongside the roadway, an unfriendly environment.

In addition to sidewalks and grid networks, building setbacks, building height, and parking play a role in a pedestrian friendly environment (Parks & Schofer, 2006). Small building setbacks make pedestrian accessibility easier, while large setbacks increase pedestrian effort to reach them as well as creating a less stimulating streetscape. Land use mix has been identified as an important aspect for a high walkability index (Ariffin & Zahari, 2013; Litman, 2017; Parks & Schofer, 2006; Saelens, Sallis, Black, et al., 2003). Higher population density, aesthetics, and greater connectedness of streets (higher number of intersections) are linked to higher rates of walking and bicycling (Ariffin & Zahari, 2013; Leslie et al., 2007; Saelens, Sallis, Black, et al., 2003). Weather conditions (A. F. Clark, Scott, & Yiannakoulias, 2014) and safety (Doyle, Kelly-Schwartz, Schlossberg, & Stockard, 2006) have also been shown to affect walkability. Lighting, sidewalks, marked pedestrian facilities, street furniture, useful signage, street trees, proximity to transportation facilities are more engaging for walkable environments(Forsyth, 2015). These environmental variables affect how comfortable someone will feel in their environment and the likelihood that they will walk to their destination.

How people respond to stress has significant consequences for people’s biological and cognitive functions. Stress occurs when there is an imbalance of environmental demands and human resources (Gary Evans & Cohen, 1987a). Constant stress experienced over a long period of time contributes to long term problems for the heart and blood vessels, contributes to breathing problems, contributes to liver and kidney problems, and nervous system complications (Tovian et al., n.d.). During a stressful event, the human body releases stress hormones such as cortisol, adrenaline, and noradrenaline (Tovian et al., n.d.). Stressful situations induce signs of increased arousal (e.g., racing heart) and are frequently construed as anxiety, nervousness, or fear (Jamieson, Nock, & Mendes, 2012). These negative emotions trigger a threat response. As stated in the previous research, urban environments contribute to these reactions in human stress responses. Thus, modifying the built environment may help improve physiological responses.

Although much has been learned about the consequences of long-term stress, little has been examined on how stress is experienced in real-time in the real-world. Laboratory studies provide information about the development and recovery of psychological response to stress, but they do not address the real-life stress that could do lasting damage on health. In these experiments, typically high precision laboratory equipment measures physiometric arousal indicators such as temperature, galvanic skin response (GSR), and heart rate in humans. The subject usually has sophisticated equipment attached to them and are monitored in a controlled environment such as a treadmill, while data is being recorded.

With new technologies and methods, we can now reliably collect significant data about the relationship between the built environment and human response so that researchers can understand how the design of urban spaces can influence well-being. There have been multiple studies done using wearables (high quality pedometers, heart rate odometers, accelerometers, barometers, GPS, GSR) using human test subjects in day-to-day application to evaluate new methods to improve the measurement of stress (Hernandez Rivera, 2015; Hoyt, R. & Karl, P., 2016; Picard, Fedor, & Ayzenberg, 2016; Rubin et al., 2015; Ruskamp, 2016a; Sano & Picard, 2013). The advantages of using these wearables and wrist-worn EDA sensors (Empatica E4, Polar watch, Garmin Vivosmart 3) are that they give researchers the ability to collect high quality data in a non-intrusive manner measuring physiometric arousal in new environments, such as urban environments (Picard et al., 2016; Sano & Picard, 2013; Yates et al., 2018). On some wearables, geolocation sensors and chronometers now enable the collection of geospatial data for spatiotemporal analytics (Yates et al., 2018). Using wrist-worn sensors, researchers are able to observe patterns of unbiased physiology that challenges some of the long-standing theoretical concepts of emotion and measurement (Picard et al., 2016). These wearables offer a unique opportunity for researchers to observe humans in real-time environments and quantify elements in the built environment that influence long-term mental health and stress.

With the discussion of mental health risk from prolonged exposure to urban environments, and the increase of urbanization, it seems that policy reform and design solutions are the best solutions to these issues (Groenewegen et al., 2006). Policy makers tend to view some urban characteristics, such as green space, as a luxury rather than a necessity and lean towards overlooking the psychological benefits of nature. This research aims to understand which environmental characteristics produce a positive psychological response to nature to help better plan and design urban spaces accordingly.

The field of urban planning and design has long been interested in the links between the built environment and human affect, but research studies regarding how the built environment directly influences health are still rare in the field. Through theories, concepts, and methods, planners have been able to provide a foundation on the relationship between the built environment and physical activity (Handy, Boarnet, Ewing, & Killingsworth, 2002). Research has focused on how certain land use designations and design policies can positively impact health by increasing public transportation and cycling/ walking (Frank, 2000; Saelens, Sallis, & Frank, 2003), as well as certain environmental characteristics positively impacting well-being; such as public spaces having shown to increase well-being (Jacobs, 1961); certain land uses (Ariffin & Zahari, 2013; Handy et al., 2002; Litman, 2017; Parks & Schofer, 2006; Saelens, Sallis, & Frank, 2003), and density (Handy et al., 2002; Saelens, Sallis, & Frank, 2003; Speck, 2013). Although we know these environmental characteristics affect heath, there has been no in-field research from planners that studies how the environment directly affects people at a personal scale.

3.0 Methodology

SITE

↓

SITE CHARACTERISTICS

↓

ROUTE

↓

RECRUITING

↓

QUESTIONNAIRE

↓

BIOPHYSICAL COMPONENTS

↓

DATA CLEANING

↓

GIS BIOPHYSICAL DATA ANALYSIS

↓

ENVIRONMENTAL CHARACTERISTICS

↓

FIRST LEVEL ANALYSIS OF HR/ EDA DATA

↓

HYPOTHESES AND PREDICTIVE ANALYSIS

↓

MACHINE LEARNING PROCESS (YATES, 2018)

Figure 1 Methodology

The experimental design closely follows the work by Ruskamp (2016), “Your Environment and You: Investigating Stress Triggers and Characteristics of the Built Environment.” This research is in line with recent work done by Brent Chamberlain and Heath Yates (2018). However, the methodology is further enhanced through spatial environmental modelling and related statistical analysis. Figure 1 Methodology introduces the full methodology completed during this analysis.

3.1 Site

Due to urbanization increasing globally (Frizell, 2014), there is a stronger demand for urban development. The main site for this study was previously established by Ruskamp (2016); it walks participants through downtown Manhattan, Kansas. The study site was chosen with careful consideration to many types of environments- recently developed, neglected, and “typical” conditions (Ruskamp, 2016). The reason for this environmental consideration was to expose participants to the extremes of the built environment states, just as Ruskamp (2016) did in his study, such as pedestrian- friendly urban streetscapes, and neglected streetscapes, in addition to the typical conditions one would normally find while walking in an urban area. Using these variables, a response related to affect is anticipated.

Manhattan, KS- although it is a small city, is no exception to the need for urban development facing many cities globally. Over the next two decades, Manhattan’s population could see a growth of over 30,000 people due to the $1.5 billion National Bio and Agro-Defense Facility moving into Manhattan in 2022 and the growth of Kansas State University. This increase will bring in an increased demand for housing, resources, transportation, parks, restaurants, built infrastructure and many other needs. Because of this growth, and proximity to Kansas State University students and faculty, this is the current ideal location to conduct a study on the effects of health and the built environment.

Figure 2 Site: Route (yellow line) in study area of Manhattan, KS (Image by Google Earth)

3.2 Site Characteristics

Once the site was established (Figure 2), a thorough site inventory and analysis was conducted. This allowed the researchers to make note of the existing environmental variables and conditions of the site that could directly influence the outcomes of the study. Assessment of the existing conditions help better understand what variables of the study are directly influencing human stress. The variables should help discover the correlations between stress and urban environmental characteristics.

The environment in which someone lives has the potential to influence mental health, and it is found to be a source of several stressors that elicit reactions (Gary Evans & Cohen, 1987a). Certain characteristics of the environment have been proven to reduce, induce, or inhibit stress responses in people; these site characteristics were thoroughly analyzed prior to the field study taken place. Figure 3 shows the characteristics mapped in GIS.

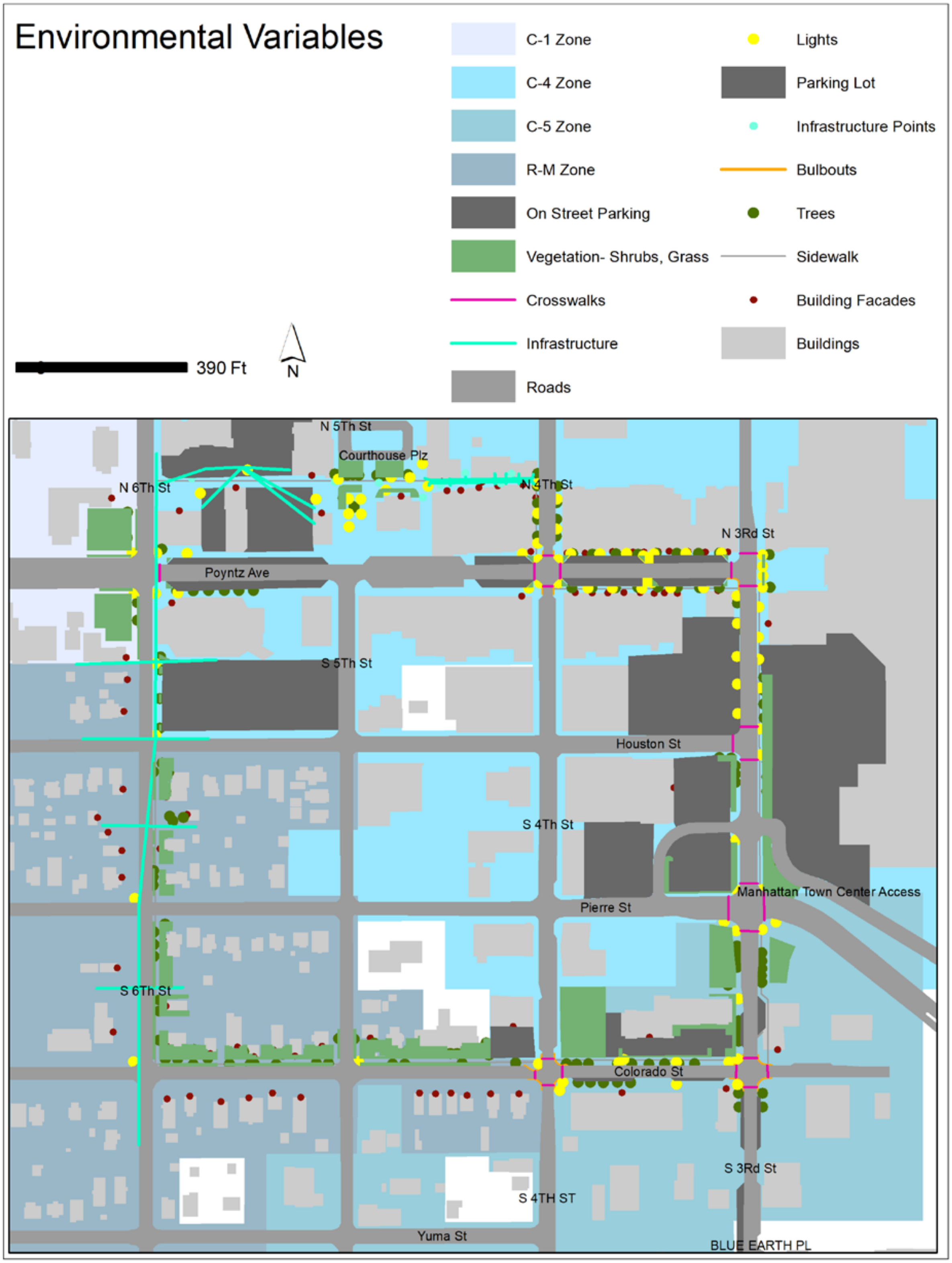


Figure 3 Environmental Variables Geospatially Mapped

The study was conducted during the fall of 2017 and the winter of 2018 during the hours of 10am to 4pm. 26 participants walked the route forward (clockwise) while 12 participants walked the route backwards (counterclockwise). See Table 1 Completed Experiments for the details of each study group in comparison with the original study completed by Ruskamp (2016). With data collection from some or all seasons and different environments, a comparative analysis could be done. To control for noise, which can contribute to comfort or discomfort, audio taken from the audio recording alongside the biophysical data. Certain weather conditions were monitored such as temperature at time of testing, precipitation, wind speed and condition, and relative cloud cover.

Table 1 Completed Experiments

EXPERIMENTS

Experiment Number	Timeline	Study Name	Location	Props	Route	People	Hours
01	Spring 2016	Your Environment and You (Ruskamp)	Manhattan, KS	Polar Empatica GoPro	Forward	14	9pm-11pm
02	Fall 2017	Linking Affect and the Built Environment (Whitaker)	Manhattan, KS	Polar Empatica Audio	Forward	12	10am-4pm
03	Winter 2018	Linking Affect and the Built Environment (Whitaker)	Manhattan, KS	Polar Empatica Audio	Backward	12	10am-4pm

3.3 Route

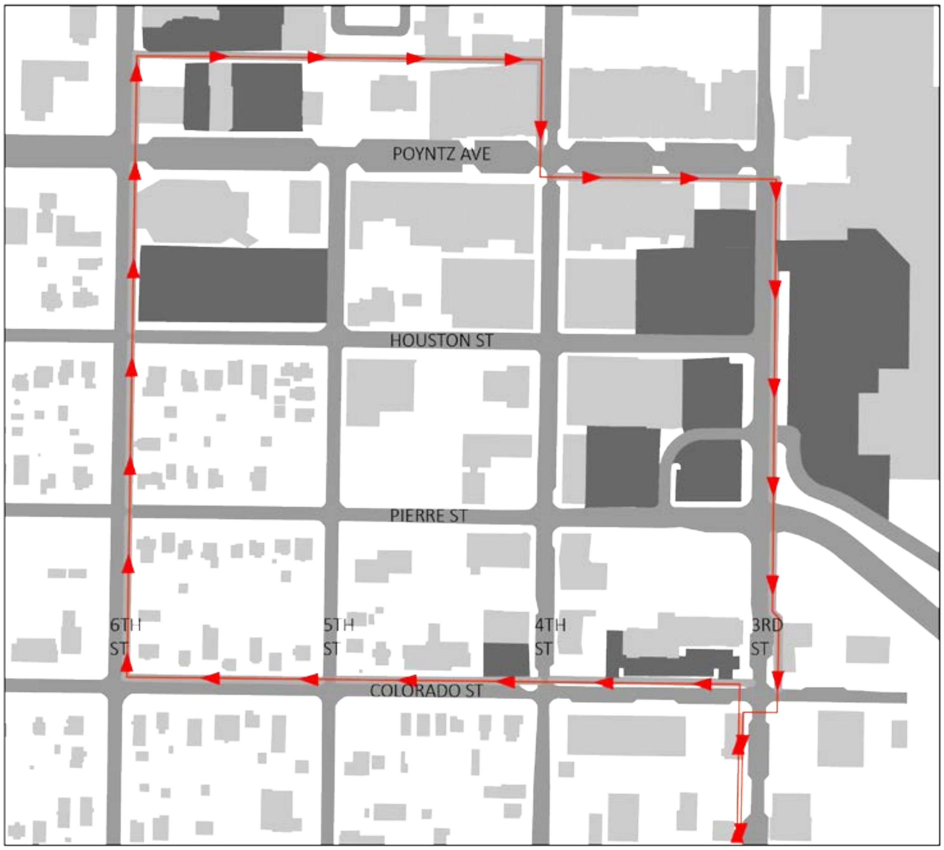


Figure 4 Walking Route- Backwards

"Participants started the route at the entrance/exit of a local hotel lobby. Once outside, they headed north on west side of 3rd Street. Once they had reached the intersection of Colorado and 3rd Street, subjects turned east and crossed 3rd Street on the south side of Colorado, before crossing Colorado on the east side of 3rd Street. Subjects walked north along the east side of 3rd Street to Poyntz Avenue. They then crossed 3rd Street, moving west, on the south side of Poyntz Avenue and continued west until reaching 4th Street, crossing over to the west side of the street. Subjects then turned north and crossed Poyntz Avenue and continued north until reaching the mid-block alley between Poyntz Avenue and Humboldt Street, where they turned west, continuing west for two blocks until reaching 6th Street. Staying on the east side of 6th Street, subjects turned south, crossing Poyntz Avenue again, and continuing south for three blocks until reaching Colorado Street. At the intersection of 6th Street and Colorado, subjects then turned east and continued for three blocks on the north side of Colorado. After reaching the intersection of 3rd Street and Colorado, subjects crossed Colorado, moving south and staying on the west side of 3rd Street, continuing to the starting point of the Hilton hotel lobby, completing a near one-mile loop (Ruskamp, 2016a).” Please see Figure 4 Walking Route- Backwards for a visual reference.

3.4 Recruiting

Initial participant recruitment included contacting professors and departments heads of programs at Kansas State University to speak to their classes and send out information to their students. Interested participants were asked to sign up with their email during class or on a Qualtrics survey, which informed individuals of the provisional guidelines and asked if they were able to complete the walk. The provisional guidelines included information on food, drink, and drug consumption followed prior to testing (see Appendix A). Once a large recruiting pool was established, a link to a Survey Monkey was distributed to all interested individuals with time slots for availability to sign up. The volunteers were scheduled using a Gmail calendar invitation which notified them a day before the study time.

A second round of participant recruitment followed the first one to increase the number of participants. This second round advertised the study on K-State Today with a link to a Qualtrics survey, which asked the participants their age, ability to sign a consent form, willingness to volunteer, ability to walk, and if they were wearing electrical implants (see Appendix A). Once a large recruiting pool was established, a link to a Survey Monkey was distributed to all interested individuals with time slots for availability to sign up. The volunteers were scheduled using a Gmail calendar invitation which notified them a day before the study time.

3.5 Questionnaire

Once participants walked the designated route, they were asked to complete a questionnaire. The purpose for the questionnaire was to determine if the qualitative reactions they felt in the environment were the same as the quantitative response they would have to images later. The results enabled a spatio-temporal analysis which identified correlations between environmental characteristics, and spatial representations of qualitative and quantitative data (see Results section). The questionnaire allowed for the collection of participant information to determine if there were any individual characteristics that predicted physiological responses within the environment. It accounted for information such as fitness levels, sense of place, feeling of community, and feeling of exposure in the built environment.

The first part of the questionnaire asked participant- specific questions taken from Ruskamp's research (2016) which included each participant's gender; body type; socioeconomic and cultural background and upbringing; habitual drug use; physical activity levels; current medications; and adherence to provisional guidelines on food, drink, and drug consumption leading up to testing. They also completed Cohen's (1983) "Perceived Stress Scale" for researchers to understand each participant's propensity to suffer from stressful behaviors to help identify potential variances between subjects in the data (confidential).

The next part of the survey involved each participant completing a quantitative analysis and reviewing their perceptions of the environment they encountered using photographs taken along the route. All images were taken from the perspective of the forward walk along the route. They were asked to quantitively reflect on their experiences using those photos. Selection of the photographs was based on capturing the changes in environmental character as the participants would experience the route. During this section of the questionnaire, referenced spatially to a context map; see Figure 4 Numbered Zones Based on Ruskamp's original questionnaire (Image by Author). Using a Likert scale, subjects denoted their perceived level safety or comfort along different segments of the route, with 1 = very unsafe and 7 = very safe. To see the full questionnaire, see Appendix C.

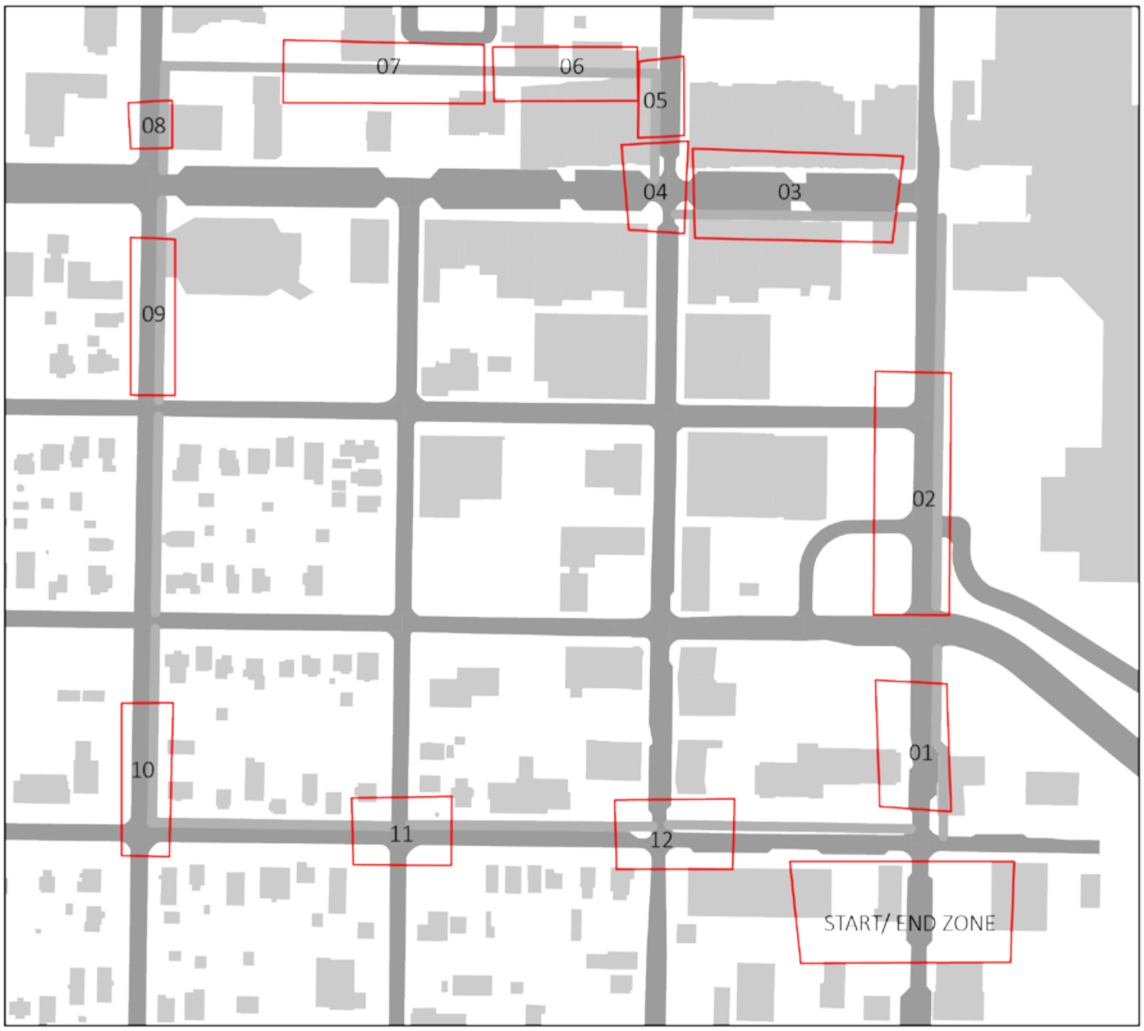


Figure 5 Numbered Zones Based on Ruskamp's (2016) original questionnaire. Data collection started at Hilton Hotel, but a location was officially identified North of the hotel along the route as the Start/End Zone in order to allow heart rate to elevate.

3.6 Biophysical components

Table 2 Biophysical Components and what each measure.

BIOPHYSICAL COMPONENTS MEASURES		
POLAR V800	EMPATICA E4	AUDIO
Geolocation (GPS) - Latitude and Longitude (one-hertz frequency)	Heart Rate (HR) - One-hertz Electrodermal Activity(EDA) - sixty-four hertz Blood Volume Pulse (BVP) - sixty-four hertz Skin Temperature	Two-minute marks of perceived stress (1-5 scale) 1- very calm 5- very stressed

Pre-walk biophysical components and items for the walk were established which gave real-time feedback for the research. After reviewing studies from (Yates et al., 2018) and Ruskamp (2016), two types of biophysical feedback sensors were selected for implementation into the testing: electrodermal activity (EDA) and heart rate variability (HRV). These two methods were selected based on the relevance of the physiological feedback they record, as well as being minimally invasive to the participants. Using wrist-worn sensors, researchers are able to observe patterns of unbiased physiology that challenges some of the long-standing theoretical concepts of emotion and measurement (Picard et al., 2016). These wearables offer a unique opportunity for researchers to observe humans in real-time environments and quantify elements in the built environment that influence long term mental health and stress. During the walk, the participants wore the two biophysical sensors- a Polar V800 watch, and an Empatica E4 watch, see Table 2 Biophysical Components for the measure of each.

3.6.1 Empatica E4

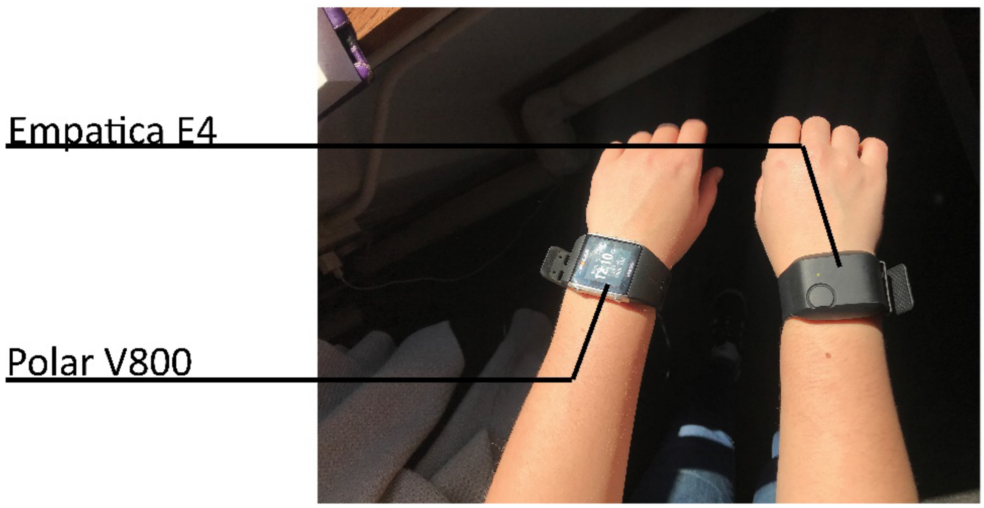
The Empatica E4 wristband is a skin conductance device that was attached by the survey moderator to each participants' dominant wrist, see Figure 6 Biophysical Component Measurements, Rationale, Limitations (Text by Parker Ruskamp) . Recent studies show that the dominant side may have a much stronger EDA signal during stress outside of the lab (Picard et al., 2016). This device records EDA, heart rate, blood volume pulse (BVP), acceleration (in g's), and skin temperature per second throughout the walk. For the purpose of this study, only the EDA and HR datasets were analyzed. Another ability of this device was to mark "instances" using a button on the wristband. The survey moderator marked an instance after the baseline time period was over and the participant began their walk, and when they had returned at the conclusion of their walk. Before beginning the walk, the moderator had the participants sit in a relaxing position for five minutes with the Empatica E4 watch turned on. They had a blindfold and noise cancelling headphones on to collect five minutes of baseline heart rate and EDA data.

3.6.2 Polar V800

The GPS device was a Polar V800 watch. This watch was worn on the non-dominant hand of all participants due to the Empatica being required to be worn on the dominant hand. The watch device records and displays GPS data, and monitors heart rate data from the electrodes. The GPS data were used to monitor the participants' location temporally.

3.6.3 Audio Recording

During the walk the participants carried a cell phone with them that had an interval timer go off every two minutes, and a recording device on. Once the timer went off, the participants would speak into the phone and rate their perceived stress levels on a scale of 1-5 of how stressed they were feeling at the time: 1 is very calm and 5 is very stressed. Previous literature has employed several approaches to assess levels of perceived stress. Scores based on self-ratings of event stressfulness are better predictors of health-related outcomes than scores derived from a simple counting of events (Cohen, Kamarck, & Mermelstein, 1983). If the participants felt strongly stressed or calm they would explain why in a few words. For example, if an ambulance went by, or if a dog barked, the participants would state “5- ambulance”. Participants



Polar V800

? Collect heart rate (HR) and GPS data from participants
? Some gaps in HR data: GPS data affected by buildings
+ Wireless HR and GPS data collection: minimally invasive

Empatica E4

? Collect EDA (electrodermal activity) and other data
? Device fit and participants movements may alter data
+ Records EDA, HR, and other measures wirelessly
- Very sensitive to fit and movement by participants

? Rationale + Benifits
? Challenges - Limitations

Figure 6 Biophysical Component Measurements, Rationale, Limitations (Text by Parker Ruskamp) were also allowed to use this phone to make emergency calls if needed. This stated preference allowed for the ability to annotate the data and compare it to the selected environmental characteristics.

Finally, participants were given a map with directions of the route (see Figure 4 Walking Route- Backwards and briefed on their requirements and safety procedures. Once ready, they began their route (see Study Area and Questionnaire Section). After they completed their walk, they were given a set of survey questions.

3.7 Data Cleaning

The Polar and Empatica devices were used to collect the physiological data from each participant. The measures collected by these devices were heart rate, electrodermal activity (EDA), blood volume pulse (BVP), skin temperature, and geo-location (GPS). Data collected by the Empatica device that was used included EDA, BVP, temperature, and heart rate measures. The Polar Device collected GPS data which were used in the analysis. For this study and Ruskamp (2016), BVP and temperature were not factored into the results or analysis, though the values were kept in place for any future analysis. The variables of EDA, Heart Rate, and GPS were identified as necessary to determine where physiological stress was in space. Table 2 Biophysical Components and what each measure shows all variables collected and those that were used in this study.

Heart rate data were selected due to the heart being a clear terminus for both sympathetic (fight-or-flight) and parasympathetic (rest-and-digest) nervous activity, allowing one to observe cardiac function and infer what processes are occurring simultaneously in the brain (Pocock, Richards, & Richards, 2013; Ruskamp, 2016a). Another factor in selecting heart rate as a variable was the ability to measure it unobtrusively, as well as the clarity of the data recorded.

EDA was utilized as a secondary way to measure stress, or sympathetic nervous activity. Rather than measuring cardiac function, EDA measures electrical characteristics of the skin (Ruskamp, 2016a). A common response of sympathetic activity is an increase in sweat gland activity, thereby reducing electrical resistance and increasing electrical activity (Everly & Lating, 2013; Peek, n.d.). A caveat of relying on EDA data is the unpredictable nature of the data and the recording device. The moderator must fit the device properly to minimize the mobility of the device's contact points. This test was ambulatory in nature which made this a potential issue.

The final measure, GPS, provided latitude and longitude coordinate points through one-second intervals during the participant's walk. These coordinate points could then be plotted geospatially, with the physiological responses recorded at each point listed as attributes of the geospatial point.

Once field testing procedures were completed, data cleaning began. Figure 6 Biophysical Component Measurements, Rationale, Limitations (Text by Parker Ruskamp) shows the measures of the Biophysical Sensors- Polar V800 watch, Empatica E4, and the non- biophysical sensor, the audio recording. Additionally, participants used "tags" on the E4 device to mark the exact times they started and stopped their walk, and the times they stopped and started baseline HR and EDA data collection. Also analyzed was the qualitative data from the survey responses.

Once the datasets were downloaded from the microphone to Google Drive, Polar (https://flow.polar.com), and Empatica (www.empatica.com/connect) websites, the data was placed into GIS for a biophysical data analysis, then sent to Yates (2018) for his machine learning analysis.

3.8 GIS Biophysical Data Analysis

3.8.1 Past GIS Analysis

In the past, Ruskamp (2016) downloaded the datasets from both the Polar and Empatica websites and created master files to manage the data from each device and participant. He organized the data in master sheets to better accommodate them for GIS and excel analysis. Appendix D, E and F in Ruskamp (2016) show the exact steps taken for organizing and formatting the data and combined master files. Once placed in ArcGIS, the master files that contained the Empatica and Polar data for each participant were imported into a geodatabase. A model was then made to streamline the data analysis process. Appendix G (Ruskamp, 2016) shows the steps taken in GIS to translate the raw data into mapped geo-spatial points with the attached physiological data at each geo-spatial point. The data were then mapped using geospatial points which provided quantitative information on physiological responses elicited by the participants throughout their walks.

During Ruskamp's study, initial analysis was done comparing the quantitative responses to the images of the route and the biophysical data collected during the walk. The hope for this form of analysis was to reinforce or contradict the biophysical data collected along the walk with the quantified preferences of the individuals. This could lead to further confirmation or questioning regarding the differences between psychological and physiological perceptual responses to environmental character. Then, analysis was completed comparing the variables of the schema data to the zones.

3.8.2 Present Analysis

During this analysis, different methods and models were created in GIS to study the environmental variables against the participant data along the route. These were chosen based on trial and error. The first group of models were made to compare the environmental variables to the questionnaire data (see Appendix F). These models produced 19 final tables given to Yates (2018) for his machine learning analysis, see more in Methodology section, as well as a final table produced for an image rating analysis done for EDA and HR variables. These models offered enough variation in environmental variables for each zone. See Figure 4 Numbered Zones Based on Ruskamp's original questionnaire (Image by Author) for the image of the Zones used for these models.

The next group of models were created to compare the environmental variables to continuous zones. These continuous zones were not chosen because it was determined that the area of the zones and continuous nature may not mimic the way we perceived different characteristics nor provide enough variability in the data. See Appendix D for the image of the Continuous Zones.

The third group of models were created to compare the environmental variables to random zones chosen along the route. The random zones were created in GIS using the Create Random tool. This group of zones were chosen for the environmental variable analysis because the random zones offered researchers a way to randomly evaluate points. See Appendix D for the image of the random zones found in GIS. See Appendix E for the Modelbuilder model created to evaluate the zones based on environmental variables and participant data.

3.8.3 Machine Learning Analysis (Yates, 2018)

During this analysis, three models were created in GIS initially (see Appendix E). The first model was created to compare the question zone data (from the questionnaire) to the environmental characteristics data. The question zones were spatially joined to the environmental variables within a distance of 50 feet. All those joins were then joined to one another to create one final table that had 12 question zones and many environmental attributes (see Appendix E).

The second model that was created used the raw.gpx Polar data from each participant (n=40), cleaned the data, then spatially joined the environmental variables within a distance of 50 feet. All those fields were then spatially joined together with the question zone data (from the questionnaire) to create 40 final maps (Appendix G).

Finally, all final tables were joined together: Question Zonal Final Table to Final Participant X Table to create 40 final tables with all of the data. The goal for this analysis was to reinforce or contradict the biophysical Polar watch data collected during the walk with the quantified question zones used during the questionnaire. Using these data an analysis was completed comparing the variables of the schema data to the zones creating final maps.

3.9 Environmental Characteristics

Researchers studying public health, environmental policy, health, urban planning and transportation have highlighted the importance of using objective measures to understand the relationship between health and the built environment (Leslie et al., 2007; Owen, Humpel, Leslie, Bauman, & Sallis, 2004; Saelens, Sallis, & Frank, 2003; Sallis, Frank, Saelens, & Kraft, 2004). To better understand how the factors in built environment can influence health, there is a need to document and identify which environmental attributes could be beneficial to the analysis. GIS provides researchers methods to facilitate the analysis of data at the local level in cities, or regional areas not for just research purposes, but for evaluating policies. Table 3: Environmental Variables shows the literature reviewed to identify characteristics and what features in GIS were used to measure the variables.

The final environmental characteristics that were chosen were: zoning, sidewalk quality, bulbouts (non-protected, protected), diversity of building facades, adjacent building height, building density, street width, road materials, parking (on street, lots), speed limit, intersection type/ delineation (crosswalk, crosswalk with stop sign, crosswalk with stoplight), lighting, undesirable infrastructure (overhead power lines, potholes, waste receptacles), and vegetation presence (grass, trees, shrubs).

Some environmental variables were important in the literature, such as transportation features, water features, urban forests, but were not added to the models because of the lack of them in this specific urban environment. Other features were difficult to measure geospatially, such as crowding and noise, so they were not accounted for in this study.

Once the characteristics were identified and drawn into shapefiles in GIS, a Modelbuilder model was created that joined each of the characteristics to the original Question Zones data to create a final question zone table. The full model is in Appendix E: Modelbuilder.

Data from the post-walk questionnaire were evaluated in Excel alongside the GIS data. The mean rating values of all participants for each image were compared to GIS data for the Image Zone. These “zones” were delineated in GIS based on where each image in the survey was taken along the route (see Figure 14 for zones). The mean rating values of all participants for each image were then compared alongside GIS data from each image’s “zone”. The data from all participants within these zones was then isolated for a comparative analysis with the image ratings. The zones were chosen based on the various differing environmental factors throughout the walk.

Table 3: Environmental Variables: Model Features, Description, Literature. Portions of this table are crossed out due to the reasons listed in "Not added in Geospatial Analysis" column.

Environmental Features		**Model Features**	**Model Description**	**Supporting Literature**	**Not added in Geospatial Analysis**
Land Uses	Zoning	PUD R-M C-4 C-5	Zoning type within a distance of 50 feet to walk/ question zone	(Ariffin & Zahari, 2013; Handy et al., 2002; Litman, 2017; Parks & Schofer, 2006; Saelens, Sallis, Black, et al., 2003)	
	~~Public Spaces~~			(Jacobs, 1961)	Not applicable to environment, too similar
Sidewalks	Sidewalk Quality		Sidewalk quality within a distance of 50 feet of walk/ question zone	(Ariffin & Zahari, 2013; Parks & Schofer, 2006)	
	~~Sidewalk Width~~			(Frumkin, Frank, & Jackson, 2004; Holt, 2015; Speck, 2013)	Lack of data
	~~Sidewalk Materials~~			(Frumkin et al., 2004; Holt, 2015)	Too similar in environment
	~~Sidewalk Obstructions~~			(Frumkin et al., 2004; Holt, 2015; Speck, 2013)	Not applicable to environment
	~~Sidewalk Presence~~			(Ariffin & Zahari, 2013; Jacobs, 1961; Parks & Schofer, 2006; Speck, 2013)	Too similar in environment
	Bulbouts	Protected Non- Protected	Frequency of Bulbouts intersecting walk/ question zones within 50 feet	(Frumkin et al., 2004; Speck, 2013)	
Building-Pedestrian Interactions	Diversity of building facades		Frequency of building facades within a distance of 50 feet to walk/ question zone	(Handy et al., 2002; Health, Evans, Mccoy, & Mccoy, 1998; Parks & Schofer, 2006;	

Environmental Features		Model Features	Model Description	Supporting Literature	Not added in Geospatial Analysis
				Saelens, Sallis, Black, et al., 2003)	
	Adjacent Building Height		Maximum/ minimum building height within a distance of 50 feet to walk/ question zone	(Speck, 2013; R. Ulrich, 1984b)	
	Building Density		Frequency of the area of buildings within a distance of 50 feet to walk/ question zone	(Handy et al., 2002; Saelens, Sallis, Black, et al., 2003; Speck, 2013)	
	~~Adjacent Building Setbacks~~			(Parks & Schofer, 2006; Speck, 2013)	
	~~Street Scale (ratio of buildings to street width)~~			(Handy et al., 2002)	
Vehicle-Pedestrian Interactions	Street Width		Width of road within a distance of 50 feet to walk/ question zone	(Burden, 2000; Handy et al., 2002; Walljasper & Spaces, 2007)	
	~~Road Conditions~~			(Parsons, 1991; Parsons et al., 1998)	Too similar in environment
	Road Materials		Materials of road within a distance of 50 feet to walk/ question zone	(Burden, 2000; Handy et al., 2002; Walljasper & Spaces, 2007)	
	~~Road Uniformity~~			(Burden, 2000; Walljasper & Spaces, 2007)	Too similar in environment
	Parking	On Street	Parking type within a distance of 50 feet to walk/ question zone	(Frumkin et al., 2004; Holt, 2015)	
		Lots			

Environmental Features		Model Features	Model Description	Supporting Literature	Not added in Geospatial Analysis
	~~Transportation Presence~~			(Burden, 2000; Holt, 2015)	Not applicable to environment
	Speed Limit		Speed Limit of road within a distance of 50 feet to walk/ question zone	(Burden, 2000; Walljasper & Spaces, 2007)	
	Intersection Type/ Crosswalk Delineation	Crosswalk	Intersection type within a distance of 50 feet to walk/ question zone	(Burden, 2000; Speck, 2013; Walljasper & Spaces, 2007)	
		Crosswalk with Stop sign			
		Crosswalk with Stoplight			
	~~Traffic Counts~~			(Ariffin & Zahari, 2013; Doyle et al., 2006; Saelens, Sallis, Black, et al., 2003)	Too similar in environment; lack of data
Safety and Appeal	Lighting		Frequency of light within a distance of 50 feet to walk/ question zone	(Gary Evans & Cohen, 1987b)	
	Undesirable Infrastructure	Overhead Power Lines	Frequency of infrastructure within a distance of 50 feet of walk/ question zone	(Ruskamp, 2016)	
		Pothole			
		Waste Receptacle			
	~~Enclosure~~			(Frumkin et al., 2004)	Too similar to environment
	~~Percent of Ground Shade~~			(Handy et al., 2002)	Lack of data
	~~Number of Locations with Graffiti~~		Collected in questionnaire; added locations with graffiti in photoshop for perception of safety	(Handy et al., 2002)	Acknowledged in survey; not applicable to environment
	~~Water Feature Presence~~			(Childs, 2012; Civco, 1979; Hubbard & Hubbard, [c1929];	Not applicable to environment

Environmental Features		Model Features	Model Description	Supporting Literature	Not added in Geospatial Analysis
				Penning-Rowsell, 1979; Shafer & Mietz, 1969; R. Ulrich, 1983b; R. S. Ulrich, 1981; Zube, Pitt, & Anderson, 1975)	
	Vegetation Presence	Grass Trees Shrubs	Number of vegetation polygons/points within a distance of 50 feet to walk/ question zone	(Abraham, Sommerhalder, & Abel, 2010b; Burden, 2000; R. Kaplan & Kaplan, 1989b; S. Kaplan, 1995b; Maas, Verheij, Groenewegen, Vries, & Spreeuwenberg, 2006b; R. Ulrich, 1983b, 1984b; R. S. Ulrich, 1981)	
	~~Perception of Safety~~		Collected in questionnaire	(Doyle et al., 2006)	Acknowledged in survey; unable to measure in GIS
	~~Perception of Attractiveness/ Appeal~~		Collected in questionnaire	(Ariffin & Zahari, 2013; Leslie et al., 2007; Saelens, Sallis, Black, et al., 2003)	Acknowledged in survey; unable to measure in GIS
	~~Crowding~~			(Gary Evans & Cohen, 1987b)	Not applicable in environment
	~~Noise~~		Collected in audio recording	(Gehl, 2013b; Health et al., 1998)	Acknowledged in audio recording; unable to measure in GIS
	~~Weather~~		Written down during testing	(A. F. Clark et al., 2014)	Acknowledged during testing; unable to measure in GIS

3.10 First Level Analysis of HR/ EDA Data

Table 4 Table of Analysis by Authors

	Number of People	Conditions	Characteristics	Zones
Ruskamp (2016)	14	Forward	Excel	Questionnaire
Yates (2018)	19	Forward	Machine Learning	Questionnaire
Whitaker (2018)	19-24	Forward/ Backward	GIS Regression Analysis	Questionnaire Random

At the conclusion of the field testing procedures and after data cleaning procedures were completed, data analysis began comparing the EDA and Heart Rate data to the Question Zone characteristics. In the past, Ruskamp (2016) downloaded the datasets from both the Polar and Empatica websites and created master files to manage the data from each device and participant. He organized the data in master sheets to better accommodate them for GIS and excel analysis. Appendix D, E and F (Ruskamp, 2016) show the exact steps taken for organizing and formatting the data and combined master files. He completed this statistical analysis to find the statistical correlations, if any, between the physiological responses of participants on the walk, and also to compare the physiological responses to image rating preferences. See Table 4 for the conditions, characteristics and zones used during the analyses from 2015-2018.

The raw data from GIS in the Ruskamp (2016) study did not reveal significant quantitative correlations between heart rate and inventoried characteristics. Yet, there were some noted correlations between EDA and inventoried items (Ruskamp, 2016); it was found that the areas with lower lighting had increased EDA levels in participants. There was also a correlation between image preference ratings and physiological responses.

The approach in this report (2018) included creating random zones in GIS and aggregating values by each participant, described in the above section.

The analytical approach to this analysis includes investigating machine learning techniques with project partners to explore methods for estimating stress using the vast real-time dataset collected from sensor data. Before handing off the data to the project partners, the raw Polar data for each participant was linked to a model in GIS, that iterated through each environmental variable chosen and Zone data (see Appendix E). Once master files for each participant were created, the .csv files were sent to Yates (2018) to examine the collected data in machine learning software. Yates (2018) automated this process using machine learning software then passed the data back for the Linear Regression Analysis.

3.11 Hypotheses and Predictive Analytics

Researchers studying public health, environmental policy, health, urban planning and transportation have highlighted the importance of using objective measures to understand the relationship between health and the built environment (Leslie et al., 2007; Owen et al., 2004; Saelens, Sallis, & Frank, 2003; Sallis et al., 2004). To better understand how the factors in the built environment can influence health, there is a need to document and identify which environmental attributes could be beneficial to the analysis. GIS provides researchers methods to facilitate the analysis of data at the local level in cities, or regional areas not for just research purposes, but for evaluating policies.

Certain environmental variables are known to reduce, induce, or inhibit a stress response in people; such as height of buildings (R. Ulrich, 1984a), vegetation (R. Ulrich, 1984a), lighting (Gary Evans & Cohen, 1987a), crowding (Gary Evans & Cohen, 1987a), infrastructure (R. Ulrich, 1981), walkability (Gary Evans & Cohen, 1987a), and noise (Gehl, 2013a). Common problems in cities which could have a negative impact on human health and well-being are limited spaces, obstacles, noise, pollution, risks of accidents, and generally poor conditions (Gehl, 2013a). The environment in which someone lives has the potential to influence mental health, and it is found to be a source of several stressors that elicit reactions (Gary Evans & Cohen, 1987a).

Using the geospatial and biophysical analysis, some hypotheses were created in response to the urban environment of Manhattan, Kansas:

Hypothesis 1: Greater levels of vegetation are correlated with lower levels of arousal.

Studies have shown the importance of having a connection to the natural environment, or places with little human influence, and the benefits of green space (Abraham et al., 2010a; Beil & Hanes, 2013; R. Kaplan & Kaplan, 1989a; S. Kaplan, 1995a; Maas et al., 2006a; R. Ulrich, 1981, 1983a, 1984a). Views of vegetation and water appear to sustain interest and attention more effectively than urban views (R. Ulrich, 1984a). Aesthetic response to the natural environment relates to important questions in environmental planning and design (R. Ulrich, 1983a) of how humans identify with the spaces between buildings more than buildings themselves, and how to design for positive human interaction in an urban environment.

The segments of the study area that have undergone more recent development have younger, smaller trees while the neighborhood areas have larger, older specimens. The presence of groundcover, such as grasses, was high in neighborhoods, and in areas of newer development. The effects of this hypothesis were likely to be felt at the southern end of 6^{th} Street and western end of Colorado Street. See Figure 7 Vegetation Map.

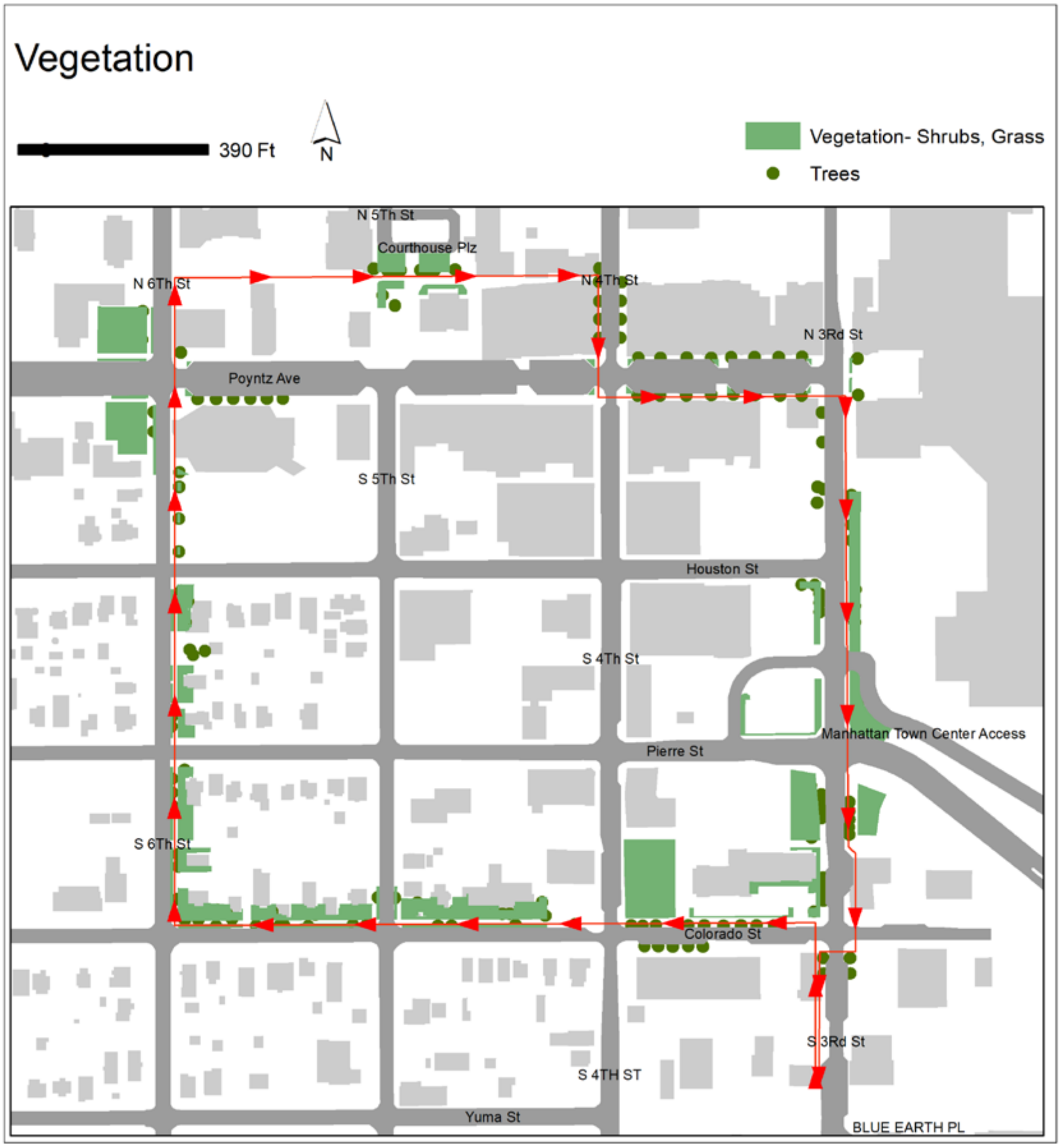


Figure 7 Vegetation Map along walking route.

Hypothesis 2: At intersections where pedestrians cross, designated infrastructure (aids) reduce arousal compared to intersections without this infrastructure.

Street design has traditionally lacked pedestrian facilities, such as adequate sidewalks, and streets are wide or have multiple lanes that are too difficult to cross, have high speeds, have complex intersections, create long delays for pedestrians at intersections, and provide little friction to protect pedestrians (Zegeer, Sandt, & Scully, 2009). Designated infrastructure, such as crosswalks, are proven to slow the speed of traffic and provide drivers with a visual reminder they are sharing the road with pedestrians and cyclists (Walljasper & Spaces, 2007).

A study done by the US Department of Transportation (Zegeer et al., 2005) found that pedestrian crashes are rare at uncontrolled pedestrian crossings; but there is a high likelihood of a severe or fatal injury in a high-speed crash, which makes it critical to provide a pedestrian-friendly transportation network.

The areas of the route with designated pedestrian crosswalks are the areas that are more urban, Poyntz Avenue and 3rd Street, while the residential neighborhoods have no designated pedestrian crossings. See Figure 8 Designated Infrastructure Aids.

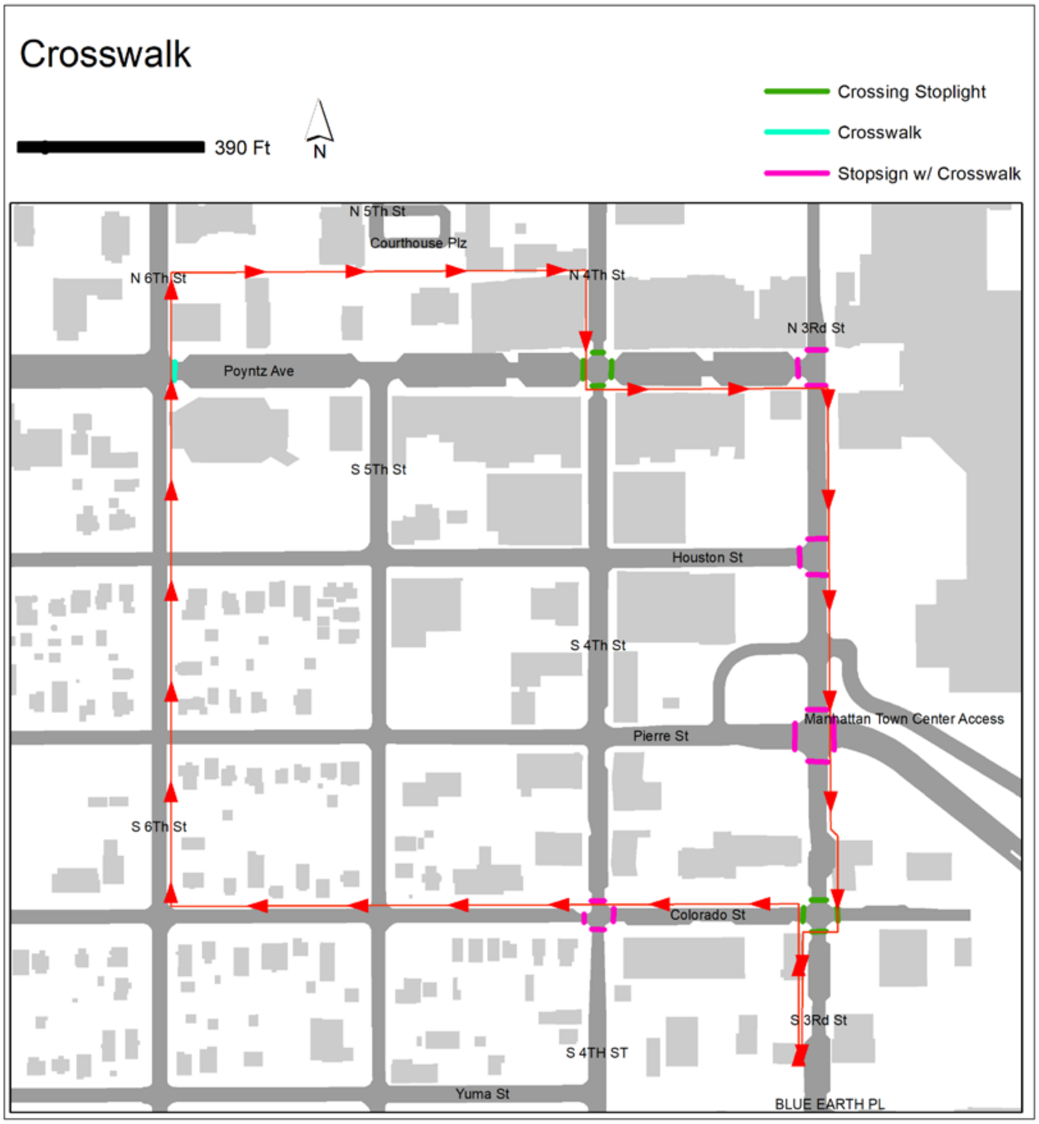


Figure 8 Designated Infrastructure Aids along walking route.

Hypothesis 3: Overhead infrastructure (powerlines and transformers) increase arousal.

The presence of infrastructure in the urban environment can create unpleasant sensory impacts in pedestrians. Unsightly biproducts of infrastructure in urban settings are unsightly visuals, foul scents, and the presence of unwanted precipitation (Ruskamp, 2016a). The presence of these visuals can enhance feelings of discomfort and have the ability to influence how pedestrians use those urban spaces. Along the study route, the area with the largest presence of infrastructure was in the mid-block alleyway north of Poyntz Avenue between 4th and 6th Street. In this alley there is a large amount of overhead electrical infrastructure, which continues obtrusively down 6th street. See Figure 9 Overhead Infrastructure Lines.

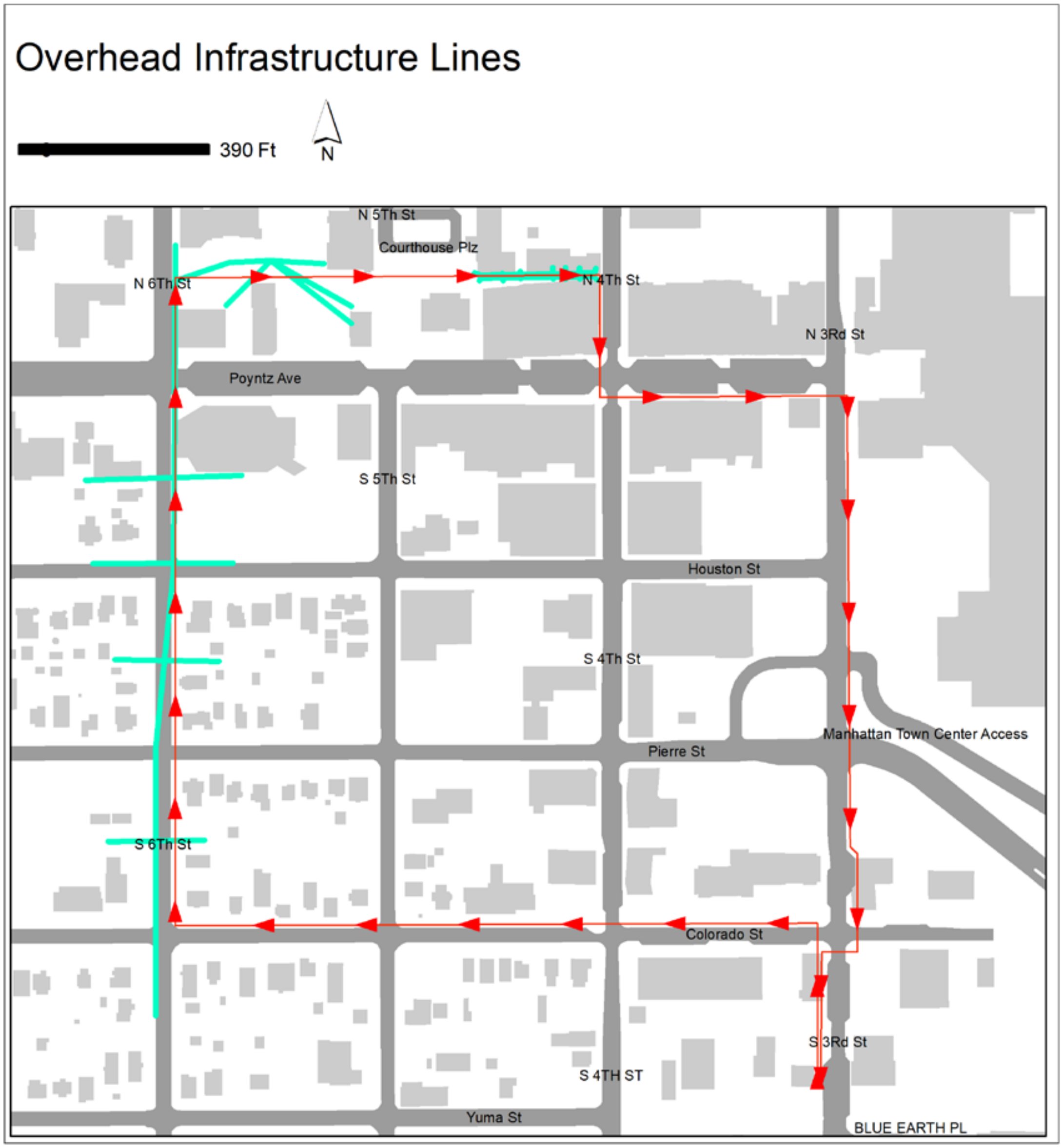


Figure 9 Overhead Infrastructure Lines along walking route

Hypothesis 4: Areas with a greater area of parking lots increase arousal.

A study which evaluated urban sites in Chicago that analyzed perceived safety and scenic quality found that parking lots are not correlated with perceived safety, but were negatively correlated with scenic quality (Schroeder & Anderson, 1984). In another study, college students rated the attractiveness and perceived safety of urban parking lots where regressions of physical features on perceived safety and attractiveness were high (Shaffer & Anderson, 1985). Attractiveness values were higher in parking lots with greater vegetation, but security was only high when vegetation was maintained in a landscape design (Shaffer & Anderson, 1985). Attractiveness and safety were higher near residential scenes and near structures with prominent entrances (Shaffer & Anderson, 1985). The areas along the route with the greatest parking infrastructure were down 3rd Street, the newly built urban areas, and also down the mid-block alleyway north of Poyntz Avenue between 4th and 6th Street. See Figure 10 for the parking lots and on street parking spaces along the walking route.

Figure 10 Parking along walking route.

Hypothesis 5: Alleyways and narrow corridors increase arousal, despite day or night conditions.

The study done by Ruskamp (2016) found that the alleyway and narrow corridor in the route caused increased EDA response in participants during the evening. This specific alley has a lack of vegetation, a lack of lighting, an increase of overhead infrastructure and a large amount of parking lots at the end of the walk.

3.12 Machine Learning Process (Yates, 2018)

Once the environmental variables were joined to the polar data in GIS in this study, the result table was sent to Heath Yates, PhD Candidate. I have paraphrased the abstract of his dissertation, Affective Intelligence in Built Environments: His approach to using this data was to detect arousal and affect in a built environment via a statistical and machine learning centric approach by using supervised machine learning algorithms such as logistic regression and general linear mixed models in the detection of affect in built environments (Yates, 2018).

After joining the environmental variables to polar data in GIS, they were sent to Yates (2018), and fused to the Empatica data (Yates, 2018). As a result of sensor fusion, he found a connection between participant biometrics, environmental variables, and the detection of their arousal affect via machine learning. “The results are mostly significant at a 0.001 level and all at a significance level of 0.05 (Yates, 2018).” 3FCV LR Model D Statistically Significant Coefficients (Yates, 2018) shows that there is a high correlation with walkability of the route, the number of trees and grasses, and overhead and ground infrastructure.

4 Results

4.1 Participants

The participants for this study were all staff and students at Kansas State University. The study population was a mixture of females (46%) and males (53%) between the ages of 18 and 68 years old. The participant pool showed a range of ethnicities, cultural and socio-economic backgrounds, physical activity levels, and habitual drug use (caffeine and tobacco) across the population, providing a strong variation from participant to participant. The goal was to recruit 30 participants. In addition to the 14 participants from Ruskamp (2016), 26 more participants were included in 2018 bringing the total to 40, more than the desired sample size. The total amount of 40 participants were used for some results, but some results had a fewer number of people because of data formatting and time issues. Table 5 shows the participant demographics and background information used in this study.

Table 5 2018 Analysis of Participant Background Information: The study population was a mixture of females (46%) and males (53%) between the ages of 18 and 68 years old. This table represents all participants for the Questionnaire Zone analysis and image rating analysis but are not the demographic data used for the statistical analysis. For the latter, a subset of this data was used with only the biophysical data. The demographic data cannot be confirmed because it was unavailable from the previous study (Ruskamp, 2016).

Question	Participant Information
Ethnicity	25 White 1 Asian
Body Type	Ectomorph (5) Mesomorph (20) Endomorph (1)
Environmental Background	Rural (6) Suburban (16) Urban (4)
Environment most identified with	Rural (7) Suburban (17) Urban (2)
Economic Background	Lower-Income (2) Middle-Income (21) Higher-Income (3)
Familiarity with Study Area	Not at all (1) Barely (2) Somewhat (8) Familiar (13) Very Familiar (2)
How often do you engage in cardio-vascular activities?	Never (0) Rarely (2) Sometimes (9) Regularly (10) Frequently (5)
Do you consume tobacco or caffeine with relative frequency?	Neither (8) Tobacco, yes, caffeine, no (0) Caffeine, yes, tobacco, no (18) Both (0)

4.2 Geospatial Inventory Findings

The final environmental characteristics that were chosen for the geospatial analysis were: zoning, sidewalk quality, bulbouts (non-protected, protected), diversity of building facades, adjacent building height, building density, street width, road materials, parking (on street, lots), speed limit, intersection type/ delineation (crosswalk, crosswalk with stop sign, crosswalk with stoplight), lighting, undesirable infrastructure (overhead power lines, potholes, waste receptacles), and vegetation presence (grass, trees, shrubs).

Once chosen, the environmental characteristics were geospatially mapped and inventoried per question zone, as well as, environmental characteristic per 20 second for a single participant. Figure 11 is an example of one environmental characteristic per question zone geospatially mapped for undesirable infrastructure lines along the walking route. As per the figure, the most undesirable infrastructure lines are located down the alleyway behind Poyntz Avenue and turning down 6th Street. See Appendix F and G for the Environmental Characteristics Per Zone Images- and Participant Points (20 seconds) Results of Inventory Analysis.

See Figure 3 for Environmental Characteristics image. See Table 3: Environmental Variables: Model Features, Description, Literature for the full table of Environmental Characteristics.

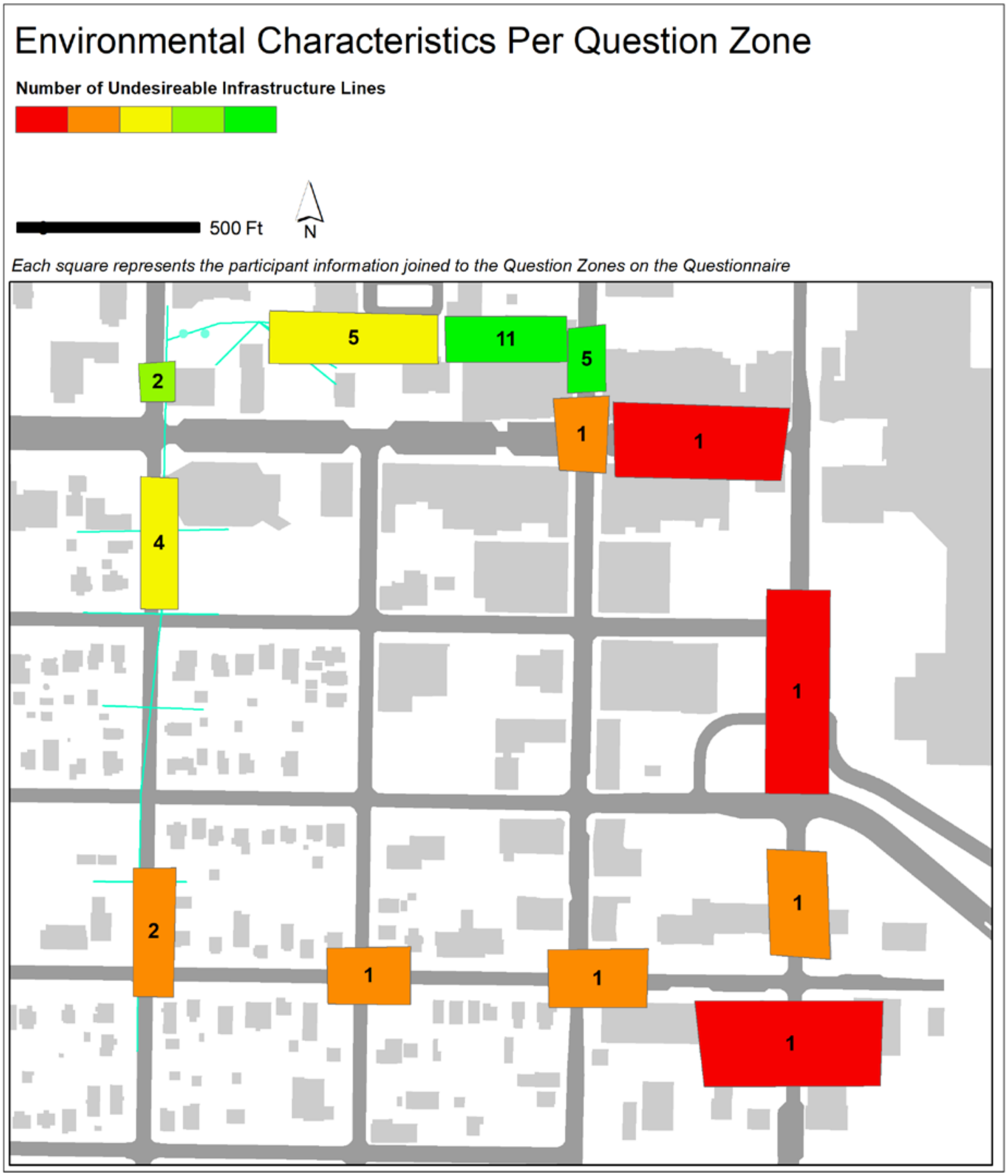


Figure 11 Environmental Characteristics Mapped Per Question Zone for Undesireable Infrastructure Lines.

4.3 Data Normalization

Biophysical characteristics differ from person to person. This is especially true of EDA, while heart rate variability between participants would not be as extreme because of similar ages. Nevertheless, for this report all biophysical data were normalized in order to scale each participant relative to their minimum and maximum values. The logic used was to ensure that any arousal would be captured based on an individual's experience and unique biophysical signature. In this case, the relative change in any one of these measures would help identify if that individual was experiencing a change in arousal.

Normalization was done by taking each observation, subtracting the lowest of all observations for the participant and dividing by the total range of their HR and EDA values respectively. For the remaining results, all data reported used this normalization process.

4.4 Questionnaire Zone Analysis

After completing the GIS analysis, the zone data from the post-walk questionnaire (see Appendix C) were evaluated in excel alongside the Heart Rate and EDA data from the participants. The mean rating values of all participants for each image were compared with the GIS data of EDA and Heart Rate in each image's Zone (see Figure 14). The zones were delineated in GIS, based on where each image in the survey was taken along the route and compared to where Ruskamp (2016) previously captured his images. The EDA and HR data from participants within the zones were isolated for a comparative analysis with the image ratings. The study accounted for a difference in each person's biophysical responses by normalizing both the HR and EDA data; baseline data was not used, and instead only data collected during the walk north of Colorado Street were included in the analysis. There were 24 participants evaluated in this analysis, 12 participants walked forward along the route and 12 walked backward along the route.

Results from the analysis showed there were significant high correlations between heart rate and EDA with various zones. The zones with the highest EDA levels were zones 11 and 12, at the end/ beginning of the walk down Colorado Street. The zones with the lowest EDA levels were zones 2 and 3, walking down 3rd Street, then down Poyntz Avenue. See Figure 12 Normalized EDA Data to Zone Analysis Correlation Chart for the EDA Zone Analysis Chart. Heart Rate also had a high statistically significant correlation with the zones. The zones with the highest heart rate were Zones 3 (walking on Poyntz), 6, 7 and 8, through the alleyway and right after/ before entering the alley. The zones with the lowest Heart Rate levels were Zones 4 and 5, crossing Poyntz at 4th Street, and walking down 4th Street right before/ after the alleyway. See Figure 13 Normalized HR to Zone Analysis Correlation Chart for the Heart Rate Zone Analysis Chart.

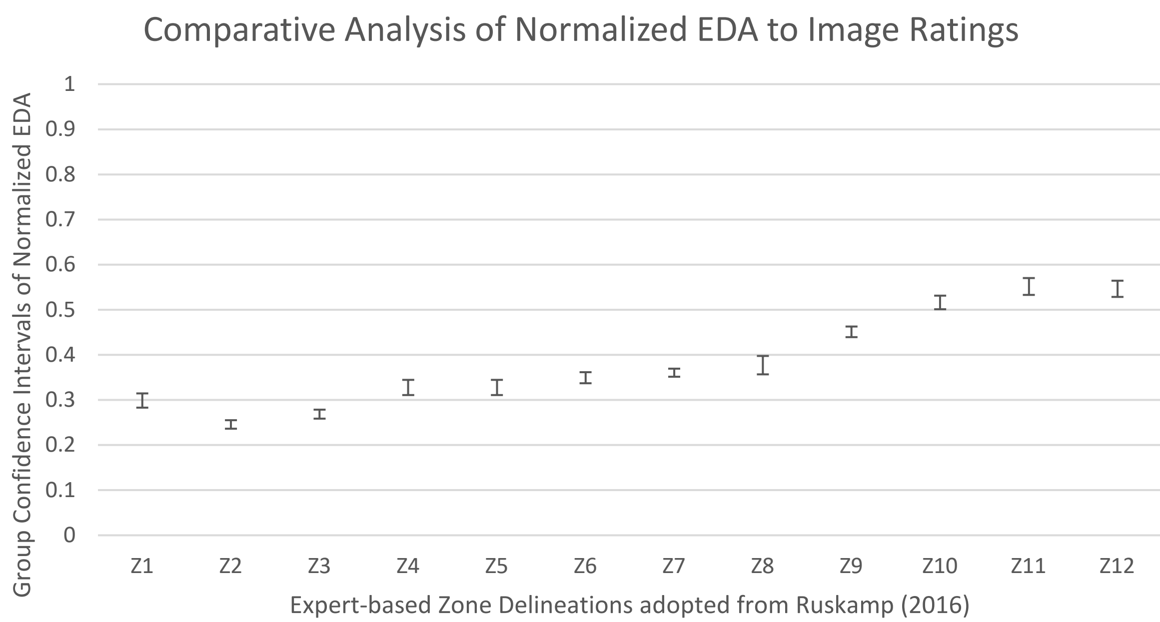


Figure 12 Normalized EDA Data to Zone Analysis Correlation Chart. X-axis represents zones (questionnaire), while Y-axis represents EDA data. The results represent confidence intervals.

Figure 13 Normalized HR to Zone Analysis Correlation Chart. X-axis represents zones (questionnaire), while Y-axis represents HR data. The results represent confidence intervals.Figure 14 Normalized EDA Data to Zone Analysis Correlation Chart. X-axis represents zones (questionnaire), while Y-axis represents EDA data. The results represent confidence intervals.

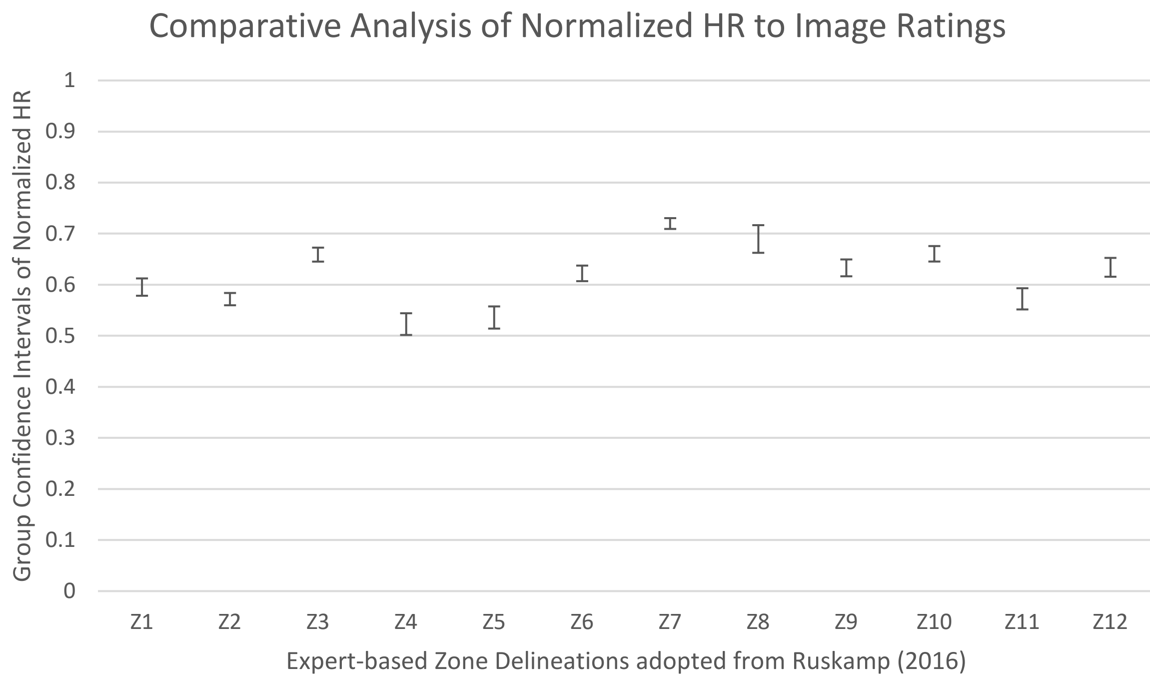


Figure 15 Normalized HR to Zone Analysis Correlation Chart. X-axis represents zones (questionnaire), while Y-axis represents HR data. The results represent confidence intervals.

4.5 Questionnaire Image Rating Analysis and Correlation of Average Biophysical Measures

Participants rated the images on the questionnaire on a 1 to 7 scale from very safe (1) to very unsafe (7), see Figure 14 for the images of the questionnaire zones. The aim of this analysis was to find correlations between the individual scene ratings from the questionnaire ratings to biophysical measures (EDA and heart rate). The next correlation was of averaged scene ratings and averaged biophysical measures. While the individual scene ratings were not as well correlated (Table 6), the overall average showed higher correlations (Table 7). A value of 1 or -1 indicates a perfect correlation, while ranges between -0.3 and -0.7 indicated a moderate correlation, and values below -0.3 indicated weak to no correlations.

Table 6 Correlation of individual scene ratings and biophysical measures as compared to questionnaire zone.

Zone	EDA	HR
Z1	-0.292	-0.186
Z2	-0.120	0.014
Z3	-0.097	0.449
Z4	0.121	-0.279
Z5	0.038	-0.274
Z6	-0.289	-0.116
Z7	0.118	-0.451
Z8	-0.173	-0.191
Z9	-0.005	-0.346
Z10	-0.030	0.162
Z11	-0.175	-0.236
Z12	0.185	-0.448

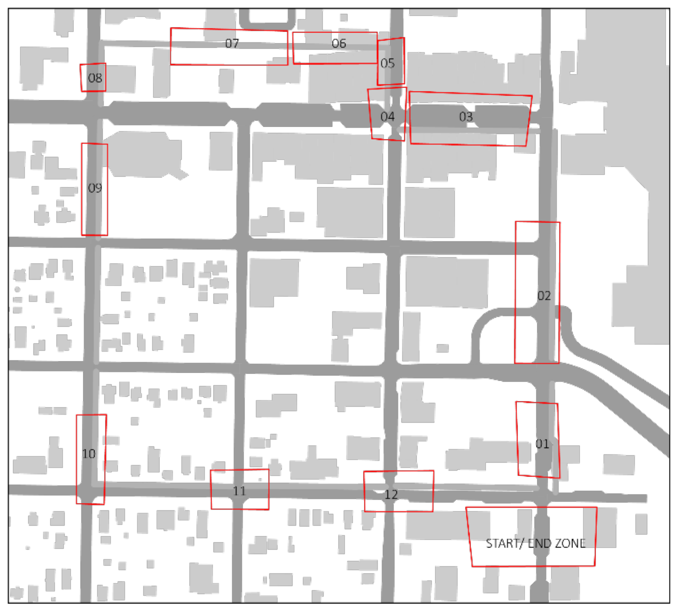


Figure 18 Questionnaire Zones

Table 7 Correlation of group average scene ratings and group average biophysical measures n=12, p > .086.

EDA	HR
-0.52	-0.24

4.6 Linear Regression Analysis using Random Zones

Several stepwise multiple linear regression models were run with normalized Heart Rate and EDA by participant within each zone as the dependent variables.

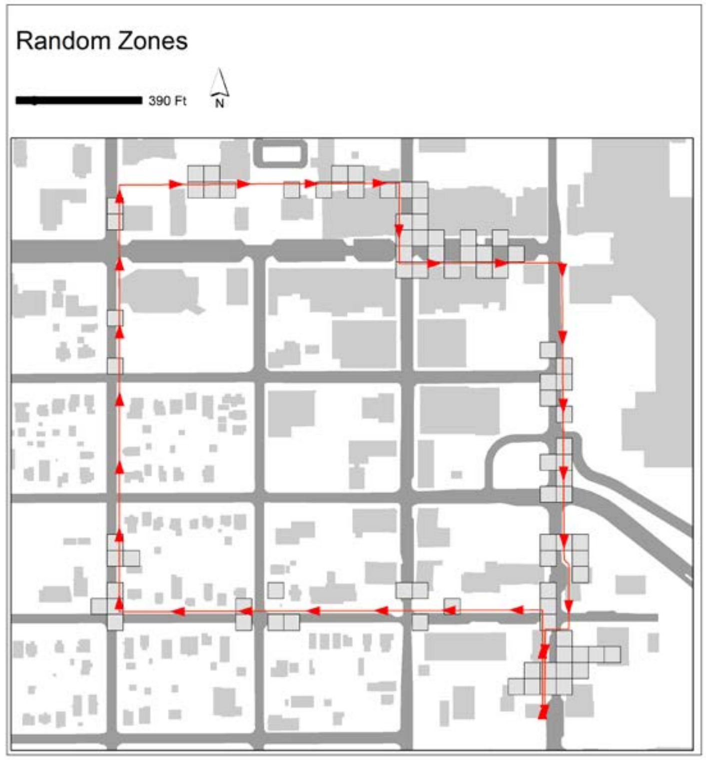


Figure 21 Random Zones calculated during geospatial analysis. Used for Linear Regression Analysis.

For each linear regression, the initial list of all independent variables are as follows: building area, maximum building height, building range, mean building height, minimum building height, building facades, road speed limit, road width, road surface, sidewalk quality, on street parking, parking lots, bulbout type, trees, grass, shrubs, lights, infrastructure lines, infrastructure points, zoning. These variables were calculated using a geospatial analysis with the random zone data. In the data, a random zone has anywhere between 3- 15 participants. Those participants each experienced a number of environmental variables in each zone, which was calculated using a geospatial analysis. See Figure 15 for Random Zone map.

The HR and EDA data values are thus an average of all observations for each participant within each zone. Unlike the scene rating data that had 26 participants, the biophysical analysis only used 19 participants. 14 participants were from Ruskamp (2016) where participants walked the route during the night and 5 participants walked during the day. In order to differentiate the models, different linear regression analyses were run for each the night and day participants. While, it would have been ideal to include the full set of participants from both the night and the day for the total of 26, there were errors in data transfer of the biophysical data that resulted in 7 fewer participants with clean data.

4.7 Nighttime Walk Analysis

A stepwise multiple linear regression analysis was ran for participants who walked the route during the night. Each variable ran against normalized EDA and heart rate data.

Heart Rate

With heart rate as the dependent variable, no combinations of independent variables were found to have an R-squared of greater than 0.05, even though there were some variables that showed significance; building area and zoning. Thus, the influence of infrastructural elements on heart rate is inconclusive using this model at this time.

EDA

With EDA as the dependent variable, the multiple linear regression analysis was R^2(adj)= 0.198, F (8,557) =18.223, p > .000, for the coefficients identified in Table 8.

Table 8 Coefficients for average EDA as dependent variable per random zone per participant at night.

Model	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
Parking Lots	-0.079	0.022	-0.173	-3.654	0.000
Zoning	-0.090	0.013	-0.287	-6.813	0.000
Building Area	0.489	0.093	0.233	5.251	0.000
Mean Building Height	-0.002	0.000	-0.142	-3.345	0.001
Trees	0.013	0.005	0.097	2.400	0.017
Shrubs	-0.082	0.014	-0.274	-5.796	0.000
On Street Parking	0.113	0.015	0.379	7.489	0.000
Building Facade	-0.033	0.007	-0.207	-4.514	0.000

4.8 Daytime Walk Analysis

A stepwise multiple linear regression analysis was ran for participants who walked the route during the day. Each variable was ran against normalized EDA and heart rate (HR) data.

Heart Rate

With heart rate as the dependent variable, the multiple linear regression analysis was R^2(adj)= 0.073, F (3,207) =6.454, p >.000, for the coefficients identified in Table 9.

Table 9 Coefficients for average heart rate as dependent variable per random zone per participant during the day.

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
Zoning	-0.089	0.023	-0.286	-3.809	0.000
Speed Limit	-0.006	0.002	-0.203	-2.912	0.004
Sidewalk Quality	0.105	0.048	0.166	2.181	0.030

EDA

Additionally, findings were discovered using normalized EDA in association with various infrastructural variables. With heart rate as the dependent variable, the multiple linear regression analysis was R^2(adj)= 0.154, F (3,207) =13.593, p >.000, for the coefficients identified in Table 10.

Table 10 Coefficients for average EDA as dependent variable per random zone per participant during the day.

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
Speed Limit	0.006	0.002	0.190	2.493	0.013
Grass	0.039	0.016	0.188	2.437	0.016
Sidewalk Quality	-0.150	0.043	-0.243	-3.449	0.001

4.9 Audio Recording Data

Audio recording data was collected during the route, participants rated their walk from a scale to 1 (most calm) to 5 (most stressed). Unfortunately, the audio data were unclear and were not used in this report. The data were unclear due to factors such as to an old phone and app not properly recording data at two-minute intervals, outside noises blocking audio data, the timer not going off regularly, and participants speaking too far from the recorder. See Table 11 Audio Recording Data Example (Yates, 2018) for one example of the audio recording data collected during the experiment.

Table 11 Audio Recording Data Example (Yates, 2018)

2:18	At 1
4:25	I am getting pretty cold, so I would say I am at 3 now
6:30	I think I am at level 1. Put hands in my pocket. Not cold anymore.
8:34	I'll say about 3. About to go down the alley way. It is pretty sketch
10:36	Back down to 1. Finished the alley way.
12:33	I think 2. I tried too early, so had to fix that. But I got it.
14:30	Still at 1. Squirrel jumped down, scared me a little bit. But I am not stressed.
16:21	I'll say I am back like 3. I am pretty sure I am at the right spot. But I am kinda lost. I think dog kinda scares me
18:13	Back down to 1. I figured it out and I am almost done. Still pretty cold though.

5 Discussion

Certain characteristics of the built environment have been shown to reduce, induce, or inhibit stress responses in people; such as height of buildings (R. Ulrich, 1984a), vegetation (R. Ulrich, 1984a), lighting (Gary Evans & Cohen, 1987a), crowding (Gary Evans & Cohen, 1987a), infrastructure (R. Ulrich, 1981), walkability (Gary Evans & Cohen, 1987a), and noise (Gehl, 2013a). The aim of this research was to determine if and how much characteristics of the built environment affect stress related responses in users.

Initially, the aim of this report was to identify stress as a result of exposure to different environmental characteristic, specifically to understand what characteristics induce “bad stress”. The intent was to then determine what characteristic(s) increase(s) heart rate as result of poor policies, poor design or limited information leading to designs that did not alleviate stressful experiences. At this point in the research, there is not enough data to ascertain what is “good” versus “bad” stress as it relates to well-being. Instead, the focus of the research shifted toward the broader term of “arousal”, which could include both kinds of stress, and other emotions such as excitement. It is an increase above the resting heart rate (Dienstbier, 1989). Affect, another term used to define what people are feeling based on their experiences, is a “…neurophysiological state consciously accessible as a simple primitive non-reflective feeling most evident in mood and emotion but always available to consciousness” (Russell, 2009). Examples of core affect include pleasure and displeasure, tension and relaxation, energy and tiredness (Ekkekakis, 2012).

Some researchers believe arousal is an integral part of emotion, while others have questioned whether arousal is necessary for the experience of emotion (M. S. Clark & Fiske, 2014). Analysis completed for this report normalized both heart rate and EDA data because of the difference in data between users. Higher EDA levels are typically quantified with fear, but in this study, it could be quantified as arousal, or affect, which may be a positive or negative reaction to the built environment. Recent work in neuroscience has found that there may be different types of positive affect, activated positive affect, relaxed positive affect, and safe positive affect. Safe positive affect has higher negative correlations (Gilbert et al., 2008). The results indicate variables that contributed to arousal.

5.1 Hypotheses Discussion

Hypothesis 1: Greater levels of vegetation are correlated with lower levels of arousal.

The multiple linear regression analysis found there was a measurable affective response due to the presence of trees and shrubs during nighttime walk. Additionally, there was an effective response due to the presence of grass during the daytime walk.

In the study using random zones as the aggregated EDA and HR data, the presence of an object or form existing was calculated as being within 50 feet of the random zone. For instance, the presence of a tree, grass area, and shrub area would have been calculated as long as part of the area fell within this distance. If it was outside of this distance it would not have been included. However, there are many ways of quantifying how these characteristics could be perceived. If, the analysis would have been conducted with 100 feet as the distance from each zone, it is possible the results would have been different. In any case, the precise characterization of the influence of distance from any kind of object or feature is not clear in the literature. Instead, authors have indicated more generally, the kinds of environmental characteristics that lead to enjoyment, fear, stress, *et cetera*. So, the data presented, may not be as indicative of a true feeling, until further analysis can be conducted.

In the machine learning analysis completed by Heath Yates (2018), he found that trees and grass influenced participant biometrics significantly. While the trend or correlation was not identified, there is clearly statistical significance that the presence of these natural characteristics does influence biophysical responses. This confirms previous research showing that vegetation is can improve mental health and well-being (Abraham et al., 2010a; Beil & Hanes, 2013; R. Kaplan & Kaplan, 1989a; S. Kaplan, 1995a; Maas et al., 2006a; R. Ulrich, 1981, 1983a, 1984a). Yates' (2018) findings support one of the Ruskamp's (2016) study aims to evaluate if vegetation did equate to reduction in stress regardless of other environmental characteristics. In this study an effective response due to the presence of trees and shrubs was found during the nighttime, but not at during the daytime. Unfortunately, the timeline of this study aligned with the dormancy periods of many plants, the months of October through February, which could have affected trees. If, in fact, these finding hold true in the real-world as they have in previous laboratory assessment, it gives additional support for planners to enforce or adopt urban vegetation policies. Adopting programs like Complete Streets, which encourages tree planting, would support these efforts.

Hypothesis 2: At intersections where pedestrians cross, designated infrastructure (aids) reduce arousal compared to intersections without this infrastructure.

Designated infrastructure aids using the multiple regression analysis were found to be insignificant. This does not suggest that crosswalk infrastructure is unnecessary, but instead that in this limited sample of infrastructure, it did not have a significant effect on heart rate or EDA. Injuries and fatalities occur at crosswalks despite the efforts of public officials to include the infrastructure. The number of injuries and deaths at crosswalks is expected to increase over the next several years due to many factors, including the growing number of older persons, renewed emphasis on physical activity, and high gas prices ("Complete Streets: Ensuring Crosswalk Safety," n.d.). To break this trend, planners need to improve crosswalk safety measures and increase education. By expanding this study to other areas and including the number of observations of biophysical responses are intersections, it could provide insight into the role different pedestrian infrastructure may influence stress.

Hypothesis 3: Overhead infrastructure (powerlines and transformers) increase arousal.

No significant results using the multiple linear regression model were found. However, the analysis completed in Yates (2018), found that there is an effect between participant biometrics and overhead powerlines and transformers. As this study progressed into the future, it will be important to identify places where overhead infrastructure occurs under different circumstances in order to tease out if there is an influence using a linear regression.

The presence of urban infrastructure has the ability to create unsightly visuals, unpleasant sensory impacts to pedestrians (Ruskamp, 2016b). While this study did not find any statistical effects from being near overhead infrastructure, Yates (2018) did find an effect. It was expected that an effect may have been realized, based on other literature suggesting that presence of these visuals can enhance feelings of discomfort and have the ability to influence how pedestrians use those urban spaces (Sims & Dent, 2016). It is likely that this effect was not found in the linear regression because most of the participants experience the environment at night and therefore the perception of influence may have been less strong than during the day. Powerlines are aesthetically unpleasing, monotonous, and boring and could potentially have long term health and safety issues, or issues with property values (Nohl, 2001). As planners, there are things we can do to counteract the effect that this infrastructure has on citizens, such as placing undesirable infrastructure underground to counteract negative biophysical response.

Hypothesis 4: Areas with a greater area of parking lot increase arousal.

The multiple linear regression analysis found there was a measurable affective response due to parking lots and on street parking during the participants' walk at night. Yet, there was no significant response during the day.

A study which evaluated urban sites in Chicago that analyzed perceived safety and scenic quality found that parking lots are not correlated with perceived safety, but were negatively correlated with scenic quality (Schroeder & Anderson, 1984). In another study, college students rated the attractiveness and perceived safety of urban parking lots where regressions of physical features on perceived safety and attractiveness were high (Shaffer & Anderson, 1985). Attractiveness values were higher in parking lots with greater vegetation, but security was only high when vegetation was maintained in a landscape design (Shaffer & Anderson, 1985). Attractiveness and safety were higher near residential scenes and near structures with prominent entrances (Shaffer & Anderson, 1985). The results of these two studies and the regression analysis performed in this study using random zones finds that there is a response both with the aesthetics and safety of parking lots. The analysis completed by this report tells us that at night there was an effective response to parking lots. This could be because there is no vegetation in the area, the parking lots are in highly urbanized areas with no prominent entrances available, or there is minimal lighting near the areas with parking lots.

Using this study and literature, planners should be able to understand that there is an effective response with biophysical data and parking lots. Parking lots do not appeal to citizens both aesthetically and also because they are perceived as being less safe. We also need to investigate whether there is a similar effect with parking structures, and in conditions with better lighting, design, and more vegetation that might increase aesthetic appeal and perception of safety.

Hypothesis 5: Alleyways and narrow corridors increase arousal, despite day or night conditions.

The multiple linear regression analysis revealed a measurable affective response due to building façades and building areas during the participants walk at night. As the amount of building façades decreased, EDA levels rose. Additionally, as the building area, or amount of buildings that are surrounding someone increases, EDA increases. In the alleyway specifically, there is very little variation in building façade, yet at the same time, building envelope may warrant the feeling of being cramped with such a narrow corridor.

Through the literature reviewed in Table 3, a diversity of building façades in an urban environment is important to make a streetscape more impressive and unique (Handy et al., 2002; Health et al., 1998; Parks & Schofer, 2006; Saelens, Sallis, Black, et al., 2003). Additionally, the density of buildings surrounding someone in an urban environment contributes to a more walkable environment conducive with health and well-being (Handy et al., 2002; Saelens, Sallis, Black, et al., 2003; Speck, 2013). In addition to the influence of building characteristics based on the Random Zone linear regression, there was an effect measured when looking at HR from the Questionnaire Zone data within the alleyway (Figure 14, Zone 6 – 7) in participants both clockwise and counterclockwise through the route. These findings and literature suggest that the hypothesis is correct, and that alleyways and narrow corridors do increase arousal despite day or night conditions.

The study done by Ruskamp (2016) found that the alleyway and narrow corridor in his route caused increased physical response in participants during the evening. This specific alley has a lack of vegetation, a lack of lighting, an increase of overhead infrastructure and a large amount of parking lots. Due to the findings and literature reviewed, planners and designers should aim to diversify and increase the number of building façades because it seems to increase pedestrian arousal and make them feel safer. Planners could also implement policies which decrease the building envelope within a space, to make people feel less cramped and more as though they are walking through a comfortable, walkable urban environment.

5.2 Other Key Findings and Anomalies

Zoning

Surprisingly, the multiple linear regression analysis found there was a measurable affective response due to zone type during the participants walk at nighttime and daytime. The lowest EDA was found in Zones C-4 and C-5 during both periods of time. These zones are in well lit, urban areas in Manhattan shown in Figure 16 which would have been experienced at the beginning of these participants' walk. Planners develop zoning policies in the United States to control land use. This plays a large role in creating and maintaining the built environment. The intent of zoning is to help make communities healthier by separating different kinds of activities, such as promoting physical activity, reducing exposure to environmental hazards, and access to amenities (Rossen & Pollack, 2012). Planners create policies and write zoning codes, but do not have any indication of how zoning may influence citizens' biophysical responses. The results of this study found that there is both a response in heart rate and electrodermal activity to differences in zoning. Since zoning is an amalgamation of multiple factors, it will be increasingly important to expand the study to find different conditions under which participants may experience the same zones.

Figure 25 Zoning along walking route.

5.3 Limitations

While this study is aimed at understanding how the urban environment influences behavioral changes in participants, the testing environment is a rather small suburban community with limited urban characteristics. Further testing should be completed in larger urban environments, or cities, to confirm and explore validity and generalizability of the findings. As the complexity of the urban environment increase, so would the number of participants. For instance, larger cities would provide opportunity to evaluate public transportation infrastructure, various lighting and noise conditions, and significantly higher density of buildings and amenities. A larger urban environment would help to increase the diversity of participant demographics. The complexity of a larger urban environment would additionally bring different zoning policies and plans which would increase the sample set and ultimately generalize the environmental characteristics that might influence physiology.

Reflections on Data Collection and Analysis

There are many factors that could have contributed to or limited the findings of the study such as the volume of data. For example, at nighttime there were 557 observations recorded for EDA, but those observations were generated only by 14 participants so while there are enough observations to represent statistical significance, we could increase the generalizability by including more participants with diverse characteristics. Additionally, weather was not accounted for in the regression analysis, but these studies were completed during certain seasons- late fall and mid-winter. Noise was not accounted for in the regression analysis but would be important to see if that had an effect on physiological data. Additional variables not accounted for were the participants background, such as gender, drug intake, caffeine intake, exercise, medication, alcohol intake. These variables would be useful as controls in the study.

During the geospatial analysis, there were three different zone types chosen: questionnaire, continuous, and random. Initially questionnaire zones were chosen by Ruskamp (2016) because it was believed each zone had significantly different environmental features based on a quantitative analysis. The hope for this form of analysis was to reinforce or contradict the biophysical data collected along the walk with the quantified preferences of the individuals. Continuous Zones were created geospatially for every possible spot the participants walked yet were not chosen because it was determined that the area of the zones and continuous nature may not mimic the way we perceived different characteristics nor provide enough variability in the data. Finally, random zones were created randomly geospatially (for 50 feet) and chosen for the environmental variable analysis because the random zones offered researchers a way to randomly evaluate points.

Ultimately, questionnaire and random zones were chosen for the Image Rating Analysis, and the Linear Regression analysis, respectively. Yet, there were many options to quantify the zone data. For example, random zones were created using a 50-foot radius, but they could have been made to be 100 feet, *et cetera.*

Reflection on Environmental Variables and Characteristics

A large part of this study was researching literature to determine the environmental factors that influence stress in the urban environment. Some environmental variables were important in the literature, such as transportation factors, water features, urban forests, but were unable to be added to the models in this study. For example, certain features, such as bicycle infrastructure, something very realistic in many urban environments, was not a variable in this study because there was no infrastructure present. If this study were to continue, it would be useful to conduct the test with different urban forms in order to evaluate and generalize to a wider variety of environmental characteristics. Other social features were not evaluated such as crowding and noise, but they could be evaluated using body cameras and audio signals in the future.

6 Conclusion

A study was conducted using non-invasive measures to determine the influence of environmental characteristics on biophysical responses. This orientation toward design and planning of spaces directly addresses planners' goals of improving the health and well-being of their citizens. By linking health-related data with urban form, planers could have a more direct way of evaluating how well policies are performing. The findings in this study are varied and amalgamated from multiple students working on this project over two years. Through the analysis we discovered there is a relationship to biophysical measures and relationship to vegetation presence, building façades, building area or envelope, zoning and parking lots. In particular, the most influential characteristics were the amount of parking in close proximity to participants at night and the quality of the sidewalks during the day. While effects were discovered, further work should be done to confirm and generalize these findings. These initial results demonstrate how using biophysical measures can help planners evaluate the effectiveness of policies and built-environments toward improving the well-being of citizens. Further, this study provides a basis on how designs can be better informed by geospatial analysis, enhanced through an extensive environmental characteristic literature review, and statistical analysis to promote health and well-being through urban design.

This research provides a group of geospatial models that planners can use for their own cities to understand how to create policies and design cities based on the biophysical responses of their citizens. This report demonstrates that it is feasible to model different environmental characteristics in order to evaluate for their influence of a range of different biophysical factors (HR and EDA for example). Furthermore, planners can use these techniques to compare how different areas, streets and zones, are relative to various infrastructural elements. This study provides a greater foundation on how public policy and design can be better informed to promote health and well-being through understanding the relationship between biophysical affect and urban form.

The research demonstrates how technology can be employed as a tool for citizen science. This research hopefully will lead to developing solutions for interventions aimed at promoting mental health and well-being in urban populations. Through this study urban planning solutions aimed at improving mental health can be added to the qualitative processes and conventional planning theories to improve urban design. This research provides an evidenced-based approach for assessing the benefits of nature or built-infrastructure within urban fabric. Hopefully, the results and future studies based on this research will inform and drive policies to build healthier communities.

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Appendix A: Pre- Test Provisional Guidelines

Again, I would like to thank you for your interest in this study. If this date: **XX PM to XX PM** on **(DATE)** is still okay with you, confirm your availability. **We will be meeting at the front entrance of the Hilton Garden Inn Hotel: 410 S 3rd St, Manhattan, KS 66502.**

Upon your arrival, you will be debriefed on the study, its intent, and our goals as researchers. Additionally, you will be hooked up to our minimally-invasive equipment that will provide us with our data. At the conclusion of field testing, you will fill out a short questionnaire on the field testing session.

Some instructions that we would like you to follow leading up to the test, to minimize the variability in results are provisions for food, drink, tobacco, exercise:

• Drink ample fluids over the 24-hours preceding the testing period.

• Refrain from consuming alcohol during the 24-hours preceding testing.

• Refrain from consuming food, beverage (with the exception of water), caffeine, and tobacco for 2 hours before testing.

• Refrain from strenuous exercise 2 hours before testing.

Clothing:

• Wear warm clothing to permit freedom of movement

• Wear comfortable footwear

If you have any further questions, comments, or concerns, please do not hesitate to contact me at this email address. Thank you again for interest, I am very much looking forward to working with you. Have a good day.

Appendix B: Response to Inquiry

Investigating Stress Triggers and Characteristics of the Built Environment Response to Inquiry

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Start of Block: Default Question Block

Q1 Potential Research Participant, First, I would like to thank you for your interest in participating in this study, it is greatly appreciated, and I am very grateful for your time. If you agree to participate you will:

Q2 Are you 18 years or older and speak English?

- O Yes (1)
- O No (2)

Q3 Willing and able to sign a consent form?

- O Yes (1)
- O No (2)

Q4 Willing to volunteer roughly 60 minutes of your time?

- O Yes (1)
- O No (2)

Q5 Able to walk (or use mobility device if needed) one mile, outside, in 20-30 minutes around downtown Manhattan during the day?

- O Yes (1)
- O No (2)

Q6 Willing to wear a wristband?

- O Yes (1)
- O No (2)

Q7 Free of electrical implants?

- O Yes (1)
- O No (2)

Q8 Please write your email and we will respond to you with a selection of times to complete the walk.

____

End of Block: Default Question Block

Appendix C: Post- Walk Questionnaire

Introduction/Brief of Questionnaire

This questionnaire is in three sections and should take roughly 15-20 minutes to complete. The first section requests personal information to support the research. The second and third sections will request you evaluate the different environments you have just experienced to further support the research.

REMINDER: ALL INFORMATION YOU SUBMIT FOR THIS STUDY IS CONFIDENTIAL.

Block 8

Enter your ID given to you by the moderator

Background Information

Please identify your gender.

Male

Female

Please identify your age

Please identify your ethnicity

White

Black or African American

American Indian or Alaska Native

Asian

Native Hawaiian or Pacific Islander

Other

What is your discipline of study? (ie. Ecology, Fine Art, etc.)

Which best describes your body type?

Ectomorph (Thin build, lanky)

Mesomorph (Medium build, moderate)

Endomorph (Heavy build, stout)

Which type of environment best describes your background and upbringing?

Rural

Suburban

Urban

What type of environment do you now most identify with?

Rural

Suburban

Urban

Which of the following best describes your economic background and upbringing?

Lower-income

Middle-income

Higher-income

Prior to this evening, how familiar were you with the study area? (ie, the route and downtown Manhattan?)

Not at all (hardly ever visited any part)
Barely (visited before, but in vehicle)
Somewhat (visit one or two places by vehicle)
Familiar (occasionally walk in parts of the study area)
Very Familiar (regularly frequent parts of the study area)

How often do you engage in cardio-vascular physical activities?

Never
Rarely
Sometimes
Regularly
Frequently

Do you consume tobacco or caffeine with relative frequency?

Neither
Tobacco yes, caffiene no
Caffeine yes, tobacco no
Both

In the last 24 hours, have you consumed alcohol?

Yes
No

In the last three hours, have you consumed any food or beverages other than water?

Neither
Food yes, beverage no
Beverage yes, food no
Both

In the last three hours, have you consumed any tobacco or caffeine?

Neither

Tobacco yes, caffeine no

Caffeine yes, tobacco no

Both

In the last three hours, have you done any moderate to strenuous exercise?

Strenuous

Moderate

None

During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, aerobics, or fast bicycling?

Number of days (0-7)

How much time did you usually spend doing vigorous physical activities on one of those days?

Hours per day

Minutes per day

Don't know/Not sure

During the last 7 days, on how many days did you do moderate physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

Number of days (0-7)

How much time did you usually spend doing moderate physical activities on one of those days?

Hours per day

Minutes per day

Don't know/Not sure

During the last 7 days, on how many days did you walk for at least 10 minutes at a time?

Number of days (0-7)

In the past week, how much time did you spend walking? (Do not include instances under 10 minutes)

Hours per day

Minutes per day

Don't know/Not sure

During the last 7 days, how much time did you spend sitting on a week day?

Hours per day

Minutes per day

Don't know/Not sure

Please list any medications you are currently taking and the condition for which they were prescribed.

Perceived Stress Scale

Have you ever been in a "Fight or Flight" situation? (response to a perceived harmful event, attack, or threat to survival)

Yes

No

If yes, did you experience a heightened sense of any of the following, compared to normal (every day feelings, without the occurrence of a stressful situation)?

Stamina

Strength

Focus

Heart rate/ pulse

Alertness

Please briefly describe what happened:

When faced with a deadline, do you become "stressed"?

Yes

No

If yes, do you operate more efficiently when you feel like this?

Yes

No

How susceptible are you to stress in everyday life?

Very susceptible: I am often stressed

Quite susceptible: I get stressed sometimes

Not very susceptible: I am fairly easy going

Not susceptible: I am very easy going

In the last month, how often have you been upset because of something that happened unexpectedly?

Never	Almost Never	Sometimes	Fairly Often	Very Often

In the last month, how often have you felt that you were unable to control the important things in your life?

Never	Almost Never	Sometimes	Fairly Often	Very Often

In the last month, how often have you felt nervous and "stressed"?

Never Almost Never Sometimes Fairly Often Very Often

In the last month, how often have you felt confident about your ability to handle your personal problems?

Never Almost Never Sometimes Fairly Often Very Often

In the last month, how often have you felt that things were going your way?

Never Almost Never Sometimes Fairly Often Very Often

In the last month, how often have you found that you could not cope with all the things that you had to do?

Never Almost Never Sometimes Fairly Often Very Often

In the last month, how often have you been able to control irritations in your life?

Never Almost Never Sometimes Fairly Often Very Often

In the last month, how often have you felt that you were on top of things?

Never Almost Never Sometimes Fairly Often Very Often

In the last month, how often have you been angered because of things that were outside of your control?

Never Almost Never Sometimes Fairly Often Very Often

In the last month, how often have you felt difficulties were piling up so high that you could not overcome them?

Never Almost Never Sometimes Fairly Often Very Often

Image Ratings Introduction

This section of the questionnaire will ask you to rate 18 different images based on how safe you feel. The images come from the environment you just experienced. Some of these images have been digitally altered.

Image Ratings

	Very Unsafe						Very Safe
Rate your feelings of safety in this space.	○	○	○	○	○	○	○

	Very Unsafe						Very Safe
Rate your feelings of safety in this space.	○	○	○	○	○	○	○

	Very Unsafe						Very Safe
Rate your feelings of safety in this space.	○	○	○	○	○	○	○

	Very Unsafe						Very Safe
Rate your feelings of safety in this space.	O	O	O	O	O	O	O

	Very Unsafe						Very Safe
Rate your feelings of safety in this space.	O	O	O	O	O	O	O

	Very Unsafe						Very Safe
Rate your feelings of safety in this space.	O	O	O	O	O	O	O

	Very Unsafe						Very Safe
Rate your feelings of safety in this space.	Very Unsafe ○	○	○	○	○	○	Very Safe ○

	Very Unsafe						Very Safe
Rate your feelings of safety in this space.	O	O	O	O	O	O	O

	Very Unsafe						Very Safe
Rate your feelings of safety in this space.	O	O	O	O	O	O	O

	Very Unsafe						Very Safe
Rate your feelings of safety in this space.	O	O	O	O	O	O	O

	Very Unsafe						Very Safe
Rate your feelings of safety in this space.	O	O	O	O	O	O	O

	Very Unsafe						Very Safe
Rate your feelings of safety in this space.	Very Unsafe O	O	O	O	O	O	Very Safe O

	Very Unsafe						Very Safe
Rate your feelings of safety in this space.	O	O	O	O	O	O	O

	Very Unsafe						Very Safe
Rate your feelings of safety in this space.	○	○	○	○	○	○	○

	Very Unsafe						Very Safe
Rate your feelings of safety in this space.	○	○	○	○	○	○	○

	Very Unsafe						Very Safe

	Very Unsafe						Very Safe
Rate your feelings of safety in this space.	○	○	○	○	○	○	○

Image Comments Introduction

You're almost done! Next, we ask that you comment on the following 8 images. Please provide a written statement explaining what characteristics of the scene increase or decrease your feelings of safety.

Image Comments

In the box below, please express what characteristics of this space increase or decrease your feelings of safety. Please be as articulate, critical, and thorough as possible. By doing so, you will give us the best possible data.

In the box below, please express what characteristics of this space increase or decrease your feelings of safety. Please be as articulate, critical, and thorough as possible. By doing so, you will give us the best possible data.

In the box below, please express what characteristics of this space increase or decrease your feelings of safety. Please be as articulate, critical, and thorough as possible. By doing so, you will give us the best possible data.

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In the box below, please express what characteristics of this space increase or decrease your feelings of safety. Please be as articulate, critical, and thorough as possible. By doing so, you will give us the best possible data.

Debriefing Statement

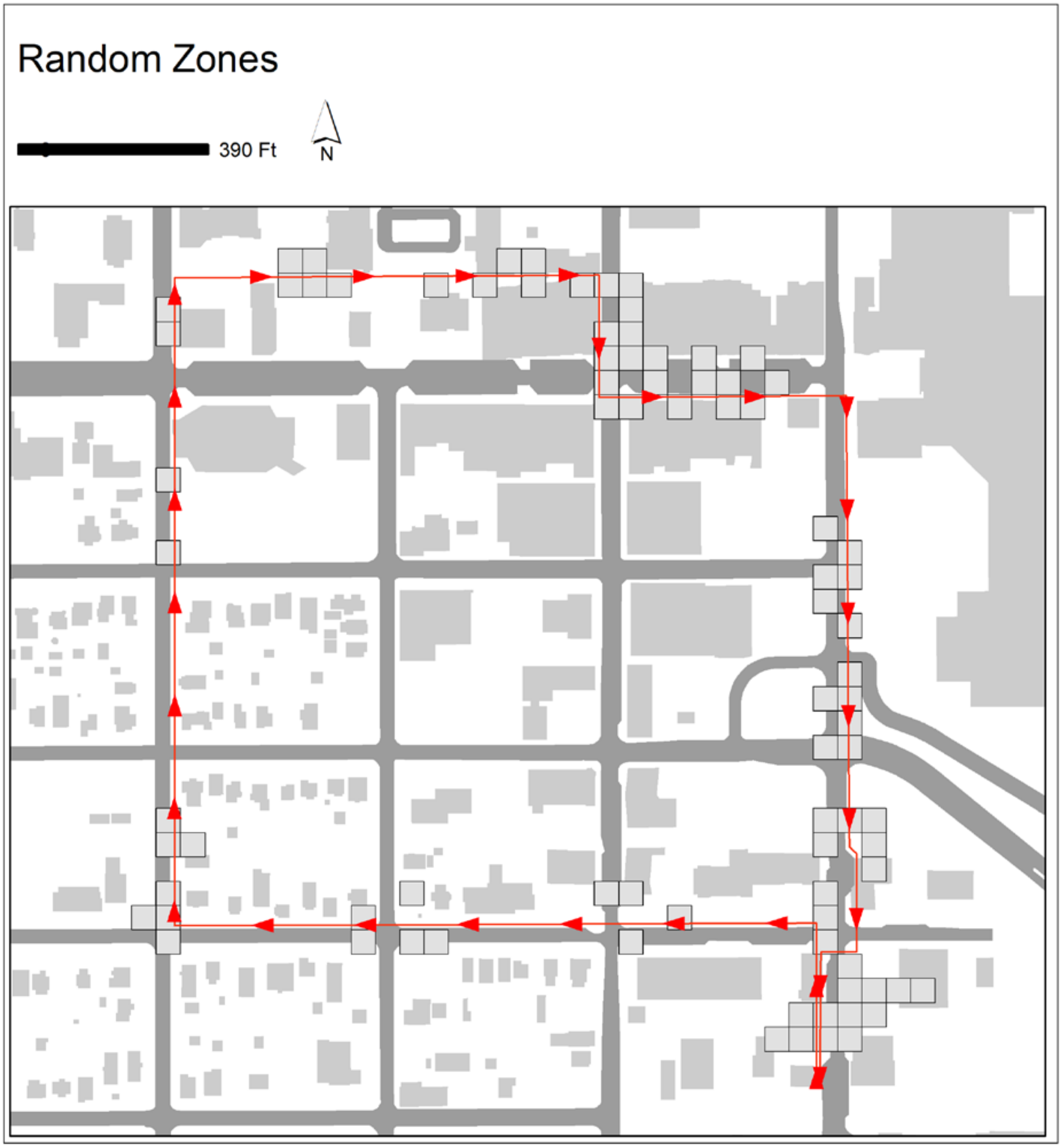
The investigators would like to express our sincerest gratitude for your help with our research. We appreciate your willingness to take time out of your schedule to assist us with our study!

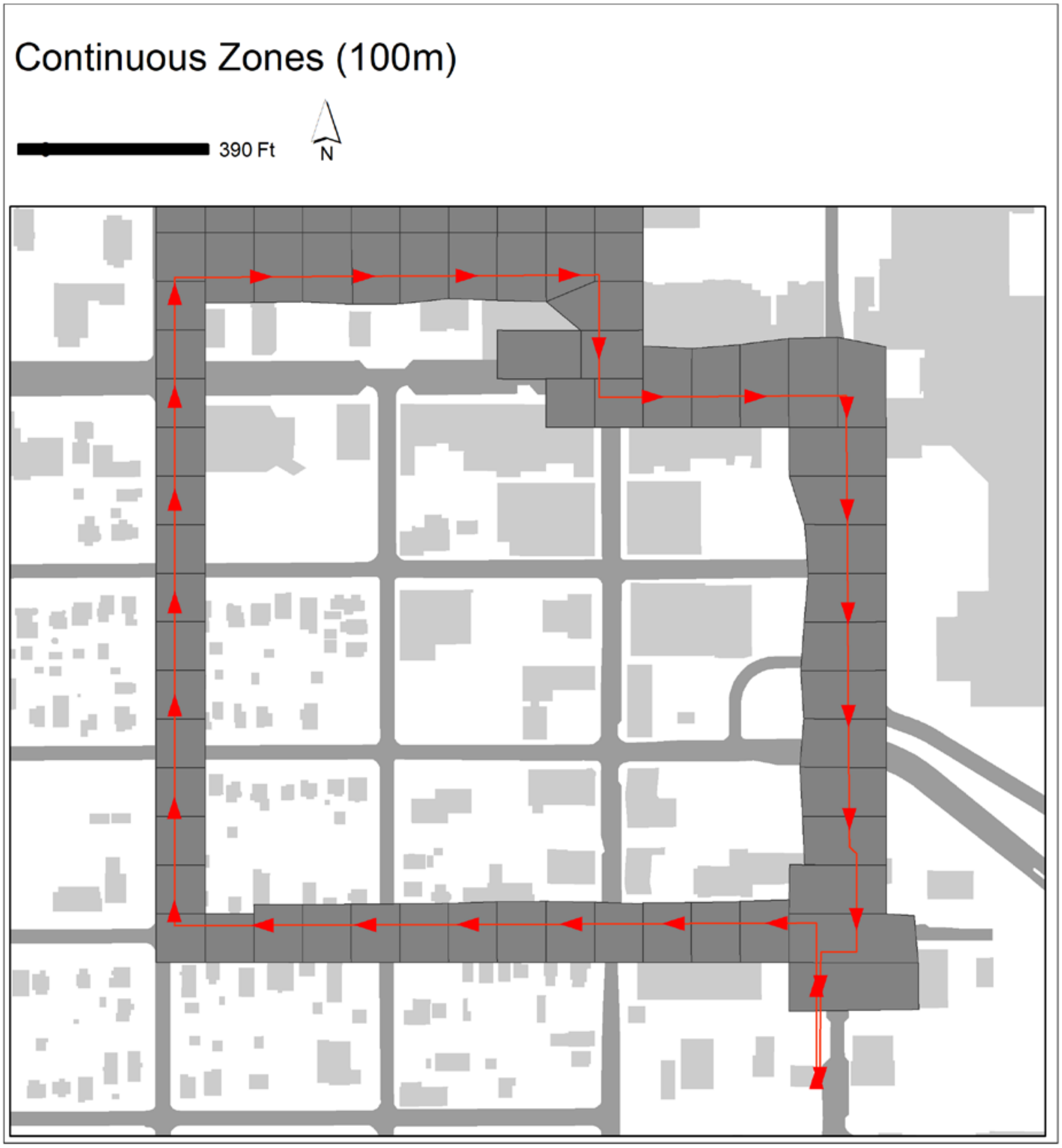
Our hope is that the findings will better inform public policy decision-making efforts regarding design and public health guidelines. This is just one of the first steps in understanding the effects environments play on human behaviors.

If you would like to receive notice of any publications of findings that come from this research, please pass along your email or contact information (note that this will not be linked with the data we collected from you today - the data is confidential). Your contact information will only be used for communication of results.

Again, I would like to thank you for all of your help and cooperation. We are incredibly grateful and fortunate to have had your assistance. We could not have done it without you!

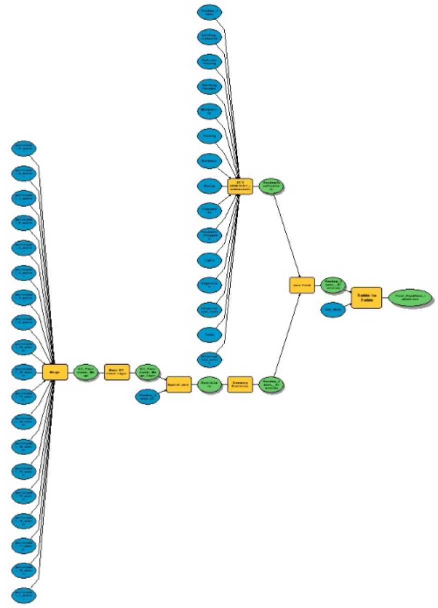
Appendix D: Zone Images



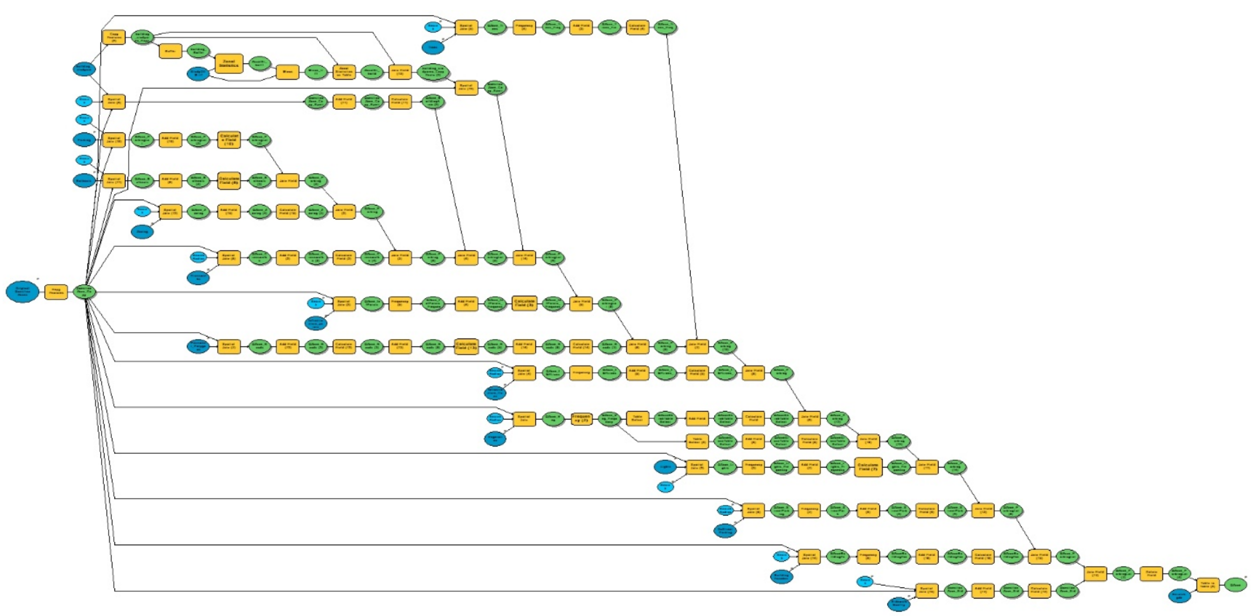


Continuous Zones (100m)
390 Ft
N

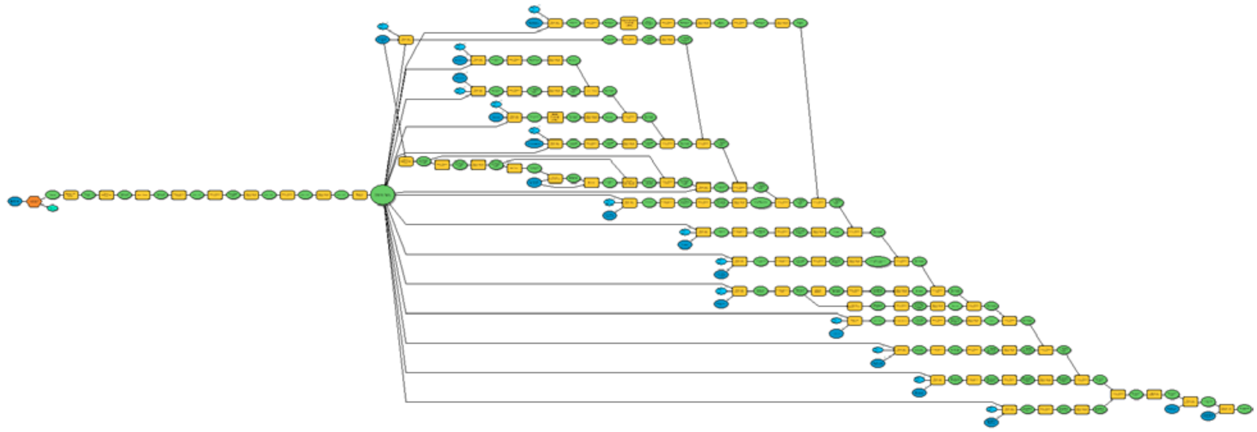
Appendix E: Models



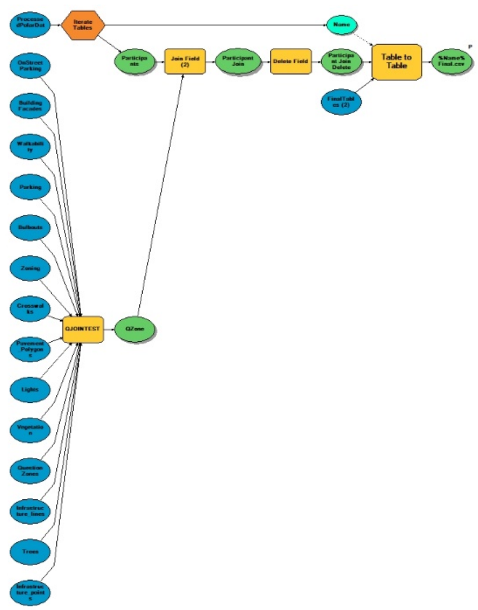
Random Zones Join to Participants Model for Characterization of Environmental Variables



Zone (Questionnaire) Joined to Environmental Variables Model 1

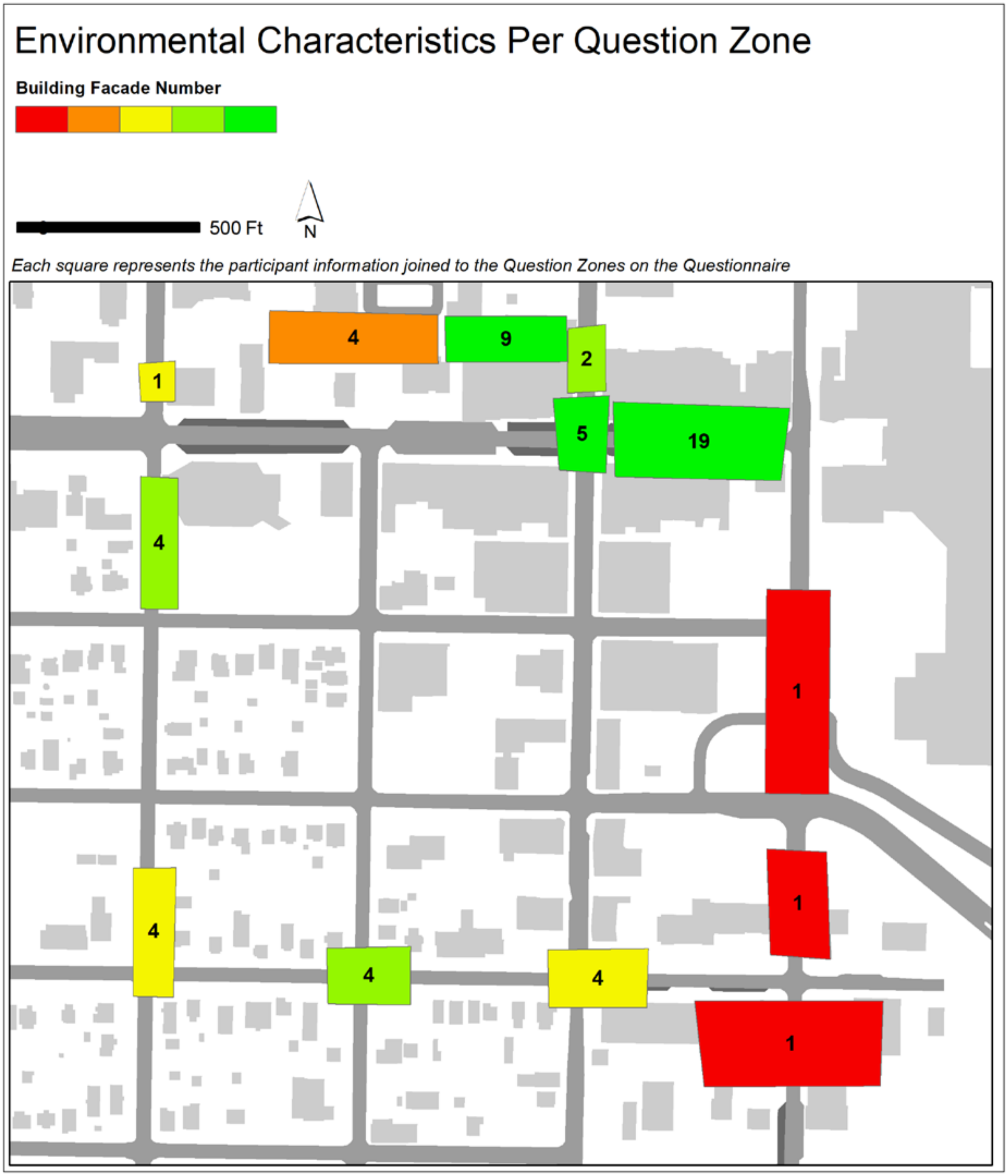


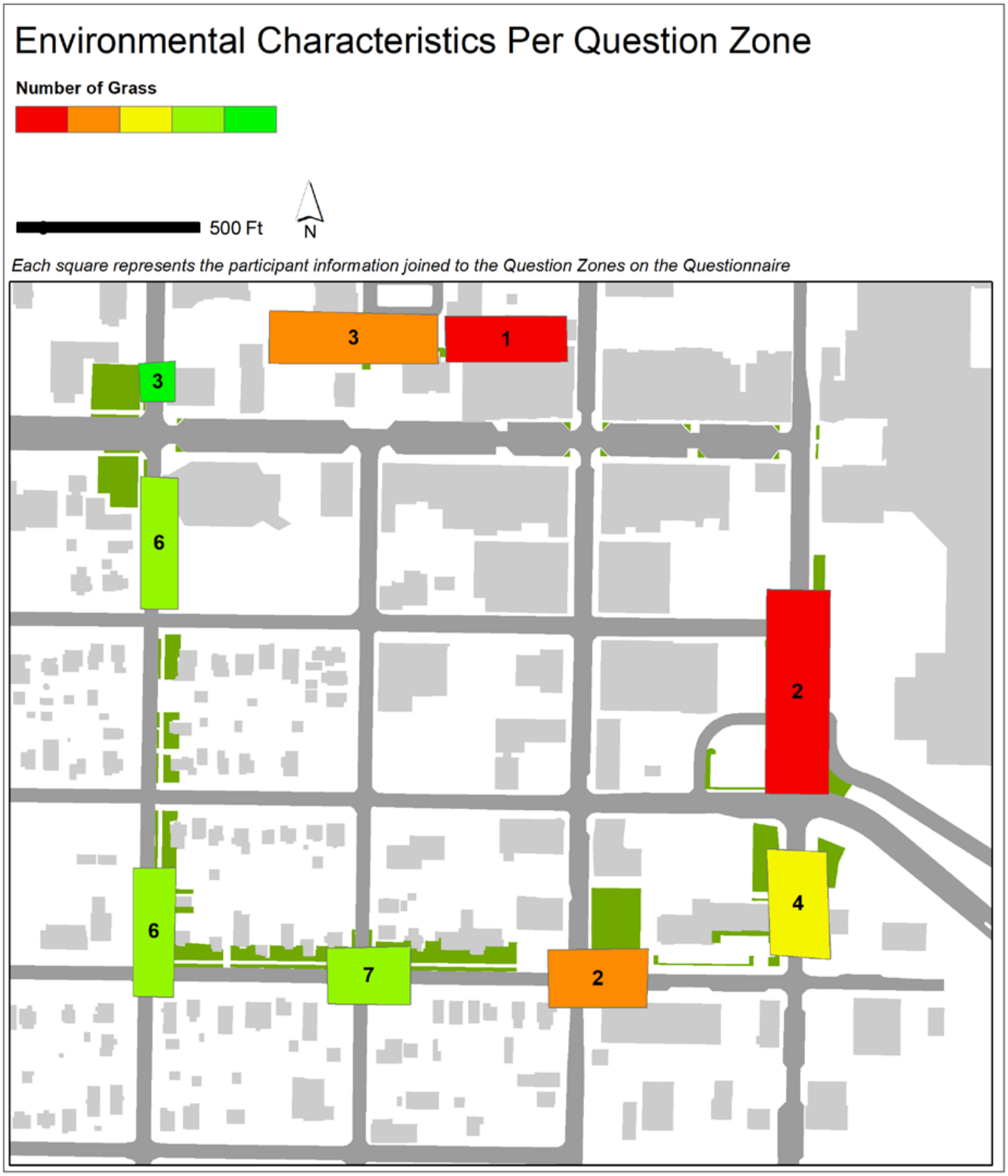
Participant Raw Polar Data Join to Environmental Variables to Zones Model 2



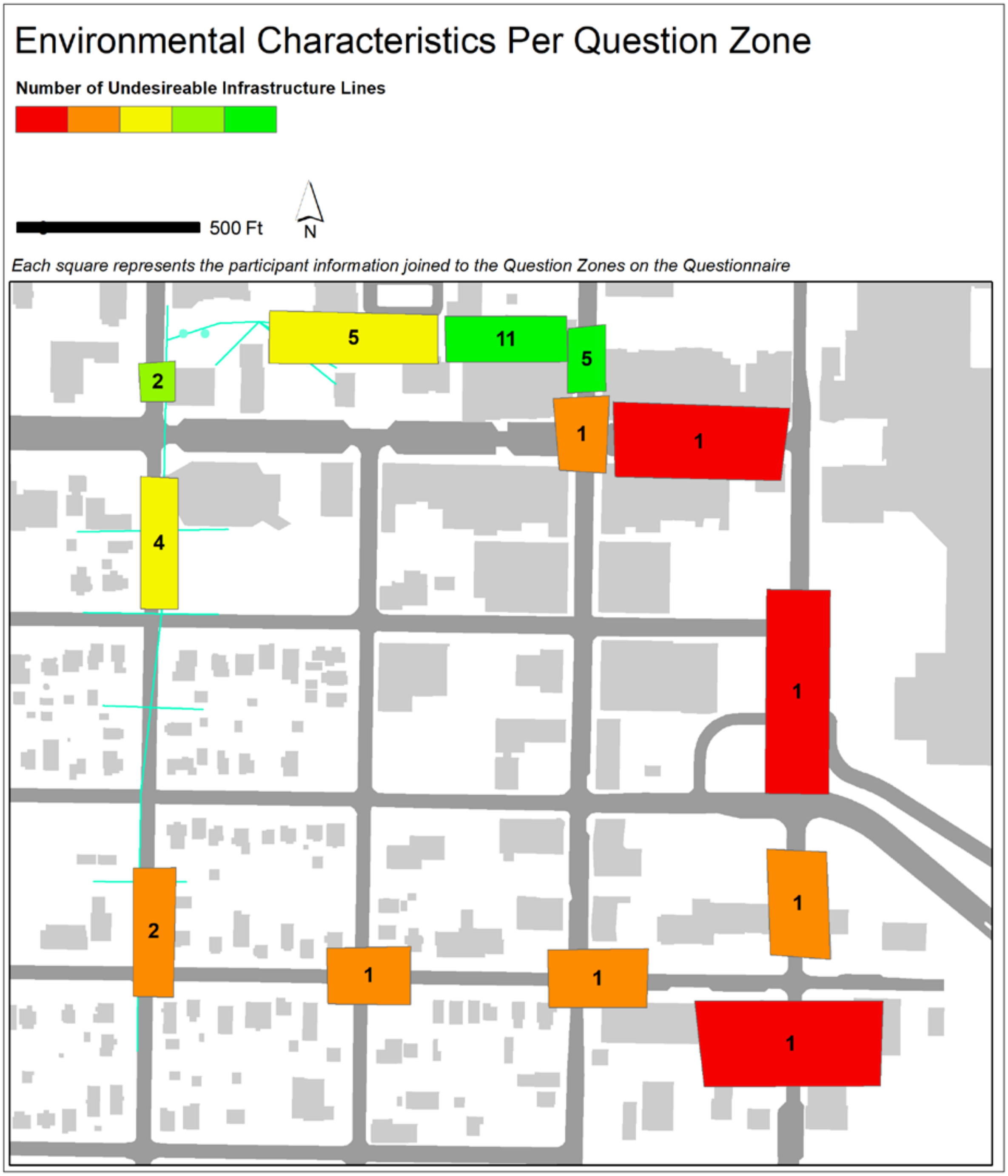
Final Table Join: Model 1 and Model 2

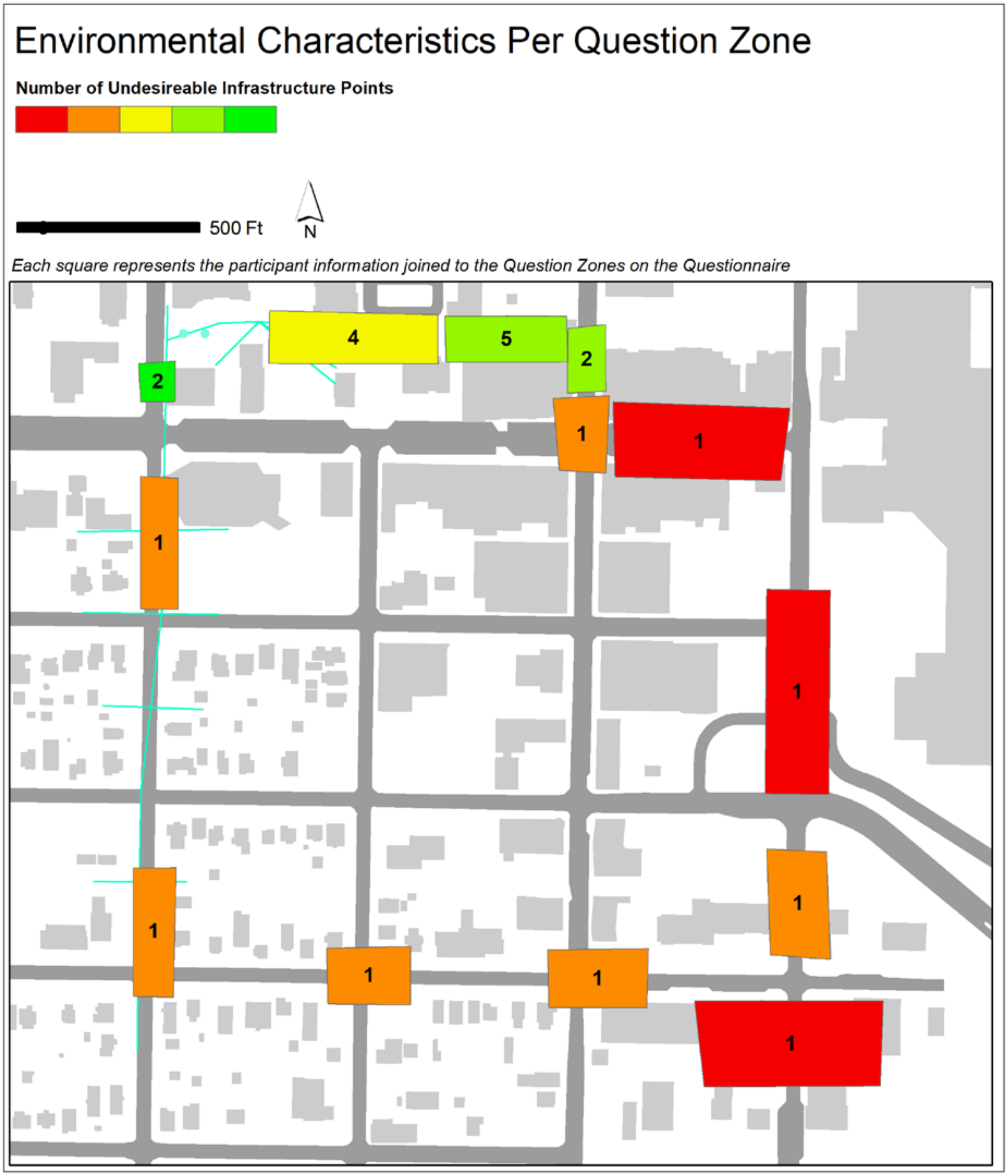
Appendix F: Environmental Characteristics Per Zone Images-Results of Inventory Analysis

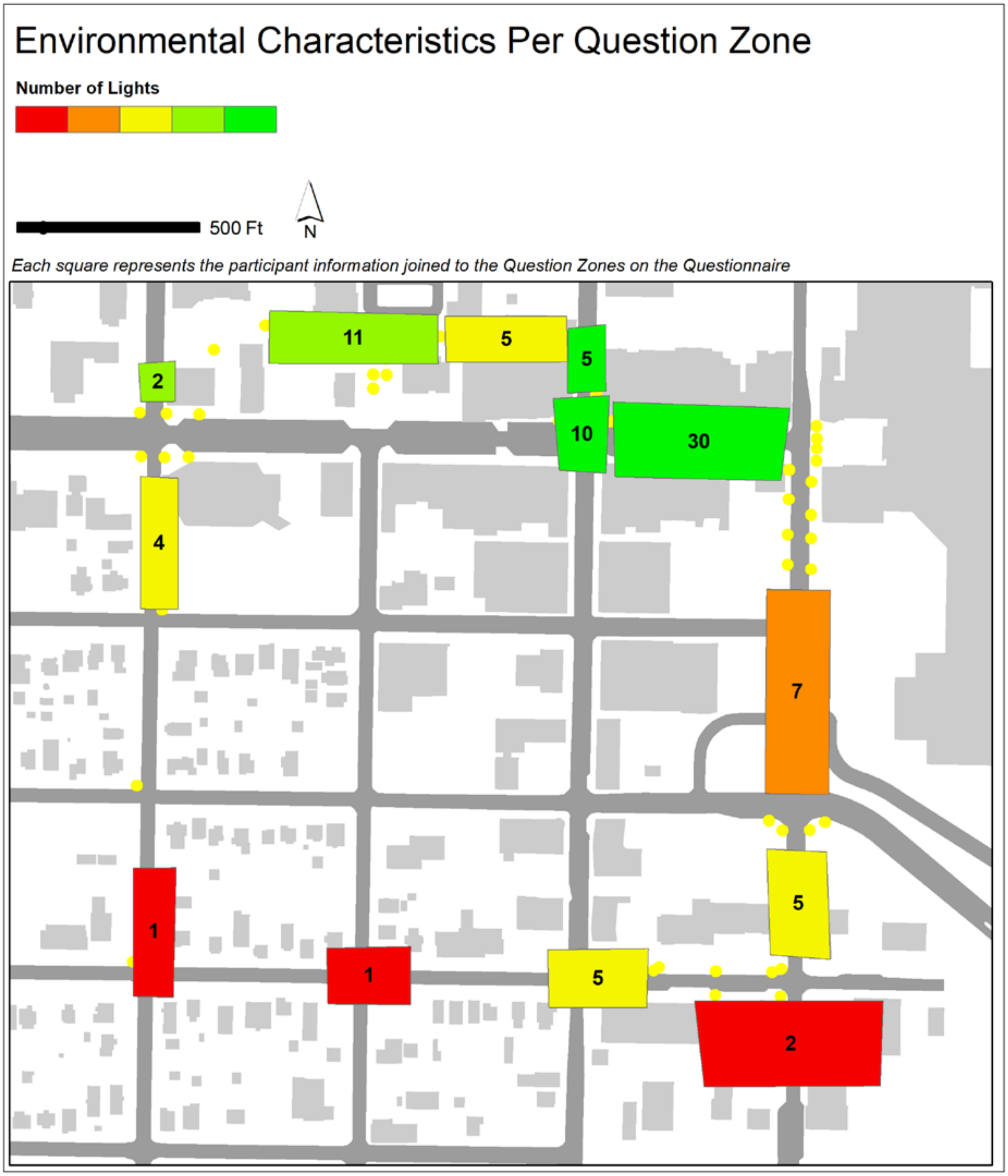


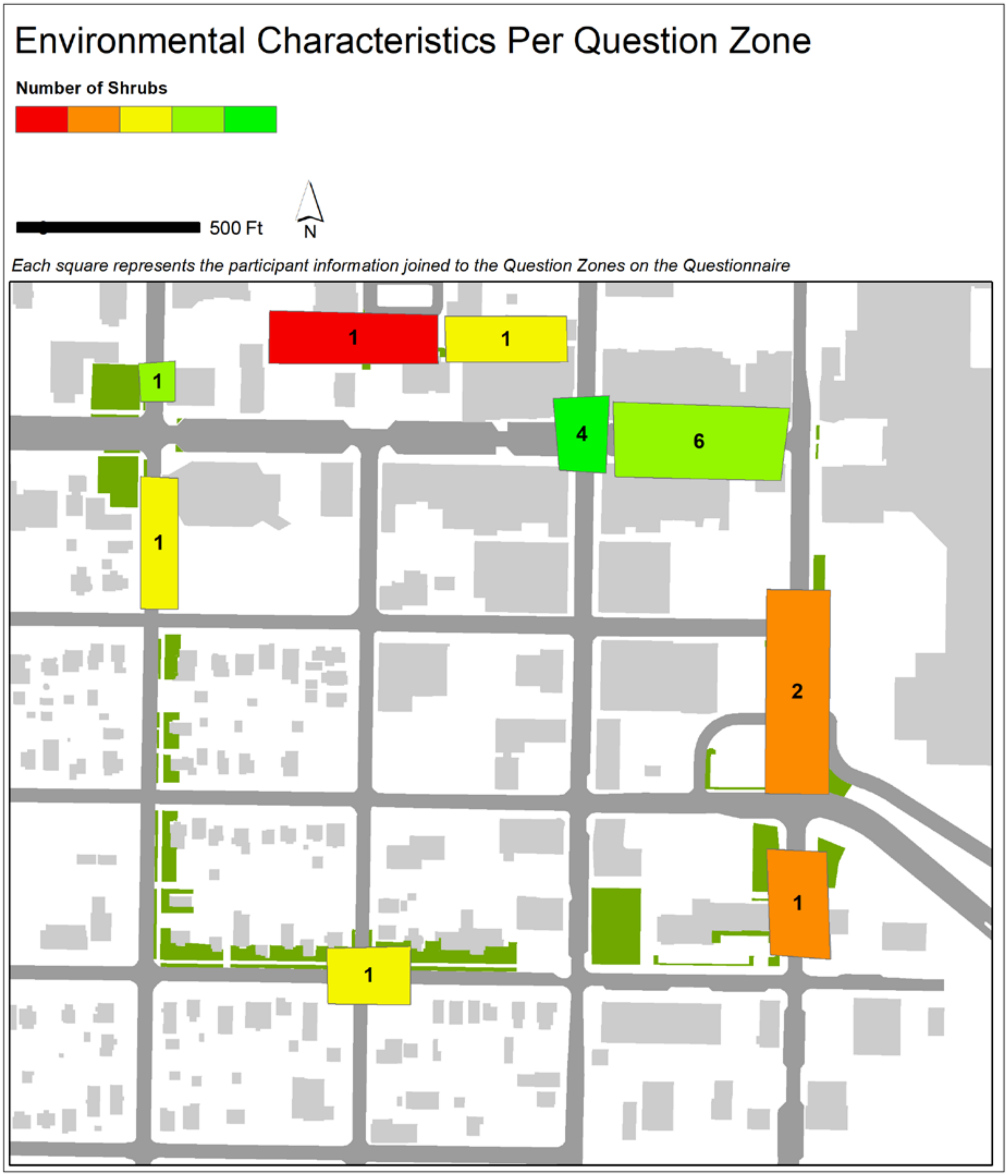


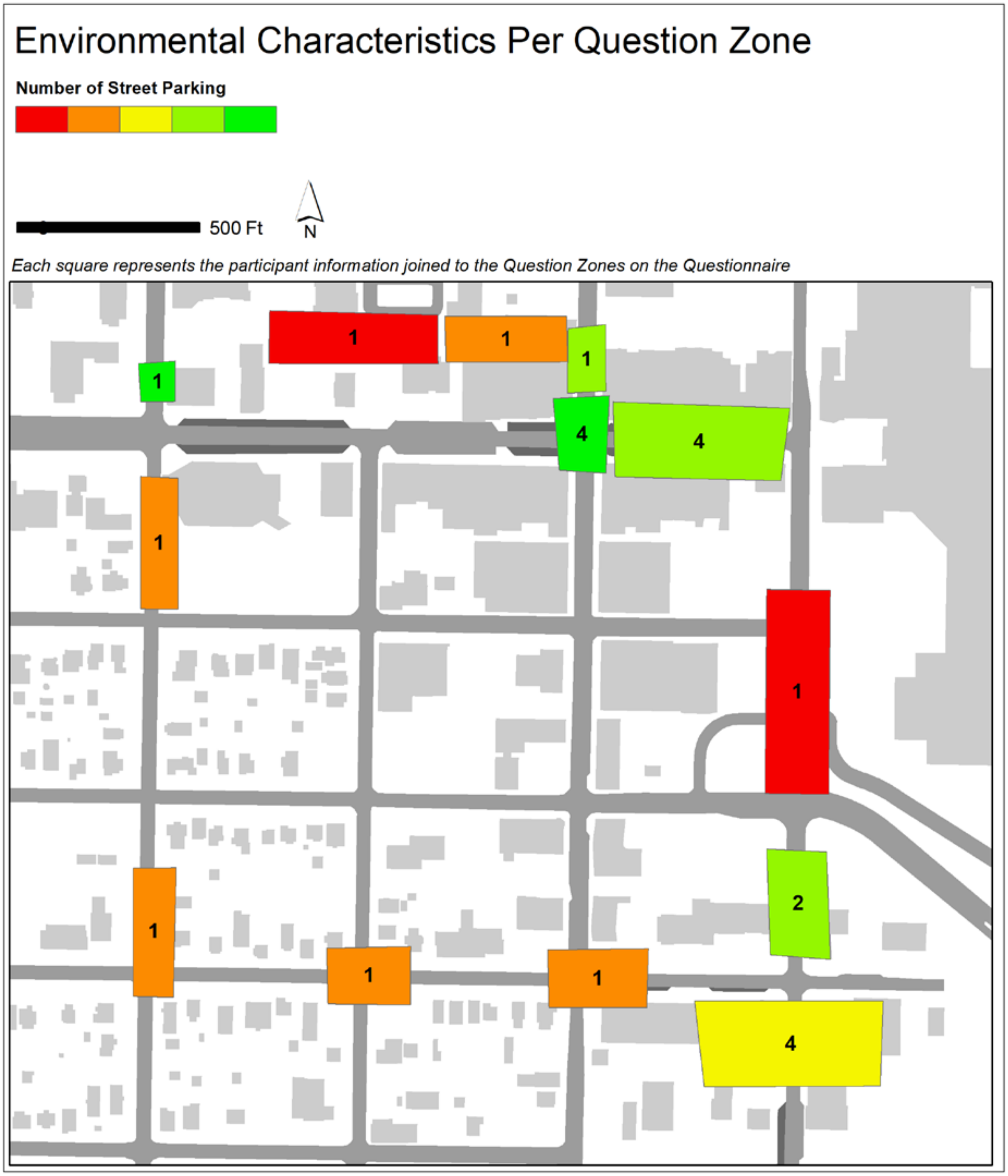
Environmental Characteristics Per Question Zone
Number of Grass
500 Ft
N
Each square represents the participant information joined to the Question Zones on the Questionnaire
3
1
3
6
2
4
6
7
2


Environmental Characteristics Per Question Zone
Number of Undesireable Infrastructure Lines
500 Ft
N
Each square represents the participant information joined to the Question Zones on the Questionnaire
5
11
5
2
1
1
4
1
1
2
1
1
1

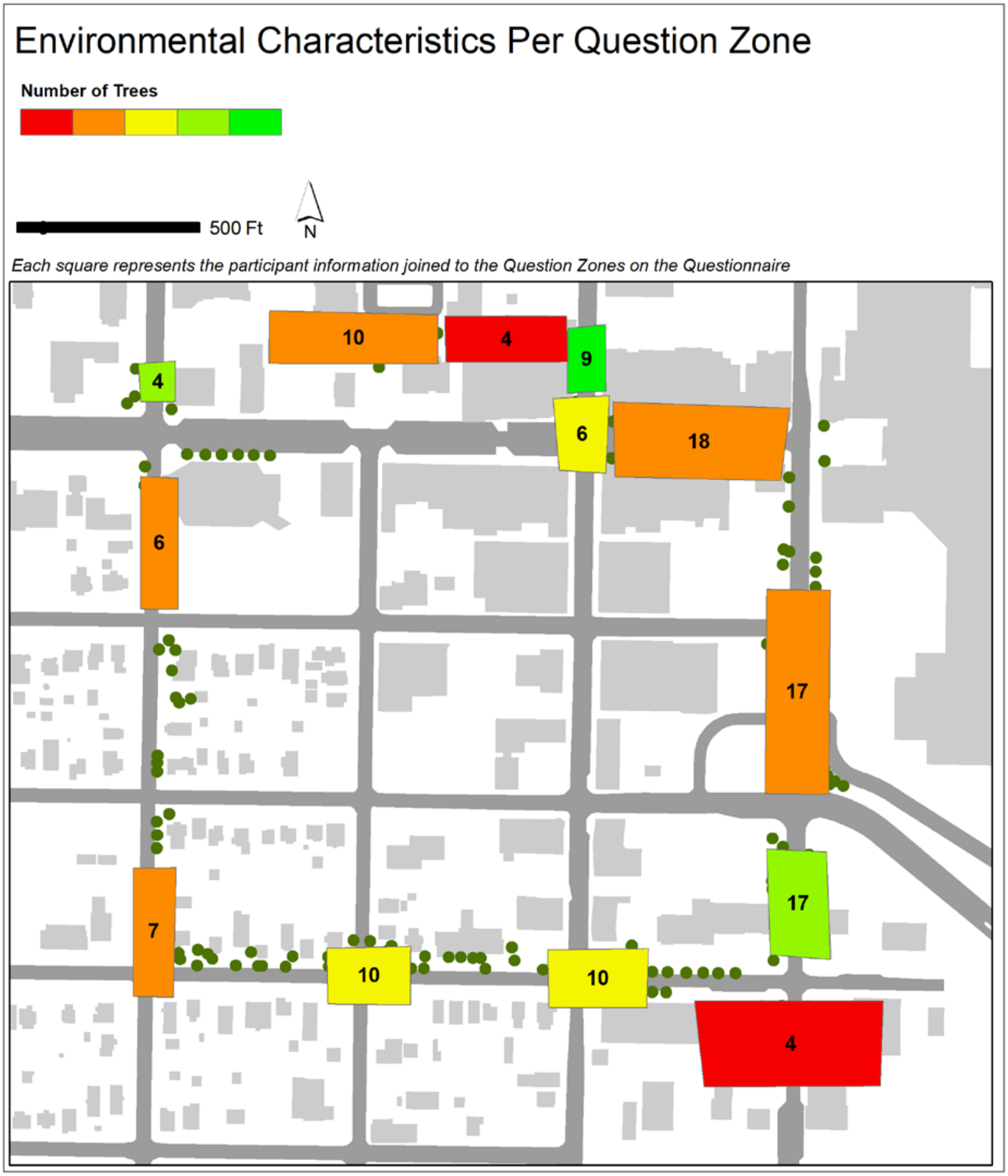

Environmental Characteristics Per Question Zone
Number of Undesireable Infrastructure Points
500 Ft
N
Each square represents the participant information joined to the Question Zones on the Questionnaire
4
5
2
2
1
1
1
1
1
1
1
1
1
1


Environmental Characteristics Per Question Zone
Number of Lights
500 Ft
N
Each square represents the participant information joined to the Question Zones on the Questionnaire
11
5
5
2
10
30
4
7
5
1
1
5
2


Environmental Characteristics Per Question Zone
Number of Shrubs
500 Ft
N
Each square represents the participant information joined to the Question Zones on the Questionnaire
1
1
1
4
6
1
2
1
1

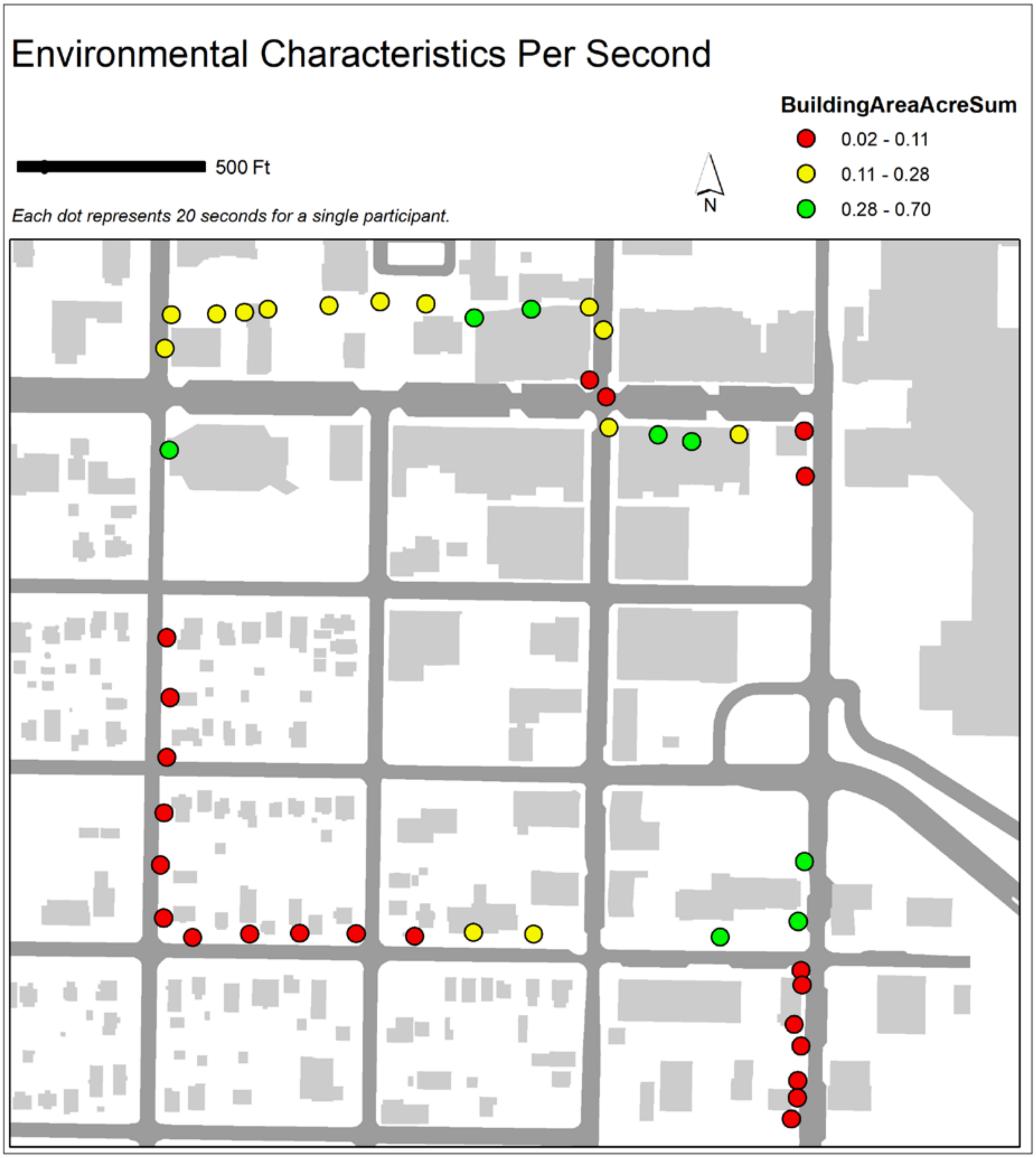


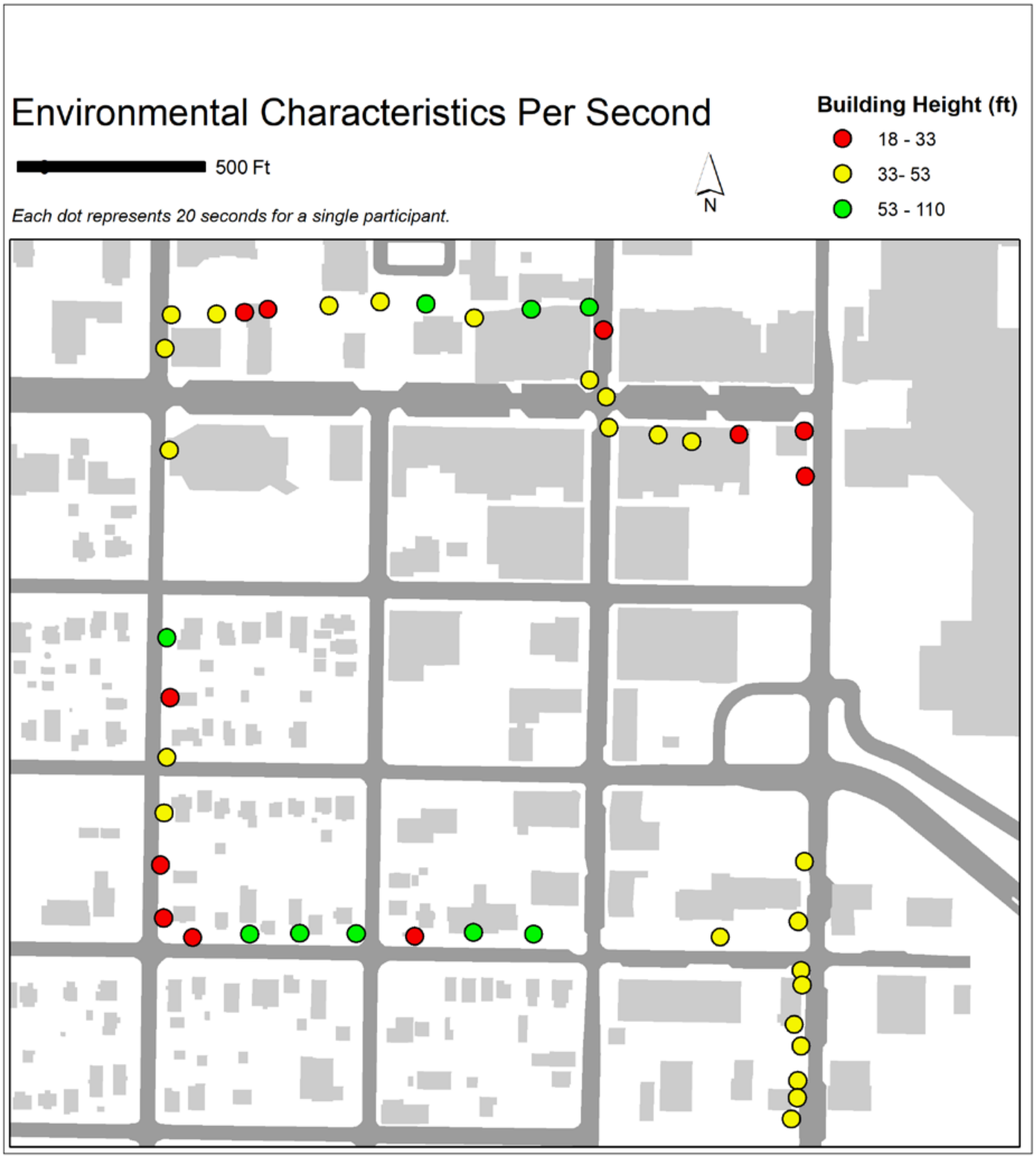
Environmental Characteristics Per Question Zone
Number of Street Parking
500 Ft
N
Each square represents the participant information joined to the Question Zones on the Questionnaire
1
1
1
1
4
4
1
1
2
1
1
1
4



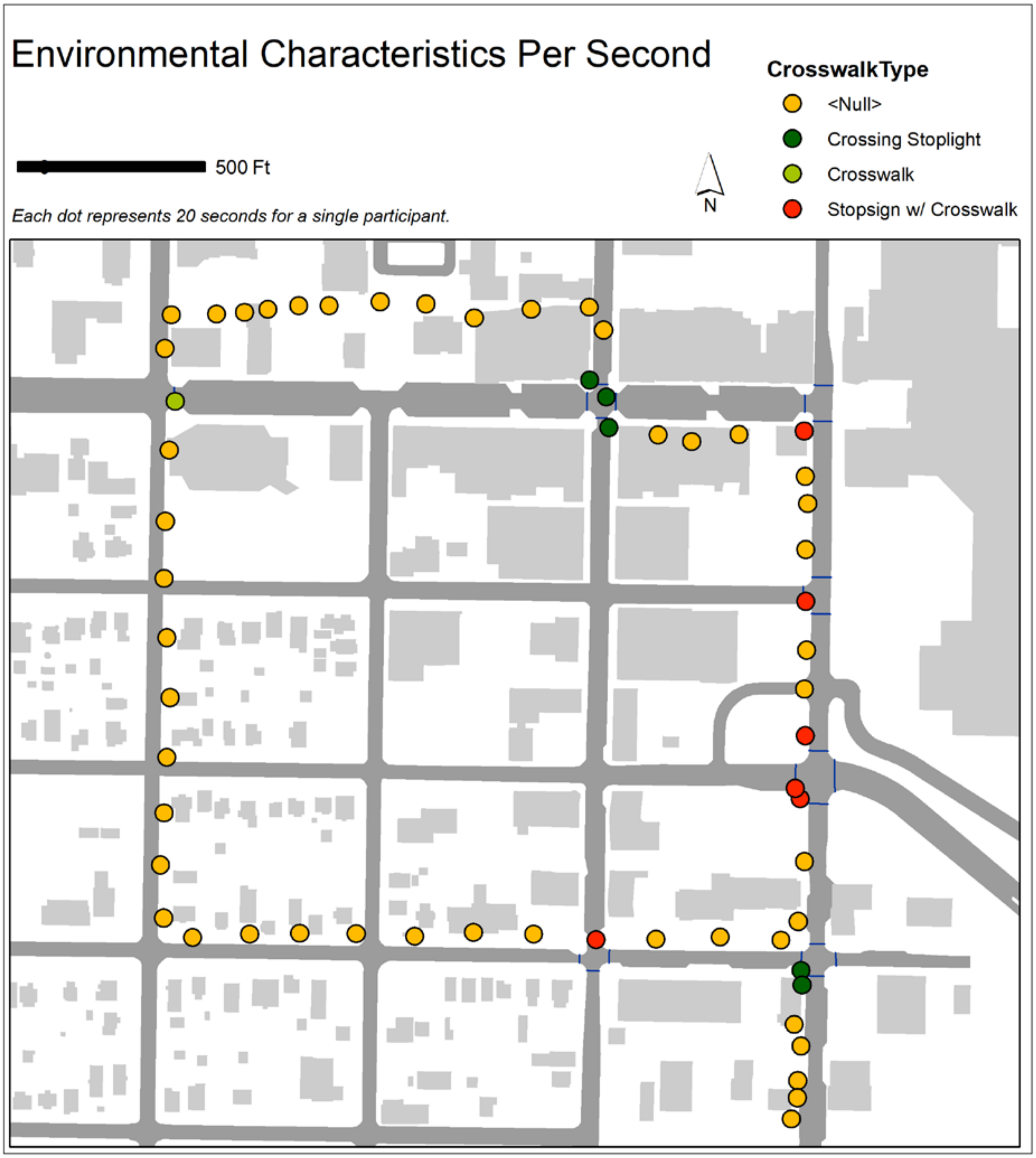
Environmental Characteristics Per Question Zone
Number of Trees
500 Ft
N
Each square represents the participant information joined to the Question Zones on the Questionnaire
10
4
9
4
6
18
6
17
17
7
10
10
4

Appendix G: Environmental Characteristics Per Participant Biometric Data (20 Second)- Results of Inventory Analysis

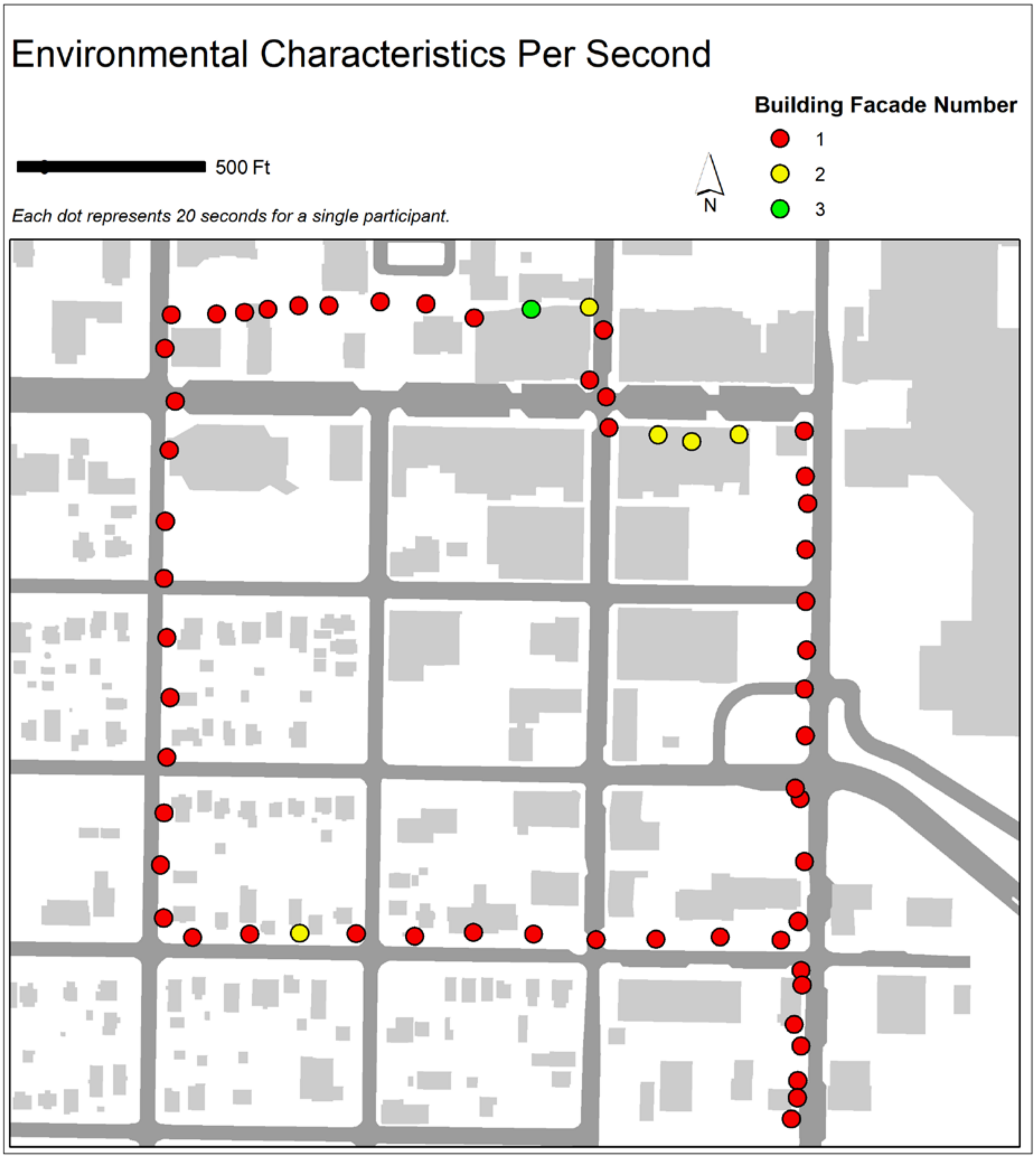



Environmental Characteristics Per Second
500 Ft
Each dot represents 20 seconds for a single participant.
N
Building Height (ft)
18 - 33
33- 53
53 - 110

Environmental Characteristics Per Second
Bulbouts
<Null>
Non-protected
Protected
500 Ft
N
Each dot represents 20 seconds for a single participant.

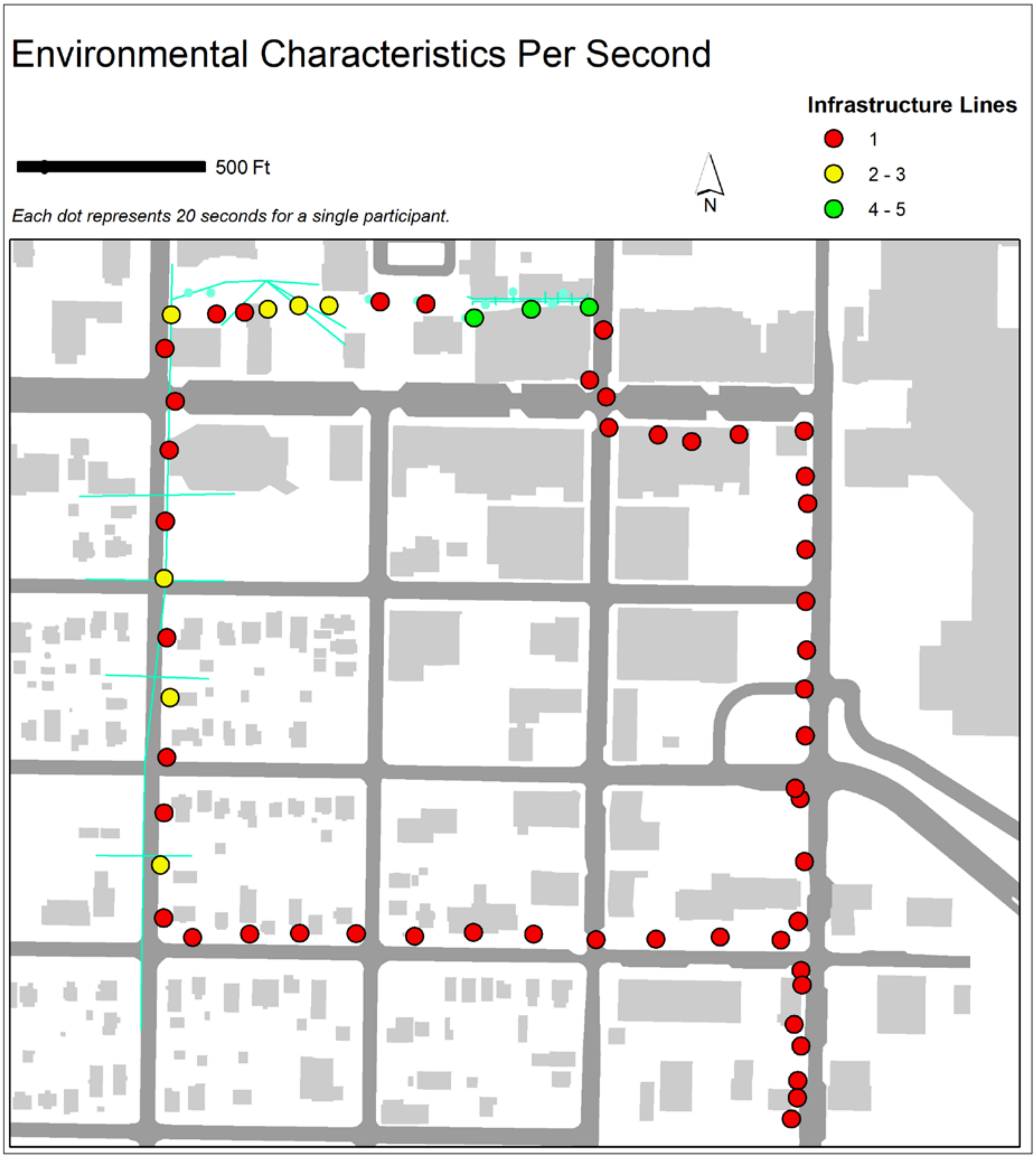


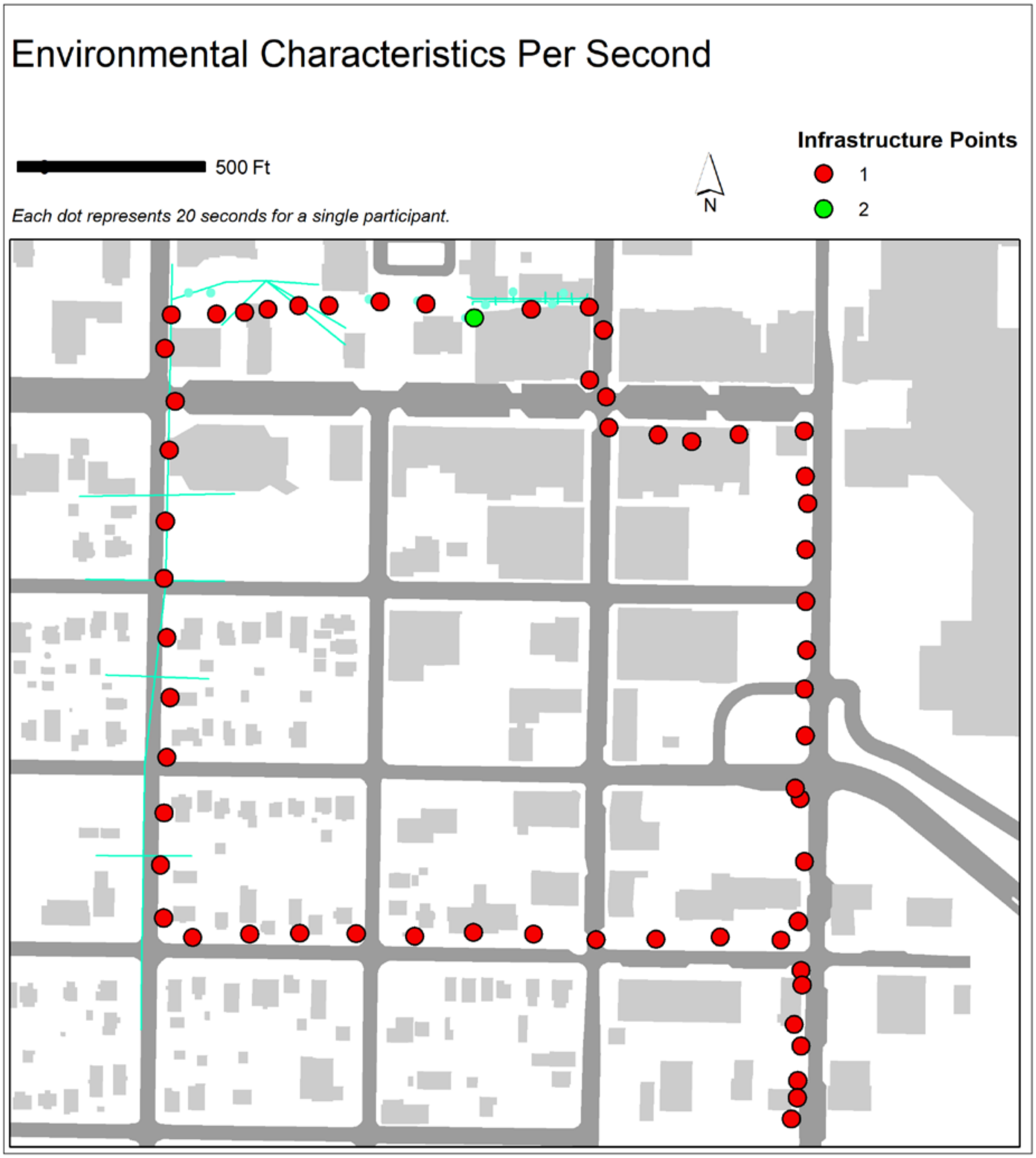
Environmental Characteristics Per Second
CrosswalkType
<Null>
Crossing Stoplight
Crosswalk
Stopsign w/ Crosswalk
500 Ft
N
Each dot represents 20 seconds for a single participant.

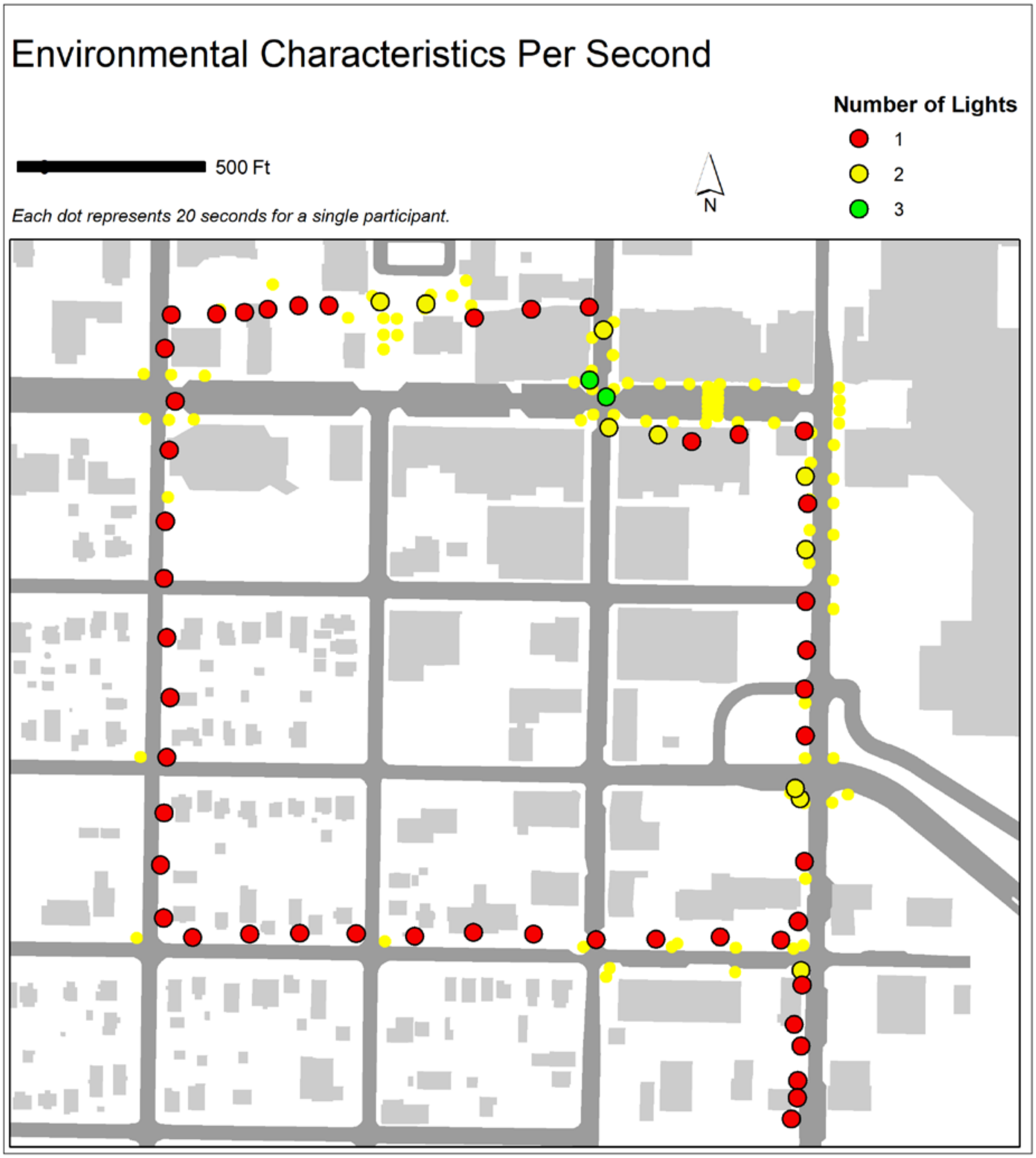


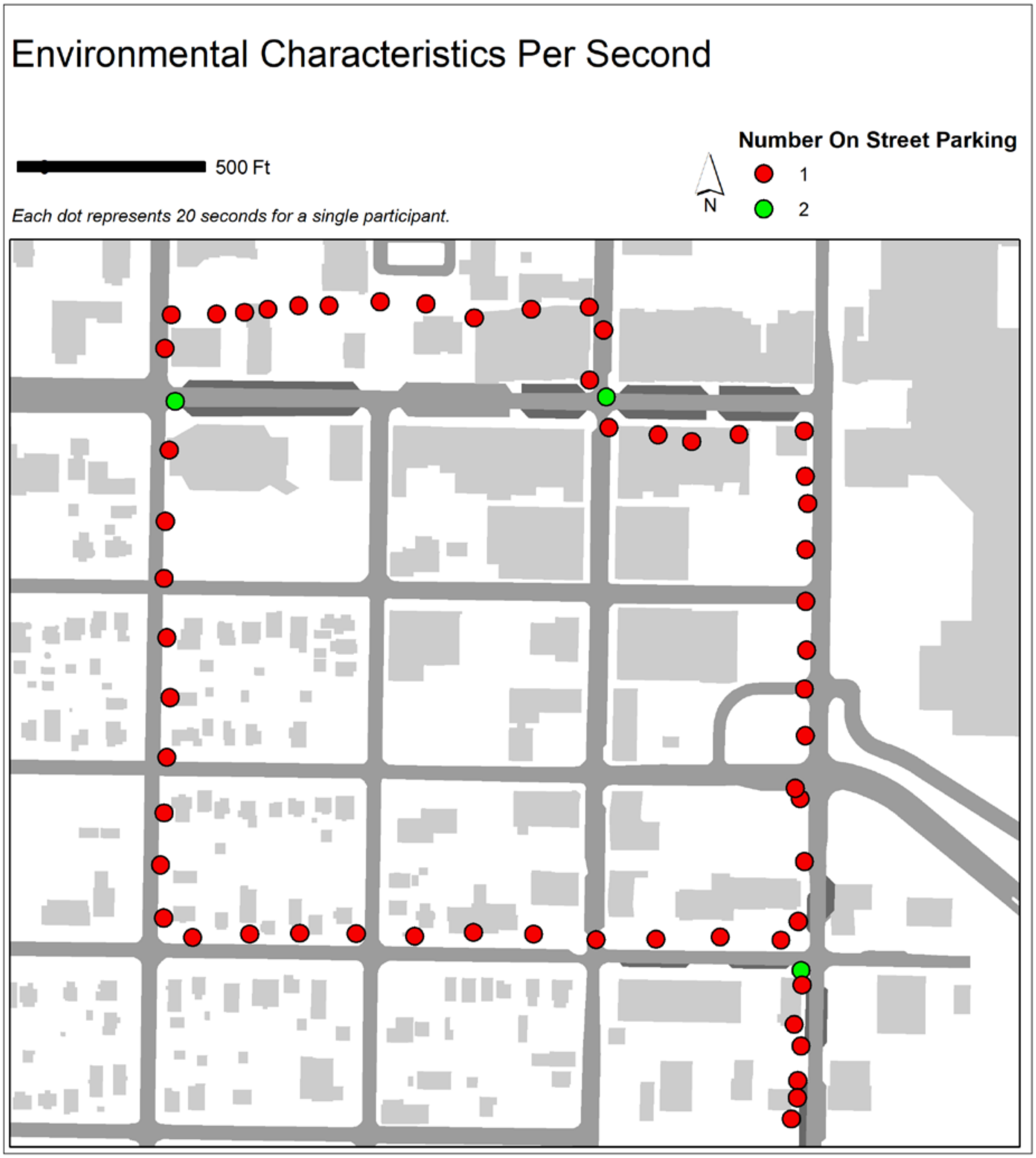
Environmental Characteristics Per Second
Building Facade Number
1
2
3
500 Ft
N
Each dot represents 20 seconds for a single participant.


Environmental Characteristics Per Second
Number of Grass
1
2
3 - 4
500 Ft
N
Each dot represents 20 seconds for a single participant.


Environmental Characteristics Per Second
Infrastructure Lines
1
2 - 3
4 - 5
500 Ft
N
Each dot represents 20 seconds for a single participant.


Environmental Characteristics Per Second
500 Ft
Each dot represents 20 seconds for a single participant.
N
Infrastructure Points
1
2


Environmental Characteristics Per Second
Number of Lights
1
2
3
500 Ft
N
Each dot represents 20 seconds for a single participant.


Environmental Characteristics Per Second
500 Ft
Each dot represents 20 seconds for a single participant.
Number On Street Parking
N
1
2

Environmental Characteristics Per Second
500 Ft
Each dot represents 20 seconds for a single participant.
N
Number of Shrub
1
2

Environmental Characteristics Per Second
Number of Trees
1
2 - 3
4 - 5
500 Ft
N
Each dot represents 20 seconds for a single participant.


Environmental Characteristics Per Second
ParkingLotAreaAcres
0.27 - 0.41
0.41 - 1.18
1.18 - 2.51
500 Ft
N
Each dot represents 20 seconds for a single participant.


Environmental Characteristics Per Second
RoadSurfaceType
<Null>
Asphalt
Concrete
500 Ft
N
Each dot represents 20 seconds for a single participant.


Environmental Characteristics Per Second
500 Ft
Each dot represents 20 seconds for a single participant.
N
Sidewalk Quality
0
1


Environmental Characteristics Per Second
SpeedLimit
<Null>
20
30
500 Ft
N
Each dot represents 20 seconds for a single participant.