ARE SMARTER NEIGHBORHOODS, MORE WALKABLE?

by

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Dissertation

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Abstract

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This dissertation seeks to investigate the association between smart city initiatives and neighborhoods' walkability. The preference for living in walkable neighborhoods has grown remarkably since 2017, in comparison to previous years, and residents of walkable neighborhoods show more satisfaction regarding their quality of life. In recent decades, people tend to live in communities that provide better QoL and are more receptive to their needs.

Meanwhile, with new technology advancements, residents and visitors have become more involved, and cities have become more responsive in recognizing their demands and providing solutions and services. Although technology plays a vital role in smart cities, not all services in a smart city are technology-based. Several of technology-based and non-technology-based characteristics come together to support the city's performance and increase QoL for residents.

Urban design qualities and gross built environment characteristics are essential factors to support a neighborhood's walkability. Several studies explored the relationship between neighborhood characteristics and pedestrian activity. This research aims to recognize the relationship between smart characteristics of the neighborhood and pedestrian activity as a gap in smart city and walkability literature. This research hypothesizes that a higher number of smart city characteristics associates with a higher number of pedestrians. It uses the mixed-method approach to test this hypothesis. The qualitative method identifies the study area and users' perception of walkable neighborhoods. Urban design qualities, built environment characteristics, and neighborhood smartness score test the hypothesis in a Negative Binomial Regression Model. The number of pedestrians counted in each block face is the dependent variable in the study. Concurrent triangulation is used to combine the findings from qualitative and quantitative methods and interpret the findings. The results of this study confirm the hypothesis. There are several lessons in this study for urban planners, urban designers, policymakers and developers.

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Chapter One: Introduction

1.1 Background

Economic growth and technological advancements in the last two decades of the 20th century created many opportunities in cities and attracted many people from rural areas to urbanized areas. Although these changes generated several struggles for cities such as pollution, shortage of resources, lack of infrastructure, poverty, social exclusion (Cropper & Griffiths, 1994; Repetto, 1987), they also increased demand for higher Quality of life (QoL) in cities.

Aiming to improve the QoL in urban space, cities used technological advancements and non-technological resolutions to enforce new policies, initiatives, and infrastructures. In recent years, the concept of the smart city has become a popular research subject. For the past ten years, a significant number of researchers from different fields, such as computer science, transportation, and energy have tried to define smart cities, their initiatives, and applications (Bowerman, Braverman, Taylor, Todosow, & Von Wimmersperg, 2000; Chourabi, et al., 2012; Coe, Paquet, & Roy, 2001; Eger, 2009; Giffinger, et al., 2007; Harrison, et al., 2010; Harrison & Donnelly, 2011; Kitchin R. , 2014). They conceptualize smart city as digital city, intelligent city, real-time city, green city, and sustainable city (Albino, Berardi , & Dangel, 2015; Finger & Razzaghi, 2017; Harrison & Donnelly, 2011; Hollands, 2008; Kitchin R. , 2014; Komninos, 2006).

Considerable number of studies define smart cities based on application of new technologies such as sensors and applications that are used for collecting data, monitoring infrastructure, power grids and other components of city (Benevolo , Dameri, & D'Auria, 2016; Chourabi, et al., 2012; Harrison & Donnelly, 2011; Kitchin R. , 2014; Streitz, et al., 2005). These studies recognized enhancing QoL as the primary goal of smart cities (Caragliu, Del Bo, & Nijkamp, 2011; Dameri , 2013; Giffinger, et al., 2007; Nam & Pardo , 2011).

The QoL is highly related to the mental and physical health of residents (Flanagan, 1978; Pacione, 2003; Van Kamp, Leidelmeijer, Marsm, & De Hollander, 2003). Walkable neighborhoods encourage physical activity. Walking as the most accessible and affordable way of exercise promotes physical and mental health. Studies show that residents of walkable neighborhoods have more physical activity (Ding, Sallis, Kerr, Lee, & Rosenberg, 2011; Macintyre, Ellaway, & Cummins, 2002; Roux & Mair, 2010) and they show higher satisfaction of their QoL (Strategies, 2017). Walkable neighborhoods provide a diversity of activities in walkable distance and support pedestrian activity and safety, which make walking an enjoyable experience (Talen & Koschinsky, 2013).

The effect of environmental characteristics and urban form on walkability has been the subject of research for several years. Several studies conceptualize urban form in the transportation system, street characteristics, density, land use patterns, and diversity of land uses (Frank & Pivo, 1994; Kitamura, Mokhtarian, & Laidet, 1997; Frank, Bradley, Kavage, Chapman, & Lawton, 2008). Frank and Pivo (1994) found that increasing the density and land use diversity is associated with more walking. Built environment characteristics such as land-use diversity, density, and street connectivity have a significant association with higher walkability (Kitchin R. , 2014; Leinberger & Alfonzo, 2012; McConville, Rodriguez, Clifton, Cho, & Fleishhacker, 2011; Saelens & Handy, 2008). Also, the residents of compact neighborhoods report more walking (Saelens, Sallis, & Frank, 2003). The traditional neighborhoods provide a greater mix of offices, and commercial land uses in proximity to residential land uses, with their grid layout offering a direct path from origin to destination; studies have shown that residents of such neighborhoods walk more (Hollands, 2008; Kitchin R. , 2014). A meta-analysis of travel and built environment conducted by Ewing and Cervero (2010) shows that walking is highly related to the diversity of land uses. This study also indicates that destination proximity and street connectivity are two important built environment characteristics associated with walking.

A study of 32 neighborhoods in Baltimore, MD and Seattle, WA showed that residents of highly walkable neighborhoods, walk 40 minutes more per week on average compared to residents of low walkable neighborhoods (Sallis, et al., 2009). In another study in Montgomery County MD, McConville et al. (2011) Surveyed 260 individuals to investigate the relationship between walking and neighborhood land uses. The results show that higher density and diversity of land uses – such as offices, retail stores, groceries, and bus stops – are positively associated with walking. According to the literature, walkable neighborhoods have urban form and environment characteristics such as higher density, higher street connectivity, diversity of land uses, and proximity of destinations. Such neighborhoods have better pedestrian infrastructure, including street lighting and continuous sidewalks with offer different routing options between two points (Jackson, 2003).

In addition to urban form and environment characteristics, urban design qualities of streets play a significant role in promoting walking as well. Busy streets, pleasant sceneries, trees, and landscaping attract pedestrians (Adkins, Dill, Luhr, & Neal, 2012; Jackson, 2003). Mehta (2014) evaluates four public spaces in Tampa, Florida, based on five dimensions: inclusiveness, comfort, meaningfulness, safety, and pleasurability. He created a public space index (PSI) and used researcher observer survey and user survey to evaluate the extents of public space in these four study areas. Figure 1.1 shows the visual results of public space evaluation in this study. For example, in Franklin Street, although meaningful activity and comfort are stronger factors in space livability, all five dimensions are important in comparison to the other three study areas (Mehta, 2014).

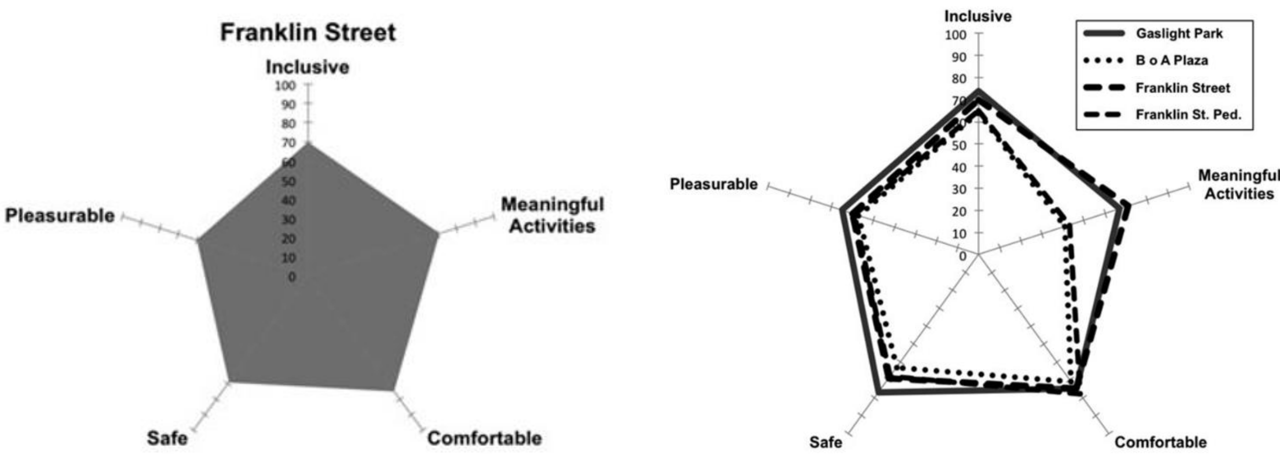

Figure 1.1. The evaluation of public space characteristics by Mehta (2014, pp. 79, 84)

Walkable neighborhoods provide a diversity of activities within walkable distances and support pedestrian activity and safety, which make walking an enjoyable experience (Talen & Koschinsky, 2013). Walkable neighborhoods encourage physical activity; walking, as the most accessible and affordable way of exercise, promotes physical and mental health.

This dissertation aims to study walkable neighborhoods and pedestrian activity in the smart city era. It first explores definitions of a smart city in the literature and provides a comprehensive review of a smart city definition. Then based on the smart city definitions in the literature, it defines smart neighborhoods as small fractions of a smart city. This research identifies smart neighborhood characteristics related to walkability and examines the relationship between smart neighborhood characteristics and the number of pedestrians in four neighborhoods in Fort Worth, TX. The built environment attributes and urban design qualities are the control variables in this study.

1.2 Problem statement

As previously mentioned, the technological advancement of the last few decades facilitates monitoring of a city’s performance in providing services to residents and improving QoL. The concept of smart city is a relatively new subject in planning, and it has not been investigated much from the planning view. Besides, reviewing literature related to the smart city shows that a considerable number of studies focus the using technologies for collecting data, monitoring infrastructure, power grids, and other components of the city. Computer scientists and transportation engineers generally conduct these studies. However, reviewing the definition of smart cities, their smart features, and the projects that have been done all across the world show that smart cities are beyond technology (Neirotti , De Marco, Cagliano, Mangano, & Scorrano , 2014). Although utilizing technology plays an important role, not all smart city characteristics are technology-based. Publicizing events, communicating public engagement events, educational achievements and training of residents play a significant role in the city's smartness (Giffinger, et al., 2007). Besides, the geographical scale of smart cities is not clear. The smart city literature draws the geographical boundaries of the smart city in larger scales – cities and regions.

On the other hand, smart buildings and smart façades are the trending subjects of architecture literature. It appears that smart streets and smart neighborhoods are lost in the gap between architecture and smart city or even urban planning literature. This dissertation aims to provide a better understanding of smart city concepts, extend the smart city definition to smaller geographical scales and revisit characteristics of walkable neighborhoods in smart era.

This research is important in different aspects. As mentioned earlier, despite several effort for defining smart cities, identifying their initiatives and applications in different fields, a universal definition for smart city is lacking (Bowerman, Braverman, Taylor, Todosow, & Von Wimmersperg, 2000; Coe, Paquet, & Roy, 2001; Giffinger, et al., 2007; Eger, 2009; Harrison, et al., 2010; Harrison & Donnelly, 2011; Chourabi, et al., 2012; Kitchin R. , 2014). This research defines a smart city based on the smart city literature and provides a new perspective to smart literature from the urban planning viewpoint.

Second, this dissertation suggests extending smart city definitions to different geographical scales and proposes using the definition of “smartness” for smaller scales such as a neighborhood. It defines smart neighborhoods as a small components of smart city and argues that a smart city is a cluster of smart neighborhoods which have unique smart characteristics and work together to create a smart city.

Third, this study suggests not limiting the smart city's definitions to technological advancements. It argues that smart city is a combination of technology-based and non-technology-based components. It introduces smart neighborhoods as systems of smart resolutions and technological components, which are unique in their characteristics with the same goal: better performance and higher quality of life. A comprehensive, thoughtful, and innovative combination and collaboration of such neighborhoods with support of smart policies, smart management, smart technology, innovative ideas, and involvement of residents on different scales and layers create a real smart city.

Fourth, based on this definition, this research identifies smart neighborhood characteristics related to walking. Although smart city and smart neighborhood are new subjects, utilizing technology in designing components of the urban environment is growing fast. Several studies focus on the application of smart furniture such as smart bikes and smart bike racks (DeMaio P. J., 2003; DeMaio, & Gifford, 2004; DeMaio P. , 2009; Midgley, 2009); smart kiosks

(Ciaramella, et al., 2018; Gómez-Carmona & Casado-Mansilla , 2018); and informative signs (Shepard, 2011) in different urban environments such as public spaces, and for different users such as tourists and costumers. Gómez-Carmona, Casado-Mansilla, and López-de-Ipiña (2018) presented the incorporation of a multifunctional digital system with urban furniture, such as bike racks, to create interactive nodes that enable citizen-city communication. They suggest that smart urban furniture is not only digitally interacting with users, but also sustainably integrating people with the urban environment. They study the use of smart kiosks as smart urban furniture in public spaces, which can be characterized based on their purpose, location, and users and different technology and information that they can utilize based on the purpose that needs to be fulfilled.

This research focuses on the performance of walkable neighborhoods in the smart era, identifying smart characteristics of neighborhoods that support walking. It investigates if smarter neighborhoods with more smart characteristics have higher pedestrian activity. It also studies the relationship between smart neighborhood characteristics and the number of pedestrians and hypothesizes that a higher number of smart characteristics in a neighborhood is associated with a higher number of pedestrians. However, this research does not focus on the influence of each smart characteristics on walking. Although it acknowledges that some features may have a stronger relationship with pedestrian activity in a walkable neighborhood, it argues that the combination of smart features improve a neighborhood's performance and enhance its walkability.

Fifth, this research aims to add smart neighborhood characteristics to the list of indicators of walkability. To my knowledge, this is one of the first studies that aims to study the relationship between smart neighborhood characteristics and pedestrian activity. The relationship between the built environment characteristics and urban design qualities on neighborhood walkability has been studied intensely in recent years (Frank L. D., et al., 2006; Doyle, Kelly-Schwartz, Schlossberg, & Stockard, 2006). This study divides factors that influence walkability and walking into three categories: built environment characteristics, urban design qualities, and smart neighborhood characteristics. This study tests several built environment characteristics, urban design qualities, and smart neighborhood characteristics related to walking. The final model presents the significant relationship between attributes in these three categories and the number of pedestrians.

1.3 Research purpose, research questions, and hypothesis

Based on the review of the literature related to smart city and walkability, this research identifies the relationship between smart neighborhood characteristics and pedestrian activity as the gap in the literature of walkability. As a major gap in the literature, this dissertation aims to respond to the following research questions:

1. What is the relationship between neighborhood smartness and the number of pedestrians?
2. Are smarter neighborhoods more walkable?

This dissertation provides examples of smart city definitions and indicators to explain the wide variety of smart city definitions that were encountered in the literature. Subsequently, it defines the smart neighborhood and its smart characteristics to be used in this research. Besides, a comprehensive review of the quality of life (QoL) establishes the connection between smart neighborhood characteristics and walkability.

The hypothesis for this research is that a higher level of smartness, which is measured by the higher number of smart characteristics, associates with a higher number of pedestrians. To test this hypothesis, this research employs Negative Binomial Regression analysis to examine the relationship between smart neighborhood characteristics and pedestrian count in selected neighborhoods of Fort Worth, Texas. This study test the hypothesis in the most walkable streets in these neighborhoods as selected by survey respondents.

Besides, the mixed-method and concurrent triangulation approach are used to provide a better understanding and interpretation of the research. The qualitative method includes a users' preference survey. The result of this survey, determine the study area in Fort Worth, TX. An index of smart neighborhood characteristics related to walkability is created based on the literature, users' preference surveys, and field observations to evaluate each study area. The quantitative data include built environment characteristics collected from secondary sources such as Census, and Walk Score website, and by using Geographic Information System (GIS). The urban design qualities are collected from the study areas using field manual from previous researches on evaluation of urban design qualities. The built environment characteristics and urban design qualities are used as control variables in this study.[1]

The number of pedestrians is counted in each block face of the study area, and the Negative Binomial Regression Model tests the hypothesis. This dissertation uses the concurrent triangulation approach to combine and interpret the findings. Hence, an endeavor is constructed to define the topic and clarify concepts and examine the research hypothesis. These definitions serve as a basis for discussing results and principles underlying different approaches to smart city

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[1] A part of this dissertation was awarded for the National Institute for Transportation and Communities (NITC) 2017 student fellowship and initial research developed during the period of fellowship and submitted as a report to the NITC committee.

and walkability. The findings of this research introduce a collection of smart characteristics as determinants of neighborhood walkability that can be used by urban planners, urban designers, and scholars to enhance walkability and QoL for residents.

Chapter Two – Literature Review & Research Approach

This chapter includes theories and empirical literature related to smart city, quality of life, and walkability upon which this study is built on. The first section explores the characterizations of walkable neighborhoods and provides a clear definition for walkable neighborhoods. The next section introduces the research concepts and forms the conceptual framework for this research. The research approach follows this section and draws the theoretical framework based on the theory of systems and ecological model for physical activity. The next section provides different definitions of smart cities and reviews smart city dimensions and defines smart neighborhoods. QoL, built environment attributes, urban design qualities, and social and cultural factors constitute the main subject of the next sections. The last section outlines theories and empirical studies that help to explain the variables used in this study.

2.1 What is a walkable neighborhood?

Although researchers and practitioners alike have tried to provide a unique definition for walkability, the majority of studies in the different fields define walkability more indirectly, using the physical characteristics of the place that supports walking with different purposes such as pleasure, leisure, and physical exercise. In this dissertation, walkability, and walking, in general, are the main concepts under research; thus, the literature review includes studies that focus on walkability and walking, separate from the purpose.

Forsyth (2015) reviews various definitions of walkability in professional reports, research publications, and public debates, explaining that the term “walkability” has been used for different phenomena. She divides these definitions into three main categories and nine themes. The three main definition categories are environmental factors, the outcome of space use, and walkability as an alternative form of travel. The first category looks at the environmental factors that make places walkable: these are traversability, compactness, being physically enticing, and safety. The second category, focusing on the outcome of space use, explores whether and how, for example, walkable environments are lively and social; how they provide sustainable transportation options; and whether or not they promote exercise. Moreover, the third category looks at walkability as an alternative solution for solving urban problems or providing better design, which Forsyth (2015) calls "proxy for a better design." For this third category, she argues that defining walkability as a "holistic solution" is not so much about defining the walking itself, but rather about the walkability promoting "being in a good place" (Forsyth, 2015, p. 285).

Forsyth (2015) provides a shared definition of walkability rather than one single definition. She suggests three possible options for such definitions:

- Minimal definition: This definition focuses on the physical walkability related to path quality, proximity, and safety as the main requirements of walking.
- Specific term: This suggests naming walkable places based on their outcome of use or dominant features, e.g., compact or exercise-inducing.
- The comprehensive definition extends beyond physical place, and that supports walking: This definition takes people, policies, and programs, including preferences, demographics, and other factors into consideration.

The concept of walkable places where destinations are near points of departure, and where people can walk safely, has roots in "Neighborhood Units" introduced by Clarence Perry (1929). Before the automobile era, and indeed even in previous centuries, walkability and walkable neighborhoods were indispensable. They were places that promote socializing, mental and physical wellbeing, democracy, and more (Kashef, 2011). With advancements in transportation technology, the rise of the automobile, and the new era of modernism, walkability declined. However, late in the 20th Century, and with the emergence of post-modernist planning – which very much highlighted non-motorized transportation – walkability became an imperative factor in achieving efficient, accessible, equitable, sustainable, and vibrant communities (Lo, 2009).

In addition to the importance of walkability in the context of human advancement, the concept of walkability is also a key component in the literature on health, transportation, and environment, and even in the literature on economy and real state (Cervero & Duncan, 2003; Gilderbloom , Riggs, & Meares, 2015; Heath, et al., 2006; Pivo & Fisher, 2011; Saelens B. E., Sallis, Black, & Chen, 2003; Van Cauwenberg, et al., 2012). Walkable neighborhoods encourage walking (Lee & Talen, 2014) and promote physical and mental health (Leslie & Cerin, 2008). In the literature on transportation and environment, the term "walkability" is used to mean physical access and quality of the path facilitating travel within certain distances (Talen & Koschinsky , 2013; Zook, Lu, Glanz, & Zimring, 2011). Related, Talen, and Koschinsky (2013) define the walkable neighborhood as one that is safe and one that has attractive and vibrant streets, sidewalks, and pathways – factors that contribute to users' enjoyability. Michael Southworth (2005) defines walkability as "the extent to which the built environment supports and encourages walking by providing for pedestrian comfort and safety, connecting people with varied destinations within a reasonable amount of time and effort, and offering visual interest in journeys throughout the network" (Southworth, 2005, p. 248). He suggests six criteria for creating effective pedestrian networks; connectivity, connection with other modes, compact land-use patterns, safety, path quality, and path context.

The health and physical activity literature shows the positive relationship between neighborhoods' physical attributes, such as residential density, aesthetics, street connectivity, well-maintained walking infrastructure, and land use mix and walking (Cervero & Duncan, 2003; Heath, et al., 2006; Saelens B. E., Sallis, Black, & Chen, 2003; Van Cauwenberg, et al., 2012). Leslie and Cerin (2008) found that walkability, safety, and access to destinations were positively associated with aesthetics and greenery, diversity of land uses, street connectivity, walking infrastructure and barriers, safety, access to services, among which safety and walkability were independent interpreters of mental health. Owen et al. (2004) reviewed the health literature to investigate the association between environmental attributes and walking. This review shows that built environment attributes, such as aesthetically pleasing environment, proximity to destinations, sidewalks and trails, and perceptions about traffic are associated with walking. In another study, Cerin et al. (2006) found that different built environment characteristics such as diversity of destinations, aesthetics, and walking infrastructure all support walking.

In comparing physical activity in high-walkability and low-walkability neighborhoods in San Diego, California, Saelens, Sallis, Black and Chen (2003) discovered that residents of high-walkability neighborhoods reported more walking time and higher residential density, land use diversity, street connectivity, aesthetics, and safety in their neighborhood, than residents of low-walkability neighborhoods – although, residents of low-walkability neighborhoods counted more facilities for walking in their neighborhood (Saelens B. E., Sallis, Black, & Chen, 2003). The categorization for high- and low-walkable neighborhoods for this study are derived from the transportation and urban planning research of Saelens et al. (2003). The reviewed studies in this research assessed the environmental dynamics related to walking and cycling, which used actual or reported walking rate as an outcome variable. The result of this review shows that built environment attributes, such as population density, land use diversity, and destination proximity, are positive correlates of walking (Saelens, Sallis, & Frank, 2003).

Furthermore, changes in the neighborhood's walkability promote walking as conventional moderate-intensity activity. People living in neighborhoods that are more compact with higher residential density, better street connectivity, and mix of land uses, walk more. (Frank, Schmid, Sallis, Chapman, & Saelens, 2005; Leck, 2006; Frank L. D., et al., 2006). Residents of these compact walkable neighborhoods report about 30 minutes more walking for transportation each week (Saelens B. E., Sallis, Black, & Chen, 2003) and more total walking (Frank, Schmid, Sallis, Chapman, & Saelens, 2005), compared to those living in less-walkable suburban areas – although the residents of less walkable areas reported better pedestrian infrastructure. The impact of compact urban forms on travel behavior and walking has been studied extensively over the past few decades; however, it is not in the scope of this research.

Additionally, the Wisconsin Pedestrian Policy Plan 2020 defines a walkable community as one that is "thoughtfully planned, designed, or otherwise retrofitted to integrate pedestrian travel into the community's fabric. In a walkable community, walking is considered a normal transportation choice and is not a distraction or obstacle to motor vehicle traffic" (Wisconsin Department of Transportation, 2002, p. 24) It indicates that walkable communities constitute "the goal of any effort to facilitate pedestrian travel" (Wisconsin Department of Transportation, 2002, p. 19). This definition does not only limit pedestrians to people who walk. It defines pedestrian as "any person walking, standing or in a wheelchair" (Wisconsin Department of Transportation, 2002, p. 19). Title 23 of the US Code (USC) defines a pedestrian as "any person traveling by foot and any mobility-impaired person using a wheelchair" (§217), and accommodating wheelchair users in the space is supported and regulated by legislation such as the American Disability Act

(ADA). Besides wheelchair users, people running, shopping, sitting, or working also contribute to streets' livability (Lo, 2009).

In addition to physical attributes, which are extensively reviewed in the literature, policies are another critical factor that supports walking. Policies can affect walkability in different ways. Development, land use, and transportation policies and programs are imperative factors influencing walking behaviors in different neighborhoods. Heath et al. (2006) reviewed the studies related to urban design, land use, and transportation, and travel policies and practices that promote walking (walking, biking, and play). This study found that community-scale and street-scale urban design, as well as land-use policies and practices, encourage walking. Although many policies and programs can be supportive of walkability, they can be a barrier too. Survey results show that although the demand for pedestrian-friendly and mix-use development has increased, zoning and regulations are the main barriers to such developments (Inam, 2002).

While exploring the research for a universal definition for walkability, I found two main groups of definitions. The first group defines walkability in direct terms. In this group, there are definitions that refer to walkability in its basic means, which Forsyth (2015) calls "minimal definition." One example is the definition provided by Talen and Kosinchy (2013), who define walkability as physical access and quality of the path facilitating travel within a certain distance. There is also a more advanced definition which includes different dimensions, similar to the one that Southworth (2005, p. 248) defines: "Walkability is the extent to which the built environment supports and encourages walking by providing for pedestrian comfort and safety, connecting people with varied destinations within a reasonable amount of time and effort, and offering visual interest in journeys throughout the network". The second group of researchers indirectly define walkability. This group's definition, which concerns studying the relationship between walkability and physical activity, and mental health, aligns with Forsyth's (2015) second shared definition option, specific terms. This group mainly focuses on the environmental attributes such as aesthetics, land use diversity, connectivity, and pedestrian infrastructure that support walking (Cervero & Duncan, 2003; Saelens B. E., Sallis, Black, & Chen, 2003; Frank L. D., et al., 2006; Leslie & Cerin, 2008). The common idea between all these definitions is that walkability supports walking. Apart from the attributes that support walkability, as mentioned before, policies that support walkability play an important role in promoting walkability and enhancing walking.

This study uses Forsyth's (2015) third option for neighborhood walkability, which includes policies, programs, and people, as well as environmental attributes that support walking. She suggests developing "a comprehensive definition that moves beyond the kind of physical place that supports walking to also consider policies, programs, pricing and people (demographics, preferences, perceptions and so on)" (Forsyth, 2015, p. 286). This dissertation considers a walkable neighborhood to be those that are aesthetically appealing, adequately connected, provide comfort and safety, offer a diversity of destinations, and support pedestrian activity. The pedestrians in this study refer to all people in the space separate from their purpose (walking, exercise, or shopping), and whether they are standing, sitting or on a wheelchair.

This definition define a walkable neighborhood based on the environmental characteristics and ambience of the place but does not identify geographical scale for such neighborhood. Moudon et al. (2006) summarized the definition of a neighborhood based on theoretical perspectives in the literature. They defined neighborhood as a geographic concept of dynamic place consists of houses and everyday activities with a community center, park or retail services in center that evokes a common sense of a place and have socio-physical uniformity.

Suttles (1972) identified four different geographical measures for neighborhoods. The block face where kids can play without supervision is the smallest neighborhood scale in Suttle's classification. The second category, "defended neighborhood", is an area with a communal identity that is distinguishable from another area. Third is "the continuity of limited liability" and refers to a district that has a local representative. The last category, "expanded community of limited liability" is largest geographical scale and covers a large section of the city. As can be seen, evidently, there is no consensus on definition for a neighborhood. Therefore, this study uses the definition of neighborhood in second geographical scale defined by Suttles (1972) which define neighborhood as a shared identity that is distinct from another area.

To measure walkability in a neighborhood, Zhou et al. (2019) identified three scales; community or point level, neighborhood or area level, and street/segment or line level. The first two are meso-scale and have been used in many studies for measuring walkability extensively (Cervero & Duncan, 2003; Ding, Sallis, Kerr, Lee, & Rosenberg, 2011; Frank L. D., et al., 2006). The meso-scale has limitations for measuring variable at segment level (micro-scale) such as urban design features or sidewalk width. Although data collection in micro-scale studies require more effort for measuring variables in each street segments, the micro-scale study of walkability, provides a unique perspective to pedestrian activity and overcomes the limitations of meso-scales in street segment levels. Many studies used the segment level to measure walkability in recent years (Ewing, Hajrasouliha, Neckerman, Purciel-Hill, & Greene, 2016; Kim, Park, & Lee, 2014; Moura, Cambra, & Gonçalves, 2017; Taleai & Taheri Amiri, 2017). This dissertation takes advantage of micro-scale study of walkability for investigating the pedestrian activity in walkable neighborhoods of Fort Worth, TX. It measures attributes of selected walkable neighborhoods in block-face level and study the relationship between smart neighborhood's characteristics and pedestrian activity.

2.2 Research Concepts

Developing a research concept is an important first step in any research endeavor, which provides a framework for identifying and collecting the necessary data. This section starts with a brief description of creative concepts, what they are, and how to develop such concepts. The information in the next step clarifies the research concept for this study and provides an improved vision of the research subject, and introduces further research opportunities.

Creative concepts introduced by experts is a foundation for starting research. Such concepts introduce creative potentials and new research opportunities to other researchers (Zeisel, 1984). By reasonably expanding such creative concepts, researchers create new hypotheses. For example, hidden dimensions (Hall, 1966) or image of the city (Lynch, 1960) are creative concepts that "giving others images with which illuminate part of the world." The creative concepts are "generating formulas," which provide a considerable amount of information on a subject with a distinct, descriptive concept (Zeisel, 1984). The central concept of this research is "smart walkable neighborhood," which is constructed on the three creative concepts previously explored by experts; smart city, Quality of Life (QoL), and walkability.

The creative concept of "smart city" emerged to solve problems of population increases, particularly in urbanized areas, and to respond to the demand of residents for higher QoL. The concept of a smart city is a generating formula that brings various dimensions such as economy, transportation, and people under the same umbrella. While there is no universal definition for "smart city" in the literature, there is consensus on smart city dimensions, which can serve as starting points for new research. A smart city is one that is conceptualized as digital city, intelligent city, real-time city, green city, and sustainable city (Albino, Berardi , & Dangel, 2015; Finger & Razzaghi, 2017; Harrison & Donnelly, 2011; Hollands, 2008; Kitchin R. , 2014; Komninos, 2006).

The second creative concept, QoL, is a vast concept containing a wide range of contexts that can be individual or regional. It brings environmental quality, physical and mental well-being, social and community activities, personal development, and recreation all together, creating a generating formula (Flanagan, 1978; Pacione, 2003; Van Kamp, Leidelmeijer, Marsm, & De Hollander, 2003).

The last creative concept used in this study is "walkability." Although compared to the two previous concepts, it has a more precise perception or definition and may, therefore, seem a narrower concept, it still includes several attributes and has various sustainability, economic, and health outcomes.

To develop research concepts, Zeisel (1984) suggests two steps; indwelling and using analogies. Indwelling refers to methods for getting familiar with the specifics of different concepts until they are perceived as a coherent whole. Analogies are used for expressing the collected information from the indwelling phase, and consequently forming principles. Constructing on the past experiences and related relationships, analogies help to summarize great bodies of information and identify the gaps in the knowledge. They also help researchers convey the way they visualize data and how the data fit together (Zeisel, 1984).

The two research questions guiding this work relate to the smart city and walkable neighborhood:

1. What is the relationship between neighborhood smartness and the number of pedestrians?
2. Are smarter neighborhoods more walkable?

Although literature helps to develop the research question, the research question defines the boundaries of relevant information and provides the framework for literature review (Blaikie, 2010). The literature review shall deliver information from previous researches (Blaikie, 2010). In order to know more about the smart neighborhood and walkable neighborhood, it is necessary to get familiar with the two broader creative concepts that embrace them. To dive into the literature, this research took a step back and looked at the concepts of smart city and walkability.

Reviewing the smart city literature provides a broad vision toward the concept and how different experts in different disciplines define the smart city. The multi-disciplinary nature of the smart city makes it challenging to have a universal definition; however, there is a unity in the primary goal of the concept and significant similarity between its dimensions in the literature. I review the smart city literature here, by first providing a various definition of smart city, then recognizing the goal of smart city, and finally identifying the smart city dimensions.

A large body of literature has investigated neighborhood walkability and its attributes – namely built environment characteristics and urban design qualities – that support pedestrian activity, highlighting the health benefits of walkable neighborhoods on residents' mental and physical wellbeing. While there is no direct link in the literature connecting the smart city to walkability, QoL serves as an important factor in both fields. QoL is a broad concept, involving aspects from the personal and community levels. However, this research focuses mainly on the physical, mental, and social wellbeing aspects of QoL to construct the relationship between the neighborhood's smartness and its walkability.

Smart city literature identifies enhancing QoL as the primary goal of smart cities (Caragliu, Del Bo, & Nijkamp, 2011; Dameri , 2013; Giffinger, et al., 2007; Nam & Pardo , 2011). The QoL is highly related to the mental and physical health of residents (Flanagan, 1978;

Pacione, 2003; Van Kamp, Leidelmeijer, Marsm, & De Hollander, 2003). At the same time, walkable neighborhoods encourage physical activity and walking as the most accessible and affordable way of exercise, promoting physical and mental health. Studies in walkable neighborhoods have more physical activity than residents in non-walkable neighborhoods (Ding, Sallis, Kerr, Lee, & Rosenberg, 2011; Macintyre, Ellaway, & Cummins, 2002; Roux & Mair, 2010) and they show higher satisfaction of their QoL (Strategies, 2017). Based on the review of the literature related to smart city and walkability, this research identifies QoL as the mutual concept that connects smart neighborhoods and walkable neighborhoods. Figure 2.1 shows the conceptual framework and the creative concepts used in this research.

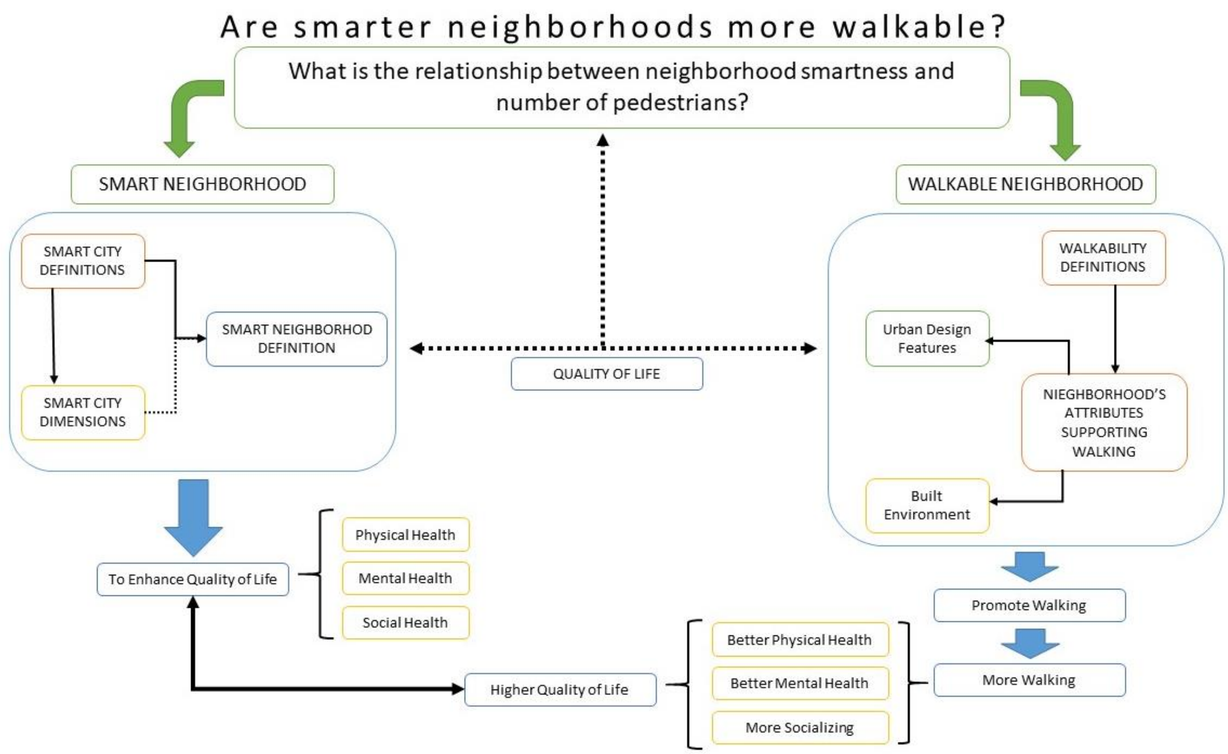

Figure 2.1. The conceptual framework and the creative concepts

Based on this conceptual framework, the next three sections provide a comprehensive review of literature related to the three main concepts identified for this research. The next section reviews smart city literature to define a smart walkability framework and determine smart characteristics of neighborhoods that attract and comfort pedestrians and associated with higher walking and higher QoL satisfaction. This section follows with the QoL literature to construct the relationship between smart city and walkability. The third section reviews the walkability literature and provides a comprehensive description of built environment characteristics and urban design features as the main characteristics of walkable neighborhoods. In addition to these concepts, the next section reviews the literature to identify social and cultural factors important to walkability.

2.3 Smart City Definitions and Dimensions

2.3.1 What is a smart city?

In recent years, the concept of the smart city has become an attractive subject in different layers of society, from residents to officials, professionals, and academicians. The idea of smart city was first introduced in the '80s and '90s after increasing population in urban areas, following the economic boom and technological developments of the last decades of the twentieth century (Cocchia, 2014). The advancement in information technology and communication introduced new ways of recognizing demands and managing services to improve the QoL for residents.

Although the concept of the smart city was first introduced in the last decades of the 20th century, it did not receive much attention from scholars until recently. Reviewing 705 papers related to the smart and digital city by Cocchia (2014) shows that the number of researches in this field has increased since 2010. Researchers in different fields such as transportation, computer science, energy, and urban studies conceptualized smart city as a digital city, intelligent city, real-time city, green city, sustainable city, etc. (Komninos, 2006; Hollands, 2008; Kitchin R. , 2014; Albino, Berardi , & Dangel, 2015; Harrison & Donnelly, 2011; Finger &

Razzaghi, 2017). They tried to define smart city and its dimensions (Bowerman, Braverman, Taylor, Todosow, & Von Wimmersperg, 2000; Coe, Paquet, & Roy, 2001; Giffinger, et al., 2007; Eger, 2009; Harrison, et al., 2010). Table 2.1 shows different definitions of smart cities in the literature, and Table 2.2 shows smart cities' dimensions defined in the literature of the smart city.

As a terminology of smart city, perhaps, Bowerman et al. (2000) provided one of the earliest definitions. They envisioned smart city as a city that uses the latest technology to monitor all components of its infrastructures and incorporate information achieved from sensors and monitoring systems for optimizing resources, maximizing services to its citizens, and enhancing urban management. A significant number of smart city researchers emphasizes the information and communication technology as the core of smart cities. They define smart cities as a sophisticated network of sensors, technologically controlled infrastructures, and connected users and devices which collect data from different sources, integrate and analyze the real-time data to enhance the performance of cities, ecologically, socio-economically, or logistically. (Hollands, 2008; Eger, 2009; Harrison, et al., 2010; Chen, 2010; Chourabi, et al., 2012; Kourtit & Nijkamp, 2012; Kitchin R. , 2014; Finger & Razzaghi, 2017).

Although Information and Communication Technology (ICT) is widely recognized as the core component of smart cities, it does not mean that ICT alone can establish a smart city automatically (Holland, 2008). Neirotti et al. (2014) argue that smart cities aim to optimize the use of both tangible (i.e., built environments, infrastructure, and natural resources) and intangible (i.e., knowledge capital, human capital) urban resources to increase livability and improve QoL. Changes in urban living environments and investments in human capital play an important role in increasing livability and improve QoL (Giffinger & Gudrun, 2010). A comprehensive definition of the smart city includes all digital and non-digital initiatives that work together to improve the QoL for residents. However, such a definition for the smart city includes a wide variety of resources, and a collection of single initiatives creates a smart city (Cocchia, 2014).

Nam and Pardo (2011) conceptualized smart cities as organic associations of technological, institutional, and human factors which brings integration of technologies, infrastructure, services, learning, education, and governance to cities in a new era. According to Coe, Paquet, and Roy (2001), a smart city invests in educating knowledge workers, developing IT skills. It expands IT training in schools and organizations and across different age groups and educational levels. Holland (2008) believes that utilizing new technologies, investing in social and human capital and adoption of smarter communities, practicing neoliberal governance, business-driven developments, and ensuring social-environmental sustainability constitute the core elements of smart cities.

Caragliu et al. (2011) believe that smart cities aim to improve QoL through participatory governance and boost sustainable economic growth by invest in human and social capital as well as IT and transportation infrastructure and smart management of natural sources. They evaluate the smartness of European cities and conclude that smarter cities have better transportation networks and ICT infrastructure and e-governance. Besides, they have a higher number of creative professionals and higher quality of human capital. Caragliu et al. (2011) designed their study based on smart dimension for evaluating smartness of mid-size European cities defined by Giffinger et al. (2007). These dimensions are smart people, smart economy, smart governance, smart mobility, smart environment, and smart living (Giffinger, et al., 2007). Giffinger et al. (2007) emphasize the importance of citizen's educational achievements and training on city's smartness and argue that smart cities are smart combinations of endowments and activities of self-decisive, independent, and attentive inhabitants. Smart cities identify smart solutions to provide premium services to citizens and enhance QoL.

Table 2.1

Definitions of Smart Cities

Source	Definition
Giffinger et al. (2007)	"A city well performing in a forward-looking way in economy, people, governance, mobility, environment, and living, built on the smart combination of endowments and activities of self-decisive, independent and aware citizens. The smart city generally refers to the search and identification of intelligent solutions which allow modern cities to enhance the quality of the services provided to citizens."
Harrison et al. (2010)	"Instrumented, interconnected and intelligent city. A city is connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city.
Nam & Pardo (2011)	"A smart city infuses information into its physical infrastructure to improve conveniences, facilitate mobility, add efficiencies, conserve energy, improve the quality of air and water, identify problems and fix them quickly, recover rapidly from disasters, collect data to make better decisions, deploy resources effectively, and share data to enable collaboration across entities and domains."
Caragliu et al. (2011)	"A city is smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high QoL, with a wise management of natural resources, through participatory governance."
Kourtit et al. (2012)	"Smart cities have high productivity as they have a relatively high share of highly educated people, knowledge-intensive jobs, output-oriented planning systems, creative activities, and sustainability-oriented initiatives."
Dameri (2013)	"A smart city is a well-defined geographical area, in which high technologies such as ICT, logistic, energy production, and so on, cooperate to create benefits for citizens in terms of well-being, inclusion and participation, environmental quality, intelligent development; it is governed by a well-defined pool of subjects, able to state the rules and policy for the city government and development"
Lara et al. (2016)	"A community that systematically promotes the overall wellbeing for all of its members, and flexible enough to proactively and sustainably become an increasingly better place to live, work and play"
The intelligent Community Forum (ICF) (2015-2018)	"Smart City projects make cities work better. They apply information and communications technology to accurately monitor, measure and control city processes, from transportation to water supplies, the location of city vehicles to the performance of electric grids. Smart Cities are about saving money, becoming more efficient and delivering better service to the taxpayer."

2.3.2 Elements of smart cities

In addition to dimensions above of smart cities, several studies define categories and classified these resources and initiatives to provide a better definition for smart cities (Harrison & Donnelly, 2011; Chourabi, et al., 2010; Neirotti , De Marco, Cagliano, Mangano, & Scorrano , 2014). Table 2.2 shows indicators of smart cities in the literature.

Table 2.2

Elements of smart City

Source	Elements of Smart City
Giffinger et al. (2007)	Smart Economy Smart mobility Smart environment Smart people Smart living Smart governance
Holland (2008)	Networked Infrastructure Economy &
Harrison et al. (2010)	Instrumented Interconnected Intelligent
(Nam & Pardo , 2011)	Technology People (Creativity, Diversity, Education) Institutions (Policy & Governance)
Chourabi et al. (2012)	Management & Organization Technology Governance Policy People & Communities Economy Built Infrastructure Natural Environment
Neirotti et al. (2014)	Natural Resources & Energy Transportation & Mobility Building Living Government Economy and People
Cocchia (2014)	Land People Infrastructure Government
The Intelligent Community Forum (2015-2018)	Broadband Creating Knowledge workforce Innovation Advocacy Digital Equity Sustainability

Although there is not any consistency among the definitions or indicators of smart cities, they purportedly create a responsive and livable environment against the backdrop of rapid population growth. Technology and innovation, environmental requirements, economic growth, and social inclusion make up the structure of smart cities.

Kourtit et al. (2012) believe that modern cities with the support of smart and innovative government and engaging creative actors enhance economic viability, QoL, and livability and create new urban cultural space and urban design. The IBM Smarter City initiatives, which mainly focus on the application of Information Technology (IT) in cities, aim to take advantage of technology to make sure that the city's physical infrastructure supports residents' needs for mobility, safety, community (Harrison, et al., 2010). Utilizing technology, investment in human capital and IT infrastructure, and understanding complexities and interconnections between physical environments and social and technical factors are necessities to enhance the QoL cities (Nam & Pardo , 2011).

Neirotti et al. (2014) classified the smart city key elements into six domains and tried to provide a comprehensive understanding of smart city using these domains. They identified thirteen sub-domains and provided a definition for each. Figure 2.2 shows the classification of smart city domains and sub-domains, and their descriptions provided by Neirotti et al. (2014). Then they analyzed the application of these domains in launched projects in 70 cities across the world concerning local economic, demographic, urban, and geographical context. They concluded that local context factors, such as population density, urban context, and economic development, profoundly affect the evolution of smart cities.

Domain	Sub-domain	Description
Natural resources and energy	Smart grids	Electricity networks able to take into account the behaviours of all the connected users in order to efficiently deliver sustainable, economic, and secure electricity supplies. Smart grids should be self-healing and resilient to system anomalies
	Public lighting	Illumination of public spaces with street lamps that offer different functions, such as air pollution control and Wi-Fi connectivity. Centralised management systems that directly communicate with the lampposts can allow reducing maintenance and operating costs, analysing real-time information about weather conditions, and consequently regulating the intensity of light by means of LED technology
	Green/renewable energies	Exploiting natural resources that are regenerative or inexhaustible, such as heat, water, and wind power
	Waste management	Collecting, recycling, and disposing waste in ways that prevent the negative effects of an incorrect waste management on both people and the environment
	Water management	Analysing and managing the quantity and quality of water throughout the phases of the hydrological cycle and in particular when water is used for agricultural, municipal, and industrial purposes
	Food and agriculture	Wireless sensor networks to manage crop cultivation and know the conditions in which plants are growing. By combining humidity, temperature, and light sensors the risk of frost can be reduced and possible plant diseases or watering requirements based on soil humidity can be detected
Transport and mobility	City logistics	Improving logistics flows in cities by effectively integrating business needs with traffic conditions, geographical, and environmental issues
	Info-mobility	Distributing and using selected dynamic and multi-modal information, both pre-trip and, more importantly, on-trip, with the aim of improving traffic and transport efficiency as well as assuring a high quality travel experience
	People mobility	Innovative and sustainable ways to provide the transport of people in cities, such as the development of public transport modes and vehicles based on environmental-friendly fuels and propulsion systems, supported by advanced technologies and proactive citizens' behaviours
Buildings	Facility management	Cleaning, maintenance, property, leasing, technology, and operating modes associated with facilities in urban areas
	Building services	Various systems existing in a building such as electric networks, elevators, fire safety, telecommunication, data processing, and water supply systems. Computer-based systems to control the electrical and mechanical equipment of a building
	Housing quality	Aspects related to the quality of life in a residential building such as comfort, lighting, and Heating, Ventilation and Air Conditioning (HVAC). It includes all that concerns the level of satisfaction of people living in a house
Living	Entertainment	Ways of stimulating tourism and providing information about entertainment events and proposals for free time and night life
	Hospitality	Ability of a city to accommodate foreign students, tourists, and other non-resident people by offering appropriate solutions to their needs
	Pollution control	Controlling emissions and effluents by using different kinds of devices. Stimulating decisions to improve the quality of air, water, and the environment in general
	Public safety	Protecting citizens and their possessions through the active involvement of local public organisations, the police force, and the citizens themselves. Collecting and monitoring information for crime prevention
	Healthcare	Prevention, diagnosis, and treatment of disease supported by ICT. Assuring efficient facilities and services in the healthcare system
	Welfare and social inclusion	Improving the quality of life by stimulating social learning and participation, with particular reference to specific categories of citizens such as the elder and disabled
	Culture	Facilitating the diffusion of information about cultural activities and motivating people to be involved in them
	Public spaces management	Care, maintenance, and active management of public spaces to improve the attractiveness of a city. Solutions to provide information about the main places to visit in a city
Government	E-government	Digitizing the public administration by managing documents and procedures through ICT tools in order to optimise work and offer fast and new services to citizens
	E-democracy	Using innovative ICT systems to support ballots
	Procurement	Allowing the public sector improving procurement procedures and the associated contract management, with the purpose of assuring best value for money without decreasing quality
	Transparency	Enabling every citizen to access official documents in a simple way and to take part in the decision processes of a municipality. Decreasing the possibility for authorities of abusing the system for their own interests or hiding relevant information
Economy and people	Innovation and entrepreneurship	Measures to foster the innovation systems and entrepreneurship in the urban ecosystem (e.g. presence of local incubators)
	Cultural heritage management	The use of ICT systems (e.g. augmented reality technologies) for delivering new customer experience in enjoying the city's cultural heritage. Use of asset management information systems to handle the maintenance of historical buildings
	Digital Education	Extensive Use of modern ICT tools (e.g. interactive whiteboards, e-learning systems) in public schools
	Human capital management	Policies to improve human capital investments and attract and retain new talents, avoiding human capital flight (brain drain)

Figure 2.2. Description of Smart City domains and sub-domains by Neirotti , De Marco, Cagliano, Mangano, & Scorrano (2014, p. 28)

2.3.3 Smart neighborhoods

The literature of smart cities, typically, covers the performance and smartness of the whole city. Combined, cities make smart regions and smart cities' cluster. The Intelligent Community Forum (ICF) (2015-2018) introduced the idea of smart communities. They argue that smart communities can be any size, anywhere, not necessarily only in large cities or technology hubs. In an intelligent community, technology is not the focus, but such communities have "vision-driven, community-based, technology smart solutions" for any problem. Intelligent Communities promote sustainability and emphasize enhancing livability, improving public transportation, air quality, and QoL in neighborhoods and cities while maintaining economic growth (The Inteligent Community Forum, 2015-2018). Lara, Da Costa, Furlani, & Yigitcanlar (2016) consider smart cities as communities that promote wellbeing and work consistently to become better places to live, work, and play.

Informed by the literature, I define smart neighborhoods as a cluster of physical elements such as streets and buildings, government bodies, and people performing in a forward-thinking way. Such neighborhoods have innovative ideas to enhance the quality of life consistently. They take advantage of technological advancement and all resources (social, environmental, infrastructural) and use a collection of technology and non-technology based solutions to provide better services, ensure economic growth, enhance livability and promote QoL. Smart cities consist of several smart neighborhoods.

2.4 Livability & QoL in Walkable Neighborhoods

2.4.1 QoL and physical and mental health

QoL has a wide range of contexts that can be individual or regional. However, the QoL of a community is based on the collective experience of residents and their subjective evaluations of the conditions of the place. For example, residents of walkable neighborhoods show higher satisfaction of the QoL in their neighborhoods, and the preference for living in walkable neighborhoods grew remarkably in 2017, in comparison to previous years (Strategies, 2017). To achieve a higher QoL, a selection of social, economic, and environmental essentials need to be fulfilled (Pacione, 2003).

Physical and mental wellbeing and socializing are the leading indicators of QoL (Flanagan, 1978; Pacione, 2003; Van Kamp, Leidelmeijer, Marsm, & De Hollander, 2003). Several studies investigated the health benefits of walkable neighborhoods and the association between neighborhoods' walkability, physical activity, and higher QoL (Frank L. D., et al., 2006; Sallis, et al., 2006; Sallis, Neville, & Fischer, 2015). Study of different neighborhood types in King County, Washington shows that a 5% increase in walkability is associated with higher physical activity, lower health risks and higher QoL (Frank L. D., et al., 2006).

2.4.2 QoL in walkable neighborhoods

Recent findings in the fields of economy and health show that walkable neighborhoods are vibrant engines of economic growth and health. Residents of walkable neighborhoods show higher satisfaction with the QoL in their neighborhoods. A considerable body of research, in recent years, has recognized the important characteristics of walkable neighborhoods. Surveying 1726 adults in 32 neighborhoods in Seattle, WA, and Baltimore, MD, shows more residents' satisfaction in neighborhoods with a diversity of land uses, the proximity of destinations, attractive aesthetics, and greater pedestrian/ traffic safety (Lee, et al., 2016). Another study in California studied characteristics related to a higher level of neighborhood satisfaction between traditional and suburban neighborhoods. The result of this study shows that the aesthetic attractiveness and safety of the neighborhood are the most important neighborhood characteristics for residents. However, residents of traditional neighborhoods show higher satisfaction (Lovejoy, Handy, & Mokhtarian, 2010). Several pieces of research show the significant association of built environment characteristics such as land use diversity and street connectivity (Cervero & Duncan, 2003; Saelens, Sallis, & Frank, 2003; Saelens & Handy, 2008; McConville, Rodriguez, Clifton, Cho, & Fleishhacker, 2011). The aesthetic attractiveness can be measured with the urban design feature of the neighborhood (Lynch, 1960; Jackson, 2003; Ewing, Handy, Brownson, Clemente, & Winston, 2006; Adkins, Dill, Luhr, & Neal, 2012).

2.5 Built Environment, Urban Design, and Walkability

2.5.1 Built environment characteristics

Researchers in transportation, planning health, and behavioral studies have recognized the influence of neighborhood in the built environment characteristics on the walking behavior of residents. Extensive reviews of literature related to the built environment and walking in past decades show the significant association of density, land use mix, and destination proximity with walking (Saelens & Handy, 2008). Transportation researchers argue that residents of sprawled neighborhoods are less likely to walk compared to those living in a denser neighborhood with greater street connectivity, and the mix of land uses and destinations in proximity (Saelens, Sallis, & Frank, 2003; Cervero & Duncan, 2003; Ewing & Cervero, 2010; Hajrasouliha & Yin, 2015). Such attributes can be seen in traditional neighborhoods with a higher density of residential units, and the diversity of land uses in walkable distances. Besides, the grid layout of traditional neighborhoods provides a direct path from origin to destination. Residents of such neighborhoods that provide a greater mixture of offices and commercial land use in proximity of residential land use walk more (Cervero & Duncan, 2003; Saelens, Sallis, & Frank, 2003).

A meta-analysis of travel and built environment conducted by Ewing and Cervero (2010) shows that walking is highly related to the diversity of land uses. This study also indicates that destination proximity and street connectivity are important built environment characteristics associated with walking. According to the literature, higher density, higher street connectivity, diversity of land uses, and proximity of destinations identify "walkable neighborhoods." Such neighborhoods have better pedestrian infrastructure such as street lighting and continue sidewalk and offer different routing options between two points (Jackson, 2003).

Study of 32 neighborhoods in Seattle, WA, and Baltimore, MD, regions, shows that adults living in high walkable neighborhoods walk 34 to 47 minutes more per week compare to residents of low walkable neighborhoods (Sallis, et al., 2009). In another study in Montgomery County MD, McConville et al. (2011) Surveyed 260 individuals to investigate the relationship between walking and neighborhood land uses. The result shows higher density and diversity of land uses such as offices, retail stores, groceries, and bus stops are positively associated with walking. The important note here is that the majority of articles investigating the association of walking and built environment separated the purpose of walking to walking for transportation and walking for leisure. However, this study does not separate walking based on purpose and focuses on walking in general.

2.5.2 Urban Design Qualities

In addition to gross built environment characteristics, urban design qualities of streets play an important role in promoting walking. Busy streets, pleasant sceneries, trees, and landscaping attract pedestrians (Jackson, 2003; Adkins, Dill, Luhr, & Neal, 2012).

Kevin Lynch (1960) discovered that color, form, and arrangement define the quality of space and make them memorable and distinguishable. He explains that “it is that shape, color, or arrangement which facilitates the making of vividly identified, powerfully structured, highly useful mental images of the environment" (Lynch, 1960, p. 9). This imageability attracts people and provides them with pleasant experiences. Mehta (2014) adds human scale, and enclosure factors to imageability to evaluate the pleasurability of public spaces in Tampa, Florida. Human scale is related to size, texture, and articulation of physical elements that correspond to the size of humans and their walking speed, or pace; enclosure defines the space. It evokes a sense of safety and comfort. It refers to boundaries of space, and the degree to which streets or public spaces are defined by physical elements such as buildings, walls, and edges. Also, complexity refers to diversity and combination of forms and physical elements, ornamentation, and activities define the richness of the environment (Ewing & Handy, 2009; Mehta, 2014).

Using the rating of video clips by an expert panel, Ewing et al. (2006; 2009) identified and operationalized five urban design qualities related to walkability. These qualities include imageability, human scale, enclosure, complexity, and transparency. They provided guidelines to measure each of these qualities based on 20 streetscape features. Using this guideline, the study of 588 street segments in New York City shows that the proportion of the first floor with windows and the proportion of active uses significantly increases pedestrian walkability (Ewing, Hajrasouliha, Neckerman, Purciel-Hill, & Greene, 2016).

However, several neighborhood characteristics make the walking experience pleasurable and not listed in these two main groups, for example, safety supported by video surveillance cameras or extra security officers. Several studies indicate that the feeling of safety and a higher number of video surveillance cameras attract pedestrians and promote walking. On the other hand, in today's smart era, new advancements in technology have been offering cities to recognize the needs and provide smart solutions to improve the QoL for residents.

2.6 Social & cultural factors

In a literature review investigating the relationship between street design and community engagement, Hassen and Kaufman (2016) found that walkability is highly associated with community engagement and social capital. Social capital refers to stronger community relations, higher levels of trust, participation, and belonging among residents. Surveying 750 households in Galway, Ireland, Hassen, and Kaufman (2016) found that residents of walkable mixed-use neighborhoods are more socially involved, more likely to know their neighbors, more likely to trust others, and more likely to have higher political participation compared to those living in the suburbs. As residents of such neighborhoods walk more and are more, they become more and more connected to their community (Leyden, 2003). The results of another study show that neighborhood characteristics and frequency of walking are associated with the frequency and quality of social interactions. The frequency of social interaction is higher for residents of highly walkable neighborhoods with a high level of social cohesion, but residents of ethnic minority neighborhoods walk less (Van Den Berg, Sharmeen, & Weijs-Perrée, 2017).

Neighborhood attributes such as aesthetics, mixed-used-ness, safety, and pedestrian infrastructure have been recognized as characteristics of walkable neighborhoods in the literature (Cervero & Duncan, 2003; Heath, et al., 2006; Saelens B. E., Sallis, Black, & Chen, 2003; Van Cauwenberg, et al., 2012). It must be noted, however, that perception of these attributes might differ depending on people’s relationships with their neighborhoods, as well as on the social, cultural and historical context of the neighborhood (Fullilove, 2001; Ingram, Adkins, Hansen, Cascio, & Somnez, 2017). While studies show that walkable neighborhoods enhance social capital (Leyden, 2003; Hassen & Kaufman, 2016; Van Den Berg, Sharmeen, & Weijs-Perrée, 2017), little is known about the effect of social and cultural factors on perceptions of walkability.

Ingram et al. (2017) used community engagement and qualitative methods to study the perceptions of walkability in the social, economic, and cultural context of five Mexican and American/Mexican neighborhoods in Tucson, Arizona. They found that perceptions of the social environment are more important than the physical environment in encouraging people to walk in the more economically underserved neighborhoods. Drug-related crime, vandalism, homelessness, and stray dogs were the most discouraging social factors for walking in these neighborhoods, while social interactions, youth center destinations, the presence of children, having grown up in the neighborhood, and knowing neighbors were encouraging factors.

Providing the conceptual framework of the relationship between the smart neighborhood characteristics and neighborhood walkability and reviewing literature related to the research concepts, this section provides a theoretical research approach for this study with a brief description of different types of research approaches in the beginning. This section argues that based on the type of research and the research questions, different techniques can be employed to collect information and conduct a study. Definitions of the problem or research questions, researchers' knowledge on the subject, and envisioning the purpose of the research provide a foundation for deciding on the research design and a setting that solves the problem the best (Zeisel, 1984). Based on this description, in the next step, the theory of systems and ecological model related to physical activity are used to explain the relationship between smart city and walkability concepts.

Table 2.3
Social, cultural, and physical factors to be considered in the design of walkable Spaces

Author/s	Cultural, social and physical factors related to walking
(Kitamura, Mokhtarian, & Laidet, A micro analysis of land use and travel in 5 neighborhoods in San Fransisco Bay Area, 1997) (Owen, Humpel, Leslie, Bauman, & Salis, 2004) (Cerin, Saelens, James, & Frank, 2006) (Van Cauwenberg, et al., 2012) (Talen & Koschinsky , The Walkable Neighborhood: A Literature Review, 2013)	Walking infrastructure (Presence of sidewalk, sidewalk quality, and sidewalk continuity)
(Saelens, Sallis, & Frank, 2003) (Cervero & Duncan, Walking, Bicycling, and Urban Landscapes: Evidence From the San Francisco Bay Area, 2003) (Frank, Schmid, Sallis, Chapman, & Saelens, 2005) (Heath, et al., 2006) (Sundquist, et al., 2011) (Vernez Moudon, et al., 2006)	Land-use diversity
(Owen, Humpel, Leslie, Bauman, & Salis, 2004) (Van Cauwenberg, et al., 2012)	Aesthetics and urban design
(Saelens & Handy, 2008)	Destination accessibility
(Frank, Schmid, Sallis, Chapman, & Saelens, 2005) (Sundquist, et al., 2011)	Street connectivity
(Frank, Schmid, Sallis, Chapman, & Saelens, 2005) (Sundquist, et al., 2011) (Vernez Moudon, et al., 2006)	Residential mix
(Vernez Moudon, et al., 2006)	Block size
(Leck, 2006)	Density
(Jackson, 2003; Adkins, Dill, Luhr, & Neal, 2012; Mehta, 2014).	Landscaping and urban design
(Ingram, Adkins, Hansen, Cascio, & Somnez, 2017; Van Den Berg, Sharmeen, & Weijs-Perrée, 2017)	Socio-cultural demographic

2.7 Research Approach

The first steps in researches that focus on users' (pedestrians) activity in an environment (streets of neighborhoods) is understanding the research subject, improving the knowledge of the subject, and understanding different aspects of the subject and their relationships. Zeisel (1984) offers four approaches to research, depending on the purpose of the research: diagnostic, descriptive, theoretical, and action. The diagnostic approach, also referred to as the descriptive approach, helps to develop the knowledge of the subject; it advances the understanding of the organization and dynamics of the whole situation, opening doors to future research in the process. The descriptive approach describes and measures attributes and their relationship to each other in a defined group; in this type of research, developing well-defined concepts and translating them into indicators of the concept is essential. The theoretical approach tests specific hypotheses that originated from a more comprehensive theory or recommended by other experiences. Finally, the action approach which analyses changes in the physical environment or regulations, that may have lasting effects on people beyond those in a research project to improve future actions by understanding earlier.

A theory that can explain this complicated relationship, between smart neighborhoods and walkability concepts, is the system theory. System theory indicates that a system is a complicated collection of interrelating interdependent elements with connected features that perform as a whole to improve the overall performance of the main system. Such systems can be any size with several core systems. In the urban context, a system can be as small as a neighborhood, and a city can be a system of systems (Dirks & Keeling, 2009; El-Shakhs, 1972; Hoover, 1955; Hughes & Mann, 1969). This research endeavors to examine the relationship between smart city and walkability concepts. Grounded on this theory, all elements of a system work together to enhance the performance of the system, which is a neighborhood in this study. In this context, to improve walkability in a smart neighborhood and increase the number of pedestrians, all smart components shall work together to achieve this goal. A smart city is a combination of smart neighborhoods with different characteristics that work together to improve the city's performance.

An ecological model of walking explains this relationship. The ecological model discusses people's interactions with their surrounding physical and socio-cultural environment, and identifies interpersonal environment, internet and technology, social environment, policy and physical environmental factors as important determinants of physical activity, including walking, in people's behavior toward physical activity (Stokols, 1992; Sallis, Neville , & Fisher, 2015).

Sallis et al. (2006) identify safety, attractiveness, appropriate space design, encouraging programs, using social media, physical environment attributes, community engagement activities, and policies supporting pedestrian activities are essential factors in people's physical activity behavior. They developed a multilevel model for these factors, as shown in Figure 2.4. I suggest a similar model for this research based on this model and place variables related to walking in different levels of the ecological model for walking. Based on the system above theory, this model consists of urban design features, physical environment attributes, policies, smartness, and socio-demographic variables. The ecological model for this research is presented in Figure 2.5. The ecological model and system theory are broadly discussed in the next sections.

2.7.1 Systems Theory and System of Systems

A system is a complex of interacting interdependent components with interrelated attributes that perform as a whole (Hughes & Mann, 1969). In this sense, a system can be any size, and for urban areas, a system refers to a large or small city or a small area (Hoover, 1955). Systems can be closed, with no interchangeable relationship with the surrounding environments, or they can be open. The open system is a complex of interrelated elements that communicates with the surrounding environment, affected by the attributes of the environment and affecting, in turn, its environment. However, the open system may change form if the relationship between components or their scope changes (Woldenberg & Berry, 1967). Since urban systems are open, “it is possible to order a city simultaneously in various systems or subsystems depending on their levels of interaction and the common functional connections between their constituent elements” (El-Shakhs, 1972, p. 13) Neirotti et al. (2014) argue that cities today are "complex systems that are characterized by massive numbers of interconnected citizens, businesses, different modes of transport, communication networks, services, and utilities." Dirks and Keeling (2009) enumerate these components as core systems of smart cities, which consist of diverse networks, infrastructures, and environments related to their key functions. They argue that a smart city is a more extensive system consisting of several core systems, emphasizing the organic combination of these core systems, which makes the main system of systems smarter. In other words, system of systems refers to a set of independent core systems with different resources and attributes that work together to create a more complex system with better performance. Based on Dirks and Keeling (2009) and Hoover (1955) theories of system and system of systems, a smart neighborhood is a complex system of systems, consisting of several systems with different sizes and importance which work together to perform better and a smart city is a larger complex system consisting of several smart neighborhoods. Figure 2.3 graphically shows the concept and the relationship between each component based on the theory of system of systems.

This research aims to investigate the relationship between neighborhood smartness and walkability. Based on the theory of systems, all components of a system work together to improve the system’s performance. In this context, to improve walkability in a smart neighborhood and increase the number of pedestrians, all smart components shall work together to achieve this goal. For this study, I used the definition of six smart city domains and their subdomains by Neirotti et al. (2014) to define smart neighborhood characteristics related to walkability. They classify key smart city elements into six domains and their associated sub-domains, and they analyze the application of these domains in launched projects in 70 cities across the world. Figure 2.2 shows Neirotti et al. (2014) smart city domains and sub-domains, and Tables 3.1a and 3.1b show the smart neighborhood characteristics related to walkability.

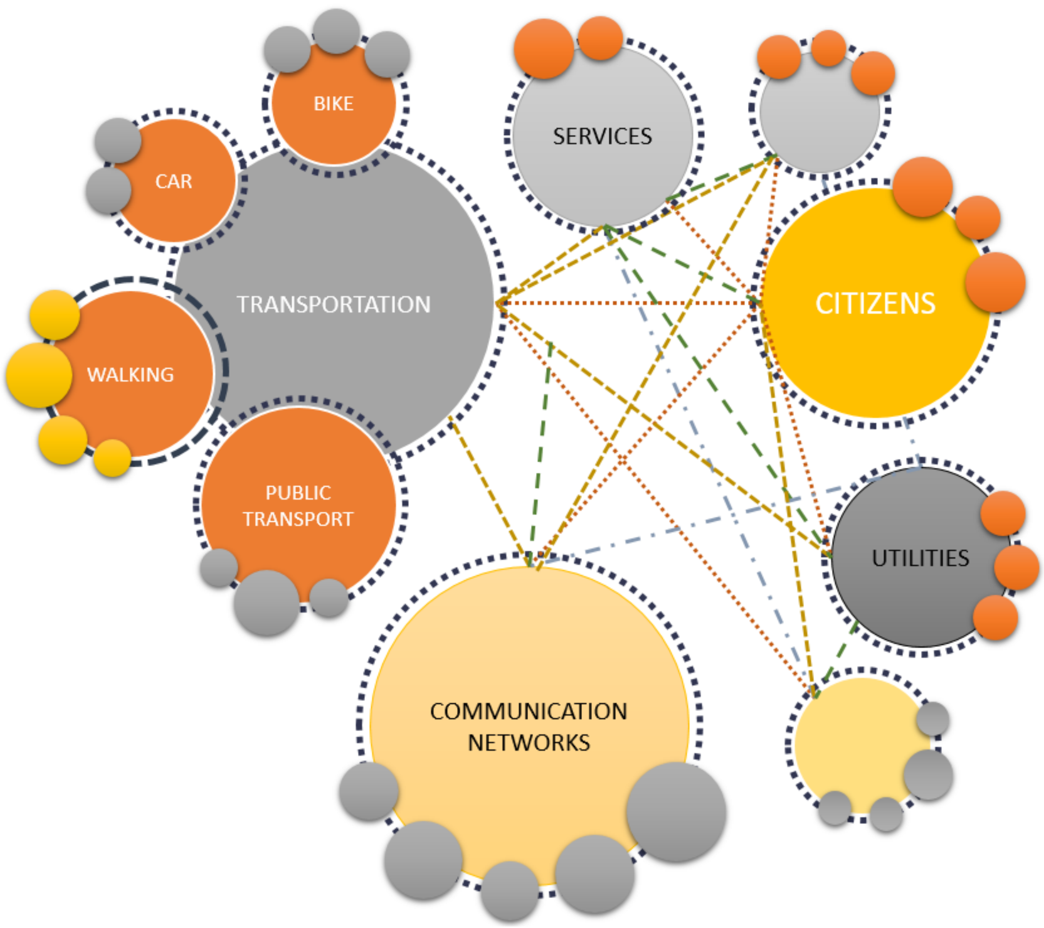

Figure 2.3. Graphical illustration of smart city concept and the relationship between each component based on theory of system of systems

2.7.2 Ecological model for physical activity

In recent years, the ecological model has been widely used to understand people's routine behaviors, such as physical activity. The physical environment is widely recognized as an important factor that influences physical activity, including walking. The ecological model refers to people's interactions with their surrounding physical and socio-cultural environment and recognizes the importance of various factors, including policy and environmental factors in people’s behavior toward physical activity (Stokols, 1992; Sallis, Neville , & Fisher, 2015). The core of the ecological model is that various factors in different levels influence behavior, and all levels of influence and intervention are important. Although this model does not recognize the variables themselves, it does stress the better performance of multi-levels in explaining behavior (Sallis, Neville , & Fisher, 2015). For physical activity, the ecological model identifies groups of factors that influence physical activity behavior in different levels: intrapersonal, which refers to biological and psychological factors, interpersonal and cultural, organizational, natural and built physical environment, and policy. This last group of factors has to do with the effects of laws, rules, regulations, and codes on physical activity (Sallis, et al., 2006). Sallis et al. (2006) recognize three main characteristics of influential interventions based on the ecological model. They state that great interventions shall “ensure safe, attractive, and appropriate places for physical activity, and implement motivational and educational programs to encourage the use of those places and use mass media and community organization to change social norms and culture” (Sallis, et al., 2006, p. 299)

In addition to their definition regarding the ecological model, Sallis et al. (2006) also developed a multilevel model to introduce key factors associated with physical activity based on the active living domains, as shown in Figure 2.2 below. The active living domains are active transport, active recreation, household activity, and occupational activity, all of which, except the last, are related to pedestrian facilities and walkability of the environment. In their model of concentric circles, the intrapersonal level is located in the center and consists of psychological, biological, demographics, and family situation factors. The next level is the perceived environment, including safety, attractiveness, comfort, convenience, and accessibility. In this model, the perceived environment also refers to the social and cultural environment, which includes factors such as perceived crime, interpersonal factors, and social support. The characteristics of the environment are at the next level. The attributes for previous levels were common to all active living domains; however, at this level, important factors are different for different domains. The characteristics of the environment at this level also include the information environment and the natural environment. The information environment identifies social media, news, and advertisements related to a specific setting, and information sources about activities as important factors associated with active living. Also, weather, air quality, and open space are important natural factors at this level.

The last level in Sallis et al.'s (2006) model is the policy environment, which is also categorized according to the type of activity and active living domain. For example, for active transport, walkability and pedestrian facilities are important environmental factors and are related to development regulations and transport investments in the policy environment level. Based on the ecological model related to physical activity, the policy environment relation with the information environment includes media regulations and in the natural environment includes transportation and land-use policies. Figure 2.4 shows the Ecological model of active living developed by Sallis et al. (2006).

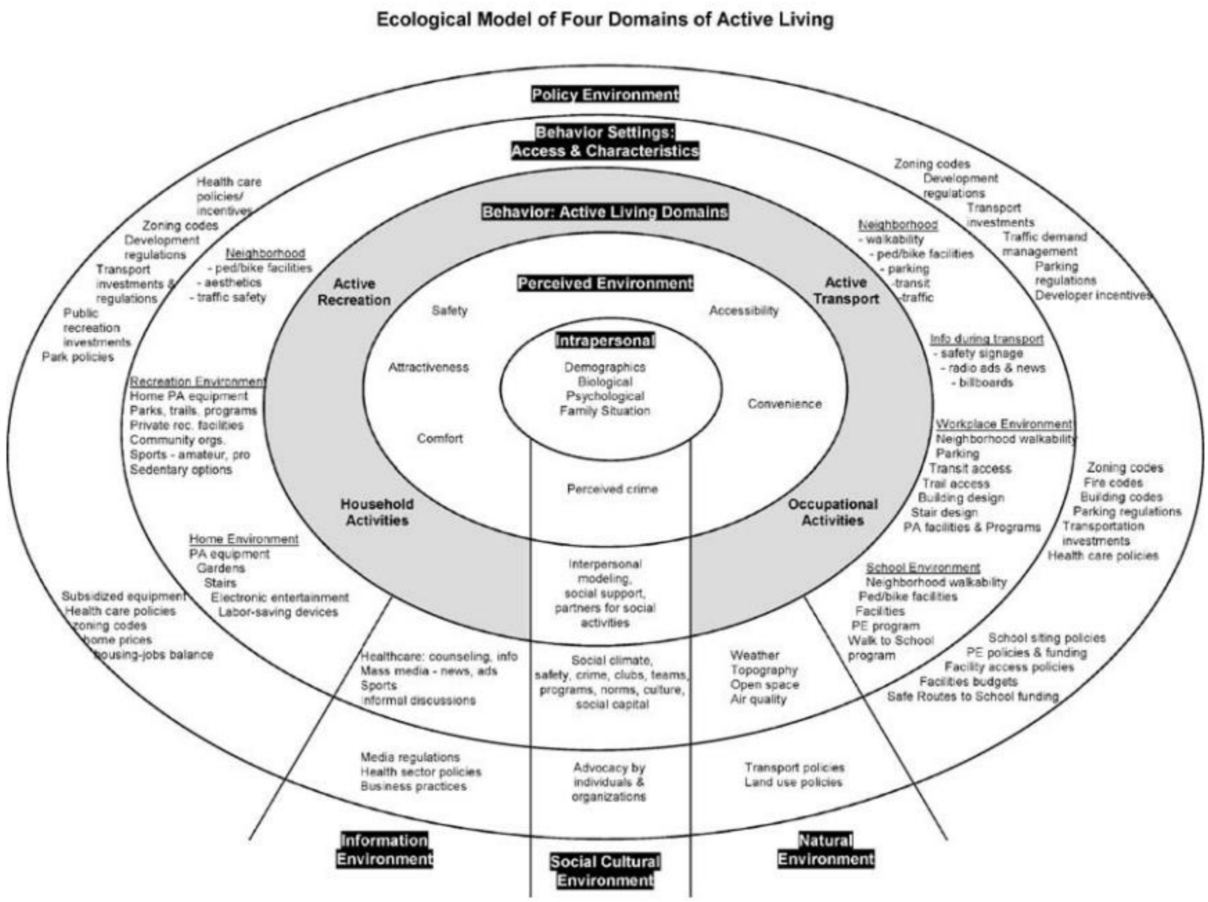

Figure 2.4. Ecological model of active living developed by Sallis et al. (2006, p. 301)

The ecological model can be applied to this research. The built environment, urban design qualities, and smart neighborhood characteristics related to walkability can be categorized into different layers. Figure 2.5 shows the ecological model of smart neighborhood characteristics related o walkability. In this figure, the smart neighborhood characteristics supporting pedestrian activity are shown in black ink and italics. Factors labeled in white ink refer to other physical environment attributes related to walkability. These factors – intrapersonal, environment attributes, policy environment, technology and internet, social and natural environments – are divided into different layers within the ecological model.

Overall, this model shows how smart neighborhood characteristics can be added to different layers of factors supporting pedestrian activity. As mentioned earlier, neighborhoods are complex systems of multiple factors interacting with each other and with their host environment. The incorporation of all components enhances the performance of the neighborhood in terms of supporting pedestrian activity and improve the neighborhood's walkability. Accordingly, this research aims to show that the existence of different smart elements is important for enhancing walkability.

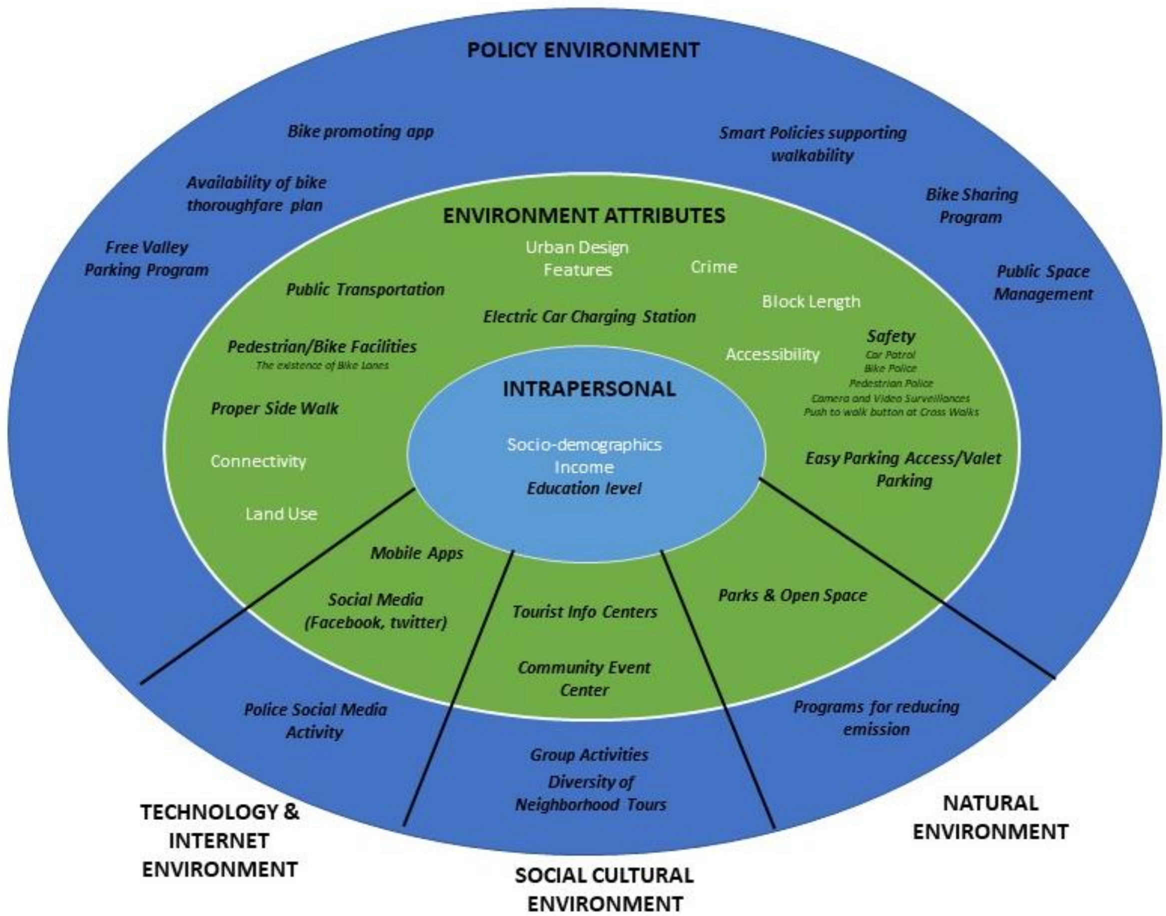

Figure 2.5. Ecological Model of Smart Neighborhood Characteristics Related to Walkability

2.7.3 Other Theories and Empirical Evidence

2.7.3.1 Human capital theory

The human capital theory was first introduced in 1960 by Theodore Schultz. Human Capital Theory emphasizes the role of individuals in economic vitality and refers to a collection of competencies, knowledge, social, and personal attributes. The human capital theory is extensively discussed in innovation, policy, and education research (Blaug, 1976; Sweetland, 1996). Studies identified human capital as an essential factor in smart cities. According to Coe, Paquet, and Roy (2001), a smart city invests in educating knowledge workers, developing IT skills, training and expanding IT training in schools and organizations, all across different age groups and educational levels. Holland (2008) believes that utilizing new technologies, investing in social and human capital, adopting smarter communities, practicing neoliberal governance, encouraging business-driven developments, and ensuring social-environmental sustainability, together constitute the core elements of smart cities. Kourtit et al. (2012) argue that "Smart cities have high productivity as they have a relatively high share of highly educated people, knowledge-intensive jobs, output-oriented planning systems, creative activities, and sustainability-oriented initiatives" (2012, p. 232). Based on the human capital theory, education are tested in the model as a smart neighborhood variable in the model.

2.7.3.2 Human ecology theory

This theory considers the relationships between people and their environments as a system of biological, social, and physical attributes of the environment. This theory was first introduced in the "1960s with the increased awareness of the interdependence of human actions and environmental quality and with interest in viewing phenomena from holistic and systems perspectives." (Bubolz & Sontag, 2009, p. 419). One of the questions suggested by Bubolz and

Sontag (2009) is to identify the application of this theory refers to activities and attributes that create and enhance environmental performance and quality of life for people. Built environment characteristics, urban design qualities, and social and socio-demographic attributes are widely recognized as important factors in neighborhood walkability. Studies show that the relationship between neighborhood's built environmental such as aesthetics, street connectivity, well-maintained walking infrastructure, safety, density, destination proximity mixed land use mix and walking (Cervero & Duncan, 2003; Heath, et al., 2006; Leslie & Cerin, 2008; Saelens & Handy, 2008; Saelens B. E., Sallis, Black, & Chen, 2003). In addition to gross built environment characteristics, urban design qualities of streets play an important role in promoting walking. Busy streets, comfort, human scale, imageability, pleasant sceneries, trees, landscaping, and similar attributes attract pedestrians (Adkins, Dill, Luhr, & Neal, 2012; Jackson, 2003; Lynch, 1960; Mehta, 2014). The human ecological theory helps to explain the relationship between the socio-cultural, built environment, and urban design qualities and walkability, and these variables were tested in the model.

2.7.3.3 Diffusion of innovative theory

The diffusion of innovation emerged in the 1960s to facilitate and expedite the adoption of innovative ideas that work to improve the performance of a social system. The diffusion refers to the process by which an innovation is defined as a shared public understanding and communicated and between elements of a social system. Diffusion is a form of communication with some degree of uncertainty due to the newness of the innovation idea. This uncertainty shows a lack of information, predictability, and structure. Diffusion as social change refers to changes in the structure and function of a social system due to innovative ideas that are adopted or rejected in a social system (Rogers, 2010). Rogers (2010) identified four elements in diffusion of innovation: innovation which refers to new ideas or object, communication channels refers to ways that users share information and communicate, time and social system which refers to a series of interconnected elements that collaborate to achieve a shared goal (Rogers, 2010). This theory can explain the new innovative ideas that work together to enhance the quality of life. Several smart city elements are identified in Table 2.2 based on the literature. Neirotti et al. (2014) defined these elements as provided in Figure 2.2, and this study constructs the smart neighborhood characteristics on these definitions, as shown in Figure 3.5a and Figure 3.5b.

Chapter Three – Methodology

This dissertation combines qualitative and quantitative methods for studying the relationship between smart neighborhood characteristics and neighborhood walkability. This chapter provides details on the selection of study areas, defining variables, methods of data collection, and data analysis. It starts with research design and how different components are connected. This section follows by study area and description of streets in the study area. The qualitative method is explained in the next section, and the quantitative methods used for data collection and analysis are discussed in the next section. This section provides a detail explanation of how measurements of neighborhood's smartness, urban design qualities, built environment characteristics and socio-economics, and demographics based on a review of literature and survey results. Expected results are provided in the last section of this chapter.

3.1 Research Design

Based on the type of research and the research questions, different techniques can be employed to collect information and conduct a study. Definitions of the problem or research questions, researchers' knowledge on the subject, and envisioning the purpose of the research provide a foundation for deciding on the research design and a setting that solves the problem the best (Zeisel, 1984).

The research design for this project aimed to provide a comprehensive understanding of the relationship between smart neighborhood characteristics and walkability. It also intended to emphasize the importance of users' perception of smart walkable neighborhoods. The qualitative section of this research acquires users' perception of the smart walkable streets. It identifies walkable streets in different neighborhoods of Fort Worth, TX, as the study area to be used in the quantitative section. The quantitative section collects the built environment, urban design, and smart neighborhood characteristics related to walkability and statically investigates the hypothesis for this dissertation. The mixed-method and concurrent triangulation approach are selected to combine the results of the qualitative and quantitative techniques.

3.1.1 Mixed-Method

The mixed-method research combines quantitative and qualitative approaches to create an effective and efficient research method to answer a research question in a single study. The mixed-method incorporates the strengths of quantitative and qualitative methodologies by using both techniques in the same framework. Knowing that all methods have limitations, in the the mixed-method, the result from one method can help to determine the other method or one method can be nested in the other method. Creswell (2003) identifies three mixed-method strategies – sequential procedure, concurrent procedure, and transformative procedure.

Sequential procedure – in which the researcher seeks to explain or develop the findings of one method with another method. In this procedure, the research starts with a qualitative method for exploratory purposes and continues with quantitative methods for generalizing the results or the other way.

Concurrent procedure – in which the researcher converges the qualitative and quantitative data to analyze the problem comprehensively. In this technique, the researcher collects qualitative and quantitative data at the same time during the study and interpret the overall result after integration of the data.

Transformative procedure – in this method, the researchers use the theoretical lens, which provides a framework for topics of interest, methods of data collection, and analysis. The data collection can be in sequential and concurrent approach.

This research uses the concurrent triangulation approach. In this method, the researcher combines the two methods to confirm or validate the findings. This model uses qualitative and quantitative methods separately to conquer the limitations of one method with the strength of the other one. The data collected in this approach is concurrent, but the priority might be given to either one depending on the practical application. In this technique, the researcher integrates and interprets the results of both models. This convergence strengthens the knowledge claims of the study.

In addition to the mixed-method approach, this study looked at the research design from a different angle. Zeisel (1984) offers three types of research design: case study, surveys, and experiments. Figure 3.1 shows the research design for this dissertation.

3.1.2 Case Study

A case study is a comprehensive study of a single case that emphasizes the uniqueness of the participants and the setting (Sommer & Sommer, 2001). In the case studies, researchers define a subject and study the subject's relationships with influencing factors through the use of various methods such as observation, analysis of physical traces, and recording of data to get adequate information about the different aspects of the subject (Sommer & Sommer, 2001; Zeisel, 1984). In case studies researchers focus on information specific to the particular subject, which may not be generalizable unless the topic has been studied before and some theories exist, or conditions of, studies are similar (Zeisel, 1984).

This dissertation focuses on the walkability in Fort Worth, TX, as a growing large city in the U.S. with a car oriented urban environment, which has nearly one million population. The results of this study apply to different cities in the same size and same urban context. Section 3.4 explains the study area comprehensively.

3.1.3 Survey

Surveys help to find more details about a phenomenon and categories or classes in a diverse group that is dispersed around various geographic areas. Researchers use surveys to collect quantifiable data to supplement data from questionnaires and interviews. Such desired quantifiable data can be collected through observations and counting traces or behaviors. It is essential in survey research design to focus on the main topic and avoid distracting questions; it is also important to carefully select sample size, population size, and sampling methods to make the quantifiable data generalizable to a larger population (Zeisel, 1984).

This study uses the users' preference survey, which is comprehensively explained in section 3.3 of the methodology for qualitative methods.

3.1.4 Experiment

Experiments help to investigate the effects of an action in a precise situation and compare it with similar situations. They focus on a few attributes at a time while controlling for various factors to make sure that the result is due to changes in targeted attributes, and not from other factors. Basically, the control facilitates attaining experimental knowledge based on understanding differences, and the control group is the group that action is not taken or before the action takes place (Zeisel, 1984). Sommer and Sommer (2001) identify three types of experiments: true experiment, quasi-experiment (also referred to as or natural experiment), and single-subject experiment.

The experiment section of this study tests the hypothesis using the Negative Binomial Regression model. This model includes smart neighborhood characteristics, urban design qualities, built environment and socio-economics, and demographic variables to study the relationship between smart neighborhood characteristics and walkability. Section 3.3 of the methodology for quantitative methods explain extensively details related to the data collection and model for this study.

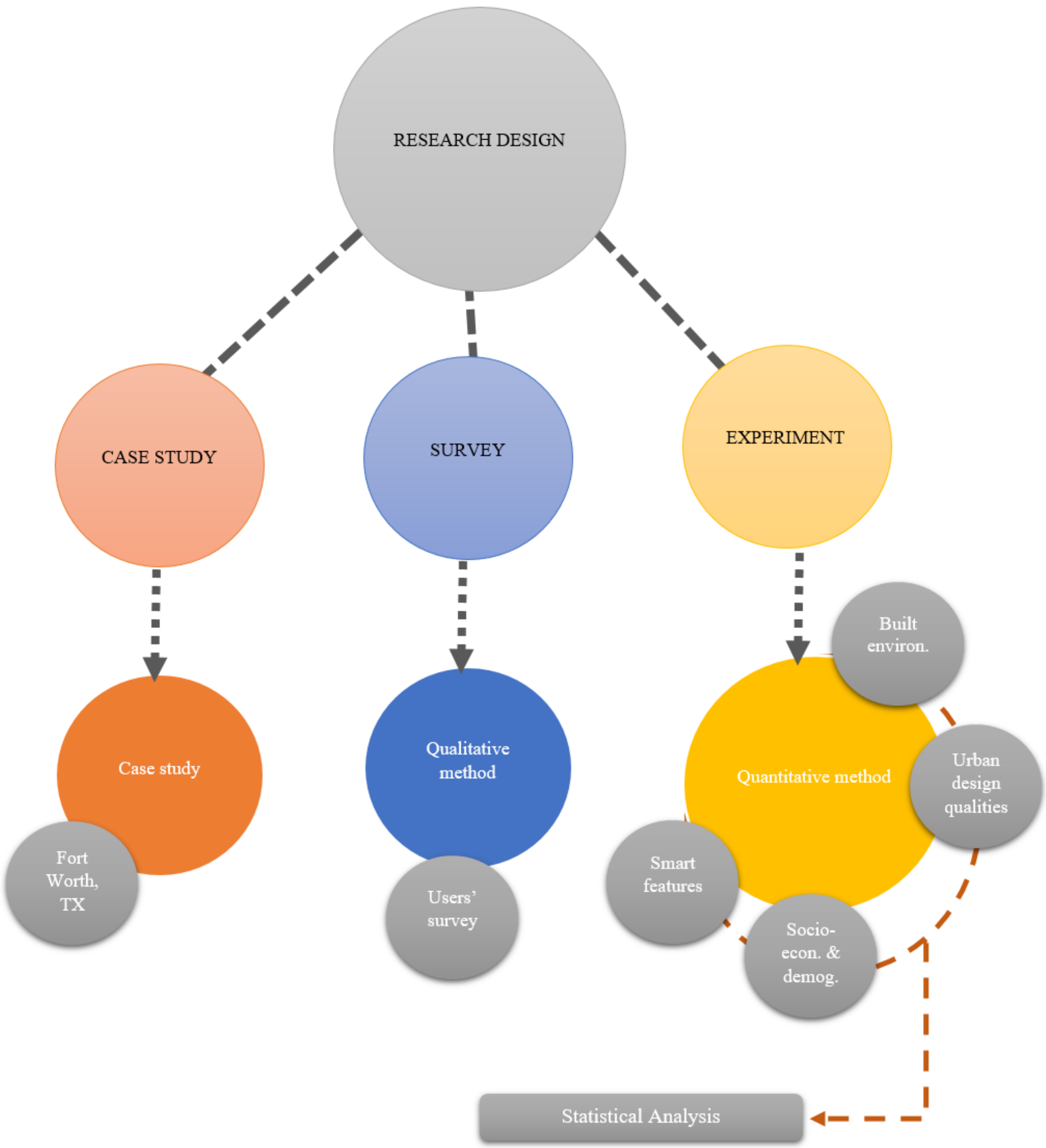

Figure 3.1. Research Design

3.2 Qualitative Approach

The qualitative research focuses on understanding humans' experiences and reflections about those experiences (Jackson II, Drummond, & Camara, 2007) and aims to understand precise social phenomenon (Creswell, 2003). Newman, Benz, and Ridenour (1998) say that "the qualitative approach is used when observing and interpreting reality to develop a theory that will explain what was experienced." A users' preference survey is designed as the qualitative method for this study. It aims to investigate the perceptions and experiences of users of walkable streets in Fort Worth, TX. As this survey directly communicates with the general public and is so-called a human-related subject, it requires the University of Texas at Arlington (UTA) Institutional Review Board's (IRB) review and approval. The IRB protocol has submitted with the required documents, reviewed, and approved by the IRB board. The consent letter issued by the UTA IRB board was provided to surveyors before the beginning of the survey.

3.2.1 Users' Preference Survey

Surveys help to find more details about a phenomenon and categories or classes in a diverse group that is dispersed around various geographic areas. Researchers use surveys to collect quantifiable data to supplement data from questionnaires and interviews. Such desired quantifiable data can be collected through observations and counting traces or behaviors. It is important in survey research design to focus on the main topic and avoid distracting questions; it is also important to carefully select sample size, population size, and sampling methods to make the quantifiable data generalizable to a larger population (Zeisel, 1984).

This survey is a volunteer-based anonymous preference survey that is designed in three sections – main, more in-depth, and general questions. This survey consists of 13 questions from which 8 is the open-ended question. The main section asks surveyors about their familiarity with the city of Fort Worth and asks them to select three walkable streets in Fort Worth. The result of this section will determine the study areas for this study. The second section asks for more in-depth questions. The four questions in this section are open-ended, asking about the specific characteristics of the selected walkable streets. This section also asks volunteers to describe what smart walkable neighborhood means to them and what they think are the smart characteristics related to walkability.

The questions in the main section are as follow:

- How familiar are you with the City of Fort Worth?
- Do you live or work in Fort Worth?
- How long have you been living in Fort Worth?
- Have you ever walked around Fort Worth?
- Name three streets (street segments) in Fort Worth that are most walkable to you?

The questions in the second section are as follow:

- What specific characteristics have made these streets walkable?
- What do you think the City of Fort Worth has done to facilitate walking for residents?
- What technology-based initiatives do you think can help to increase walkability?
- Do you know if the city has used any of these technologies to attract pedestrians or increase walkability in your selected streets?

The questions in the third section are as follow:

- What type of neighborhood do you currently live in?
- What are your top reasons for choosing this location to leave?
- How do you go to work?
- Additional thoughts?

Before starting the survey, a letter of IRB approval was presented to respondents. Then a brief description or presentation clarifies the meaning of the walkable neighborhood and smart neighborhood for participants.

3.3 Quantitative methods

Quantitative research has been used in numerous studies. The quantitative research approach offers detailed measurement and data. Quantitative research deals with quantities and data classification and constructs statistical models to explain observations statistically. The quantitative approach tests a hypothesis for confirmation or disconfirmation (Newman, Benz, & Ridenour, 1998). It systematically and scientifically investigates the data and the relationship between a dependent variable and independent variables. There are two types of Quantitative research designs – descriptive and experimental. The descriptive approach which establishes and measures the relationship between the variables once. The experimental establishes causality and subjects are measured before and after an event.

The quantitative methods for this study consist of three sections. The first section identifies the independent variables and provides a description and data collection methods for each variable. The second section defines the dependent variable and explains the method for collecting this data. The last section explains the method used for analyzing the data and test the hypothesis.

3.3.1 Independent Variables

The independent variables in this study are in four different categories: smart neighborhood characteristics, urban design qualities, built environment characteristics, and socio-economics and demographics. While the smart neighborhood characteristics are the tested factors in this study, the other three groups, urban design qualities, built environment characteristics, and socio-economics and demographics, are the control variables. The variables in each group are selected based on the literature related to walkability and smart city and data availability. This data is collected from the study areas and secondary sources and computed using different tools such as GIS (Geographic Information System by Environmental Systems Research Institute (ESRI)), Google Maps, and site observations.

This section provides an extensive description of variables, data collection techniques, and data sources. It starts with smart neighborhood characteristics and follows with urban design qualities, built environment characteristics, and socio-economics and demographics. Table 3.3 shows the independent variables for this study in table format. It also includes a brief description for each variable, their data source, and the level for each variable.

3.3.1.1 Smart neighborhood Characteristics

The smart neighborhood characteristics for this research are in two categories: smartness score system and direct impact. The idea behind the smart score system is that based on the demands and type of services in each neighborhood, different smart features can be defined under each smart city initiative, and not all neighborhoods necessarily have the same smart characteristics. Instead, a collection of smart characteristics work together to support smarter neighborhood, which provides better services, is more vibrant and livable and has a better QoL.

All smart neighborhoods have similar smart characteristics, and not all of them support the same demands. This study aims to identify smart characteristics in walkable neighborhoods and explore the impact of the combination of them on higher pedestrian activity. To achieve this, it defines smart neighborhood characteristics related to walkability based smart city domains and subdomains described by Neirotti et al. (2014), provided in Figure 2.2.

As broadly discussed in the previous chapter, Neirotti and his team (2014) used these domains to verify impactful smart city elements by analyzing launch projects in numerous cities. Each study area is evaluated based on the number of smart characteristics it has, and the final smart score is some of all smart characteristics each street has (max. 28). Tables 3.1a and 3.1b summarize details of smart neighborhood characteristics related to walkability and maximum score available for each smart characteristic. The maximum achievable score for each street is 28. The total score for each street is included in the final model. The important note for all data collected in this section is that all searches for this information are based on the main study areas: Magnolia St., Main St., W 7th St., and Exchange St. Here is the extended description for each smart neighborhood characteristic related to walkability:

Public Lighting – which is under natural resources and energy domains, refers to public lighting fixtures that have more than one function (illuminating the space). These lights can adjust the intensity of light, provide Wi-Fi connectivity, accommodate air quality, or weather sensors, which report real-time information to the centralized management system.

Info Mobility – is a sub-domain of transportation and mobility. It focuses on the information platforms that provide pre-trip and on-trip information to improve the quality of the transportation system and reduce traffic. Based on this definition, four platforms were identified that provide information about walking and biking. These websites were identified by google searching the phrase “walking in Fort Worth." The literature for non-motorized means of travel recognizes biking facilities as an indicator of walkability (Yun , Zegras , & Heriber, 2019).

People Mobility – is another sub-domain of transportation and mobility, which concentrates on the innovative and sustainable ways of people's mobility and encourages alternative modes of transportation and environmentally friendly fuels. Several site observations and reviews of literature related to an environmental-friendly transportation system that matches the objectives of this sub-domain identified existence of bike lane, free neighborhood valley parking, and car charging stations as smart features for this section. Each study area achieves 1 point for each of these characteristics.

Entertainment – is a part of the living domain (Neirotti , De Marco, Cagliano, Mangano, & Scorrano , 2014). This sub-domain focuses on the information platforms specialized in events, tourism, entertainment, and nightlife. Based on this definition, this study identified major platforms that publicize the local events, tourist information centers, community event center. Each study area achieves 1 point for each of these characteristics. This section also includes apps and social media activities in each street that announce events or provide information. Each street gets one point for activity in apps, Facebook, Twitter, and other websites up to 4 points. Each street also can get up to 3 points if it has different neighborhood tours: scooter tours, walking tours, and carriage tours. Diversity of events is another factor in the entertainment sub-domain. It consists of movie night, neighborhood music concerts, sports events, and art events and can increases the smart score for each street up to 4 points.

Public Safety – is another section in the living domain. Safety is one of the concerns of pedestrians for choosing streets to walk. This section divides police force to bike police, pedestrian police, and police car and each street gets 1 point for each type of these police forces. Police active involvement in social media for announcements and information update brings one more point for each street. The maximum score for this section is 4.

Public Spaces Management – is a part of the living domain. Pubic space management and maintenance is the core subject of this section. It includes platforms that provide information about places to visit.

Transparency – is a sub-domain of governance domain, which focuses on the transparency of government and accessibility of official documents and decision processes of municipality. This section includes transparency of the City of Fort Worth regarding their programs and future developments for promoting walking in Fort Worth.

The second category of smart neighborhood characteristics is direct impacts. These variables were tested directly in the model. As discussed in the previous chapter, smart cities emphasize human capital, education, learning opportunities, and information. This study includes several human capital and education-related variables in the model. Education attainment is obtained from the American Community Survey (ACS) and refers to the percentage of each education level in the quarter-mile buffer around each street. ESRI Business Analyst provides number of libraries, number of information related businesses, and educational opportunities in the study areas. The educational opportunities refer to the number of education facilities in the area.

The list of smart neighborhood characteristics related to walkability, their description, and data sources is provided in Table 3.3.

Table 3.1a

Smart Neighborhood Characteristics related to walkability based on definitions by Neirotti et al. (2014) - Part one.

Smart Neighborhood Characteristics Related to Walkability				
Domains, Sub-Domains & Descriptions by Neirotti et al. (2014)		Smart Characteristics	Details	Score
Natural Resources & Energy				Yes = 1 No = 0
Public Lighting	"Illumination of public spaces with street lamps that offer different functions, such as air pollution control and Wi–Fi connectivity. Centralized management systems that directly communicate with the lampposts can allow reducing maintenance and operating costs, analyzing real-time information about weather conditions, and consequently regulating the intensity of light by means of LED technology"			Max.: 1
Transport and Mobility				
Info-Mobility	"Distributing and using selected dynamic and multi-modal information, both pre-trip and, more importantly, on-trip, with the aim of improving traffic and transport efficiency as well as assuring a high quality travel experience"	Walking in Fort Worth https://www.active.com/fort-worth-tx/walking	Announcing walking events in Fort Worth	Max.: 1
		NCTCOG, Try Parking It Program. www.tryparkingit.com	Reducing emission, alternative transportation solutions, reward program for attracting users to use alternative transportation such as ride-share, biking, and walking	Max.: 1
		Bike Sharing Program https://fortworthbikesharing.com/	Encouraging alternative transportation, bike sharing information, bike stations, bike routes	Max.: 1
		Bike thoroughfare plan https://fortworth.bcycle.com/printable-map	Encouraging alternative transportation, bike routes bike sharing information, bike stations	Max.: 1
People Mobility	"Innovative and sustainable ways to provide the transport of people in cities, such as the development of public transport modes and vehicles based on environmental-friendly fuels and propulsion systems, supported by advanced technologies and proactive citizens' behaviors"	Bike Lanes		Max.: 1
		Free Valet Parking Program		Max.: 1
		Car Charging Station		Max.: 1
			Max. Score	8

Table 3.1b
Smart Neighborhood Characteristics related to walkability based on definitions by Neirotti et al. (2014) - Part two.

Smart Neighborhood Characteristics Related to Walkability				
Domains, Sub-Domains & Descriptions by Neirotti et al. (2014)		Smart Characteristic	Details	Score
Living				Yes = 1 No = 0
Entertainment	"Ways of stimulating tourism and providing information about entertainment events and proposals for free time and night life"	Tourist Information Center		Max.: 1
		Visit Fort Worth https://www.fortworth.com/	A comprehensive guide to events, things to do, hotels, restaurants and so on.	Max.: 1
		Social Media Activities	Apps Facebook Twitter Other Website	Max.: 4
		Diversity of Neighborhood Tours	Scooter Walking Carriage	Max.: 3
		Diversity of Events	Movie Nights Neighborhood Concerts Sport Events Art Events	Max.: 4
		Community Event Center		Max.: 1
Public Safety	"Protecting citizens and their possessions through the active involvement of local public organizations, the police force, and the citizens themselves. Collecting and monitoring information for crime prevention"	Police Force	Bike Police Pedestrian Police Police Car Police Social Media Activity	Max.: 4
Public Spaces Management	"Care, maintenance, and active management of public spaces to improve the attractiveness of a city. Solutions to provide information about the main places to visit in a city"	Visit Fort Worth https://www.fortworth.com/	A comprehensive guide to events, things to do, hotels, restaurants and so on.	Max.: 1
Government				
Transparency	"Enabling every citizen to access official documents in a simple way and to take part in the decision processes of a municipality. Decreasing the possibility for authorities of abusing the system for their own interests or hiding relevant information"	Walk Fort Worth http://fortworthtexas.gov/walkfw/	Policies, programs, and future developments for increasing walkability, ensure safety and convince, and promoting walking in Fort Worth	Max.: 1
			Max. Score	20

3.3.1.2 *Urban Design Qualities*

This study measured the urban design features in each block face. The block face is one side of the street between two intersections when the block is on the right side, and the street is on the left side. To measure urban design qualities, this study uses the methodology developed by

Clemente, Ewing, Handy, & Brownson (2005) for measuring the urban design qualities prepared for the Active Living Research Program of the Robert Wood Johnson Foundation. The urban design qualities measured by this method are imageability, transparency, human scale, enclosure, and complexity. These urban design qualities were quantified and operationalized by evaluating and rating of more than 200 video clips from 22 cities in terms of 20 urban design features (Ewing, Handy, Brownson, Clemente, & Winston, 2006). Table 3.6 identifies the urban design qualities, their descriptions, and features. The observational protocols of the report by Clemente, Ewing, Handy, & Brownson (2005) and the final publication of the original research project (Ewing, Handy, Brownson, Clemente, & Winston, 2006) are the base for several researches and field manuals for measuring urban design qualities and is available on the website of Active Living Research (ALR). The (ALR) website provides tools and field manual for measuring urban design qualities based on this method. The urban design features of each block face are measured manually in the field, and five urban design qualities are computed and tested in the model.

Table 3.2
Urban design features related to walkability (Clemente, Ewing, Handy, & Brownson, 2005; Ewing, Handy, Brownson, Clemente, & Winston, 2006) available on the website of Active Living Research (Active Living Research, n.d.).

Urban Design Quality	Description	Urban Design Features
Imageability	The quality of a place that makes it distinct, recognizable, and memorable	1. number of courtyards, plazas, and parks (both sides, within study area)
		2. number of major landscape features (both sides, beyond study area)
		3. proportion historic building frontage (both sides, within study area)
		4. number of buildings with identifiers (both sides, within study area)
		5. number of buildings with non-rectangular shapes (both sides, within study area)
		6. presence of outdoor dining (your side, within study area)
		8. noise level (both sides, within study area)
Enclosure	The degree to which streets and other public spaces are visually defined by buildings, walls, trees, and other vertical elements.	1. number of long sight lines (both sides, beyond study area)
		2a. proportion street wall (your side, beyond study area)
		2b. proportion street wall (opposite side, beyond study area)
		3a. proportion sky (ahead, beyond study area)
		3b. proportion sky (across, beyond study area)
Human Scale	Human scale refers to a size, texture, and articulation of physical elements that match the size and proportions of humans and correspond to the speed at which humans walk.	1. number of long sight lines (both sides, beyond study area)
		2. proportion windows at street level (your side, within study area)
		3. average building heights (your side, within study area)
		4. number of small planters (your side, within study area)
		5. number of pieces of street furniture and other street items (your side, within study area)
Transparency	Defined as the degree to which people can see or perceive human activity or what lies beyond the edge of a street or other public space.	1. proportion windows at street level (your side, within study area)
		2. proportion street wall (your side, beyond study area)
		3. proportion active uses (your side, within study area)
Complexity	The visual richness of a place that depends on the variety of the physical environment, including: the numbers and kinds of buildings, architectural diversity and ornamentation, street furniture, and human activity.	1. number of buildings (both sides, beyond study area)
		2a. number of basic building colors (both sides, beyond study area)
		2b. number of accent colors (both sides, beyond study area)
		3. presence of outdoor dining (your side, within study area)
		4. number of pieces of public art (both sides, within study area)

3.3.1.3 Built Environment Characteristics

As discussed in the last chapter, the impacts of the built environment on walking has been studied extensively in planning, health, and transportation literature. The built environment characteristics are the control variables in this study. They are mainly collected from secondary sources: EPA Smart Location Database, ESRI Business Analyst, Walk Score Website, and North Central Texas Council of Governments (NCTCOG) database. Geographic Information System (GIS) by ESRI is used as a tool for calculating different variables specific to the study area.

Besides, a fewer number of built environment variables are counted in the field. This section provides an extended description of built environment variables and data collection techniques. Table 3.3 summarizes this section in a table format.

As discussed in the previous chapter, the walkability literature emphasizes the impact of sidewalk width and block length on walkability. This study uses the Google Earth measuring tool to measure the width of the sidewalk and block length for this study.

Another group of neighborhood variables is related to land-use. Percentage of parking lots, percentage of vacant lands, and percentage of park and recreation are obtained from NCTCOG Land Use Database and computed using GIS for the study area. These variables are measured in quarter-mile buffer around each block face. In addition, land-use diversity, which represents mix of land uses, is obtained from EPA Smart Location Database. This database also provides employment diversity for each study area, which is mix of employment types and occupied housing.

Besides, Walk Score measures destination accessibility in this study. Walk score is an Internet-based platform that rates the walkability of a specific address on a scale of 0 to 100 by accumulating the number of nearby stores and amenities within an extended walking distance. Thirteen destinations included in measuring walkability are groceries, restaurants, bars and coffee shops, libraries and bookstores, fitness centers, drug stores, clothing or music stores, schools, cinemas, parks, and hardware stores. For this study, I obtained addresses of the approximate midpoint of each block face using Google Street View and then entered the Walk score website to acquire a score for each segment. This platform also provides a transit score for each of the entered addresses.

3.3.1.4 Socio-economics and Demographics

Another group of control variables in this study is socio-economics and demographics. Table 3.3 shows these variables with their descriptions and data sources. This study obtained number of employees and number of businesses from ESRI Business Analyst. Age, ethnicity, population density, and age come from U.S. Census data and the 2017 American Community Survey (ACS).

Table 3.3
Variables and Data Sources

Variable		Description	Data Source
DEPENDENT VARIABLE			
	Number of Pedestrians	Number of pedestrian in each block face	Manual In-Field Count
INDEPENDENT VARIABLES			
Smart Characteristics	Educational Opportunity	Number of education related facilities	ESRI Business Analyst*
	Number of Libraries		ESRI Business Analyst
	Number of Information Related Businesses		ESRI Business Analyst
	Educational Attainment	Education level of residents in the study area	ACS**
	Smart Score	Calculated as number of smart features for each site	Identified in the Field or Online
Urban Design Qualities	Imageability	Refer to Table 3.6	Clemente et. al (2005)
	Enclosure	Refer to Table 3.6	Clemente et. al (2005)
	Human Scale	Refer to Table 3.6	Clemente et. al (2005)
	Transparency	Refer to Table 3.6	Clemente et. al (2005)
	Complexity	Refer to Table 3.6	Clemente et. al (2005)
Built Environment	Width of Sidewalk		Google Maps
	Block Length		Google Maps
	Pedestrian Audible Crossing Signal	Number of pedestrian audible crossing signals	Counted in the Field
	Employment Diversity	Mix of employment types & occupied housing	EPA Smart Location Database
	Land Use Diversity	Mix of land uses	EPA Smart Location Database
	Distance to CBD	CBD for Fort Worth	NHGIS****
	Percentage of Vacant Land	Calculated using GIS	NCTCOG Land Use Data
	Percentage of Parking	Calculated using GIS	NCTCOG Land Use Data
	Percentage of Parks & recreation	Calculated using GIS	NCTCOG Land Use Data
	Walk Score		Walk Score Website
Socio-Economics & Demographics	Age		ACS
	Population Density	Population per square mile	ACS
	Ethnicity		ACS
	Race		ACS
	Number of Employees		ESRI Business Analyst
	Number of Businesses		ESRI Business Analyst

* Environmental Systems Research Institute
**American Community Survey (ACS)
***North Central Texas Council of Government (NCTCOG)
****National Historical Geographic Information System (NHGIS)

3.3.2 Dependent Variable

The average number of pedestrians from eight passes up and down a particular block face is the outcome variable for this study. A study of urban design features related to walking has used pedestrian count as the dependent variable to measure pedestrian activity in streets of New York (Ewing, Hajrasouliha, Neckerman, Purciel-Hill, & Greene, 2016). There are several techniques for counting pedestrians such as manual in-field counts, manual counts from video, automated counts from video, and many more. This study uses manual in-field count and counts the number of pedestrians. The manual in-field count is the most prevalent method in the U.S for collecting pedestrian volume data (Ryus, et al., 2014). The same description is used for the pedestrian count, shown in Figure 3.2, as described in the field manual for measuring urban design qualities (2005).

In this exercise, the observers start from one end of the street in the study area and count every individual whom they encounter on their side of the street as they walk the length of the block face. The individuals that are walking, running, standing, sitting are counted as pedestrians in this study. The counting exercise is repeated four times for each study area on the scheduled data collection time. The average number of counts is considered as the number of pedestrian for each block face.

7. count people

Step 1
Walk entire length of study area (one block length or roughly 300 feet—120 steps).
Step 2
As you walk, note on your side of the street when you encounter walking, standing, or sitting pedestrians; do not include people sitting at outdoor eating areas.
Note: Count pedestrians that you pass and any pedestrian that is no more than 50 feet ahead of you.
Step 3
Record the number of walking, standing, or sitting pedestrians you encountered on one walk through the study area.
Step 4
Repeat steps 1-3 another 3 times recording the number of people each time.
Step 5
Compute the average number of people encountered from the four instances of walking the study area.

Figure 3.2. Description of manual in-field pedestrian count (Clemente, Ewing, Handy, & Brownson, 2005, p. 13).

The number of pedestrians is counted between 11 AM – 1 PM and between 6 PM to 8 PM, which is typical lunch and dinnertime in the U.S., on one selected weekday and one selected weekend day. The counting days are scheduled for days with similar temperatures, and counting days was canceled in case of a severe weather forecast.

The average of four rounds of pedestrian count for each block face rounded to the nearest integer. I counted the number of pedestrians in 76 block faces in four selected streets.

3.3.3 Statistical Analysis

Poisson Regression and Negative Binominal Regression are two popular models used for dependent variables that are counts, such as, in this study, the number of pedestrians, with several small values, a few large values, and no negative values. The distribution of the pedestrian counts dictates which model to use. Poison regression is used when the counts of the dependent variable are uniformly dispersed, and the variance has the same value as the mean. Negative Binominal Regression is used when the dependent variable is overdispersed, and the variance of counts is greater than the mean. Testing the overdispersion with the alpha test determines which model to use for count data. Below is a brief description of both Poisson regression and Negative Binominal regression models.

3.3.3.1 Poisson Regression

Poisson regression is a type of generalized linear model (GLM) (Poisson Regression, n.d.). GLM is an extension of the classical linear model and is used generally in typical linear regression models with a continuous dependent variable and continuous and/or categorical independent variables, which are not necessarily normally distributed like classic linear regression. In the classical linear regression model, the outcome variable is normally distributed, but in Poisson Regression, the dependent variable is a count with the Poisson distribution (McCullagh & Nelder, 1983).

The Poisson regression model is used to model count data, meaning that the observations of the dependent variable are nonnegative integers: 0, 1, 2, 3... The Poisson Regression explains the significant relationship between the dependent variable and explanatory variables. For example, the application of Poisson regression is to study the relationship between the colony counts of bacteria and several environmental conditions and dilutions (Poisson Regression, n.d.; Yang & Berdine, 2015). Poisson regression is used for the dependent variable that has a Poisson distribution, meaning that the mean and variance are the same. Poisson distribution is the probability of a set of events happening in a certain period and/or space with a certain average rate. Statistically, the Poisson distribution is discrete with one value for both mean and variance (Rodrıguez, Poisson models for count data, 2007). In this model, the maximum likelihood is used to estimate the parameters and regression coefficients; the chi-square shows the model's performance and its goodness of fit. The Poisson distribution models the probability of "y" occurrences with the below formula:

$$Pr(Y = y \mid \mu) = \frac{e^{-\mu} + \mu^{y}}{y!}$$

In which y= 0, 1, 2,.. equals to the number of pedestrians in our study and μ is the mean value per street segment. Considering that the mean and variance are equal in Poisson distribution, the Poisson regression model determines μ by a collection of independent variables with the below expression:

$$\mu = exp(intercept + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k)$$

Below is the Poisson regression model for observation *i* with a set of independent variables and a dependent variable that follows the Poisson distribution. The independent variables for this study that fit in this model are provided in Table 3.3 in the next section.

$$Pr(Y_i = y_i \mid \mu_i) = \frac{e^{-\mu_i} + {\mu_i}^{y_i}}{y_i!}$$

$$\mu_i = exp(intercept + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki}) = exp\ \mu({x_i}'\beta)$$

However, there are a couple of limitations to the Poisson regression model. One is the equi-dispersion, which refers to equal parameters for variance and mean. In the count data, it is very common that the variance is greater than the mean, i.e., when there is over-dispersion. The other problem is that Poisson predicts the lower counts of zero in the model than it is observed (Cameron & Trivedi, Essentials of Count Data Regression, 1999). The negative binomial regression model is a popular alternative model used to overcome the over-dispersion, while the zero-inflated model takes care of actual and excess zeros (Martin, Demétrio, & Hind, 1998; Robinson & Smyth, 2008). The output of Poisson regression and negative binomial regression model includes regression coefficient estimates with their standard errors, the Wald and Chi-square test statistics, and their associated p values. Model of maximum likelihood estimates the regression coefficients in Poisson regression with the below formula using the logarithm of the likelihood function:

$$ln[L(y,\beta)] = \sum_{i=1}^{n} y_i ln[\mu(x_i'\beta)] - \sum_{i=1}^{n} \mu(x_i'\beta) - \sum_{i=1}^{n} ln(y_i!)$$

3.3.3.2 Negative Binomial Regression

Negative binomial regression is a generalized Poisson regression, which includes a gamma noise variable, known as alpha, to eliminate the limitation of equal mean and variance in the Poisson model. The larger alpha denotes a greater overdispersion. In overdispersed data, the variance is higher than the mean, and the negative binomial regression is used for observations that are overdispersed. The negative binomial model is based on the Poisson model, with an additional overdispersion parameter to characterize unobserved heterogeneity (Rodrıguez, 2013; Negative Binomial Regression; Cameron & Trivedi, 1999). The overdispersion parameter is called alpha, and the likelihood ratio alpha test is used to test overdispersion and determine whether Negative Binomial distribution or Poisson distribution is more appropriate (Cameron & Trivedi, Essentials of Count Data Regression, 1999). Any value for alpha more than 0 means that overdispersion is observed; if alpha equals zero, that means that no overdispersion is observed (Martin, Demétrio, & Hind, 1998; Negative Binomial Regression; Cameron & Trivedi, 1999; Cameron & Trivedi, 1998). The below formula presents the negative binomial distribution:

$$Pr(Y_i \ = \ y_i|\mu_i,\alpha) = \frac{\Gamma(y_i+\alpha^{-1})}{\Gamma(y_i+1)\Gamma(\alpha^{-1})}\left(\frac{\alpha^{-1}}{\alpha^{-1}+\mu_i}\right)^{\alpha^{-1}}\left(\frac{\mu_i}{\alpha^{-1}+\mu_i}\right)^{y_i}$$

Where $\alpha = \left(\frac{1}{v}\right)$ and v is a random error. Similar to the Poisson regression model, y equals pedestrian count, and μ is the mean value per block face. The negative binomial regression model shown below determines μ by a collection of independent variables.

$$\mathrm{Pr}(Y_i \ = \ y_i|\mu_i,\alpha) = \frac{\Gamma(y_i+\alpha^{-1})}{\Gamma(y_i+1)\Gamma(\alpha^{-1})}\left(\frac{1}{1+\alpha\mu_i}\right)^{\alpha^{-1}}\left(\frac{\alpha\mu_i}{1+\alpha\mu_i}\right)^{y_i}$$

$$\mu_i = \exp(\text{intercept} + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki}) = \ \exp\mu(x_i{}'\beta)$$

One of the ways to test the difference between the negative binomial and Poisson regression is a likelihood ratio test of alpha for the null hypothesis H_0: $\alpha = 0$ against an alternative $\alpha > 0$. Because, in fact, the Poisson regression is a special case of negative binomial where $\alpha=0$ (Cameron & Trivedi, 1998). Overdispersion in such models can be presented in the below formula in which α is an unknown factor, and g(μ) = μ2 or g(μ) = μ (Cameron & Trivedi, 1999).

$$V(\ y_i|x_i) = \mu_i + \alpha g(\mu_i)$$

Suppose that in both null and alternative hypotheses, the mean is correctly quantified as exp $(x_i{}'\beta)$, and in the null hypothesis H_0: $\alpha = 0$, $V(\ y_i|x_i) = \mu_i$. Accordingly, estimating a Poisson regression model and creating fitted values using $\mu^\wedge = \exp\ (x_i{}'\beta^\wedge)$ and running the ordinary least square (OLS) model without constant is the next step. The reported t-statistics for α is asymptotically normal for the null hypothesis H_0: $\alpha = 0$ where μ_i is an error term (Cameron & Trivedi, 1999).

$$\frac{(y_i + \mu_i^\wedge)^2 + y_i}{\mu_i^\wedge} \ = \ \alpha\frac{g(\mu_i^\wedge)}{\mu_i^\wedge} + \ \mu_i$$

Model of maximum likelihood estimates of the regression coefficients in a negative binomial regression model is with the following formula:

$$L = \sum_{i=1}^{n} \{\ln[\Gamma(y_i + \alpha^{-1})] - \ln[\Gamma(\alpha^{-1})] - \ln[\Gamma(y_i + 1)] - \alpha^{-1}\ln(1 + \alpha\mu_i) - y_i\ln(1 + \alpha\mu_i) + y_i\ln(\alpha) + y_i\ln(\alpha\mu_i)\}$$

The hypothesis for this research is that streets with a higher number of smart characteristics have a higher number of pedestrians. Accordingly, the null hypothesis (H0: $\beta = 0$) for this research is that an increase in the smart score (sum of smart characteristics) does not increase the number of pedestrians. A combination of urban design, built environment and socio-demographic variables along with the smart score for each street (Magnolia, Main, W7th, and Exchange) is tested in the model to identify a model that explains the dependent variable the best. The final model only includes variables in the best-fitted model. IBM SPSS Package 21.0 software is used to estimate the regression model of pedestrian counts.

3.4 Study Area

This study considers the choice of the users' preference survey to determine the study area. As mentioned in the qualitative section, respondents were asked to select three streets in Fort Worth, TX. Streets that were selected the most are chosen as the study area. Each street represents one neighborhood in Fort Worth, TX.

The sample in this study includes the number of pedestrians in the block faces of selected streets in Fort Worth, TX. Fort Worth was selected based on its recent population growth. According to the Census Bureau, Fort Worth ranked third among the fifteen cities with the largest population increase between 2017 and 2018. With a 19,552 numeric increase in population, Fort Worth has slightly below one million population and ranks 13 Most Populous

Cities in the U.S. (Newsroom / News Releases, Press Releases, Tip Sheet Statements / Fastest-Growing Cities Primarily in the South and West, 2019). Fort Worth is also located in the Dallas-Fort Worth Metropolitan area, which has the largest population growth in the United States in 2017 (Newsroom / News Releases, Press Releases, Tip Sheet Statements / Dallas-Fort Worth-Arlington Has Largest Growth in the U.S., 2018). Based on this information, the user preference survey is designed for selecting four walkable streets in Fort Worth, TX.

The survey starts with a definition of walkable neighborhoods. The brief introduction of the subject that is presented to volunteer respondents is: "In recent decades, people have tended to move to and live in communities that provide a better quality of life and that are more receptive to their needs. The preference for living in walkable neighborhoods grew remarkably in 2017, especially compared to previous years. Several built environment and urban design characteristics are identified that promote walking, such as street furniture, parks, landscape, retails, and restaurants…". The survey asks volunteer respondents to select walkable streets (places) in Fort Worth, Texas, that they prefer to walk. The selected streets are determined as study areas in this research. [2]

Out of 120 distributed surveys, 50 people responded and selected their walkable streets in Fort Worth. The respondent of the survey were not necessarily living in the neighborhood or City of Fort Worth. However, these streets are known for their walkable characteristics not only in their neighborhood but also rather regionally. Each of the street is representing a walkable neighborhood in Fort Worth, TX.

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[2] As noted previously, some portions of activities mentioned here and some in the following sections had started as parts of the NITC 2017 Student Fellowship Award research.

Respondents select Main Street in Sundance Square neighborhood, W Magnolia Street in Near Southside, W7th Street in Cultural District, and Exchange Street in Stockyard. Figures 3.3a and 3.3b show the study areas based on the result of the survey.

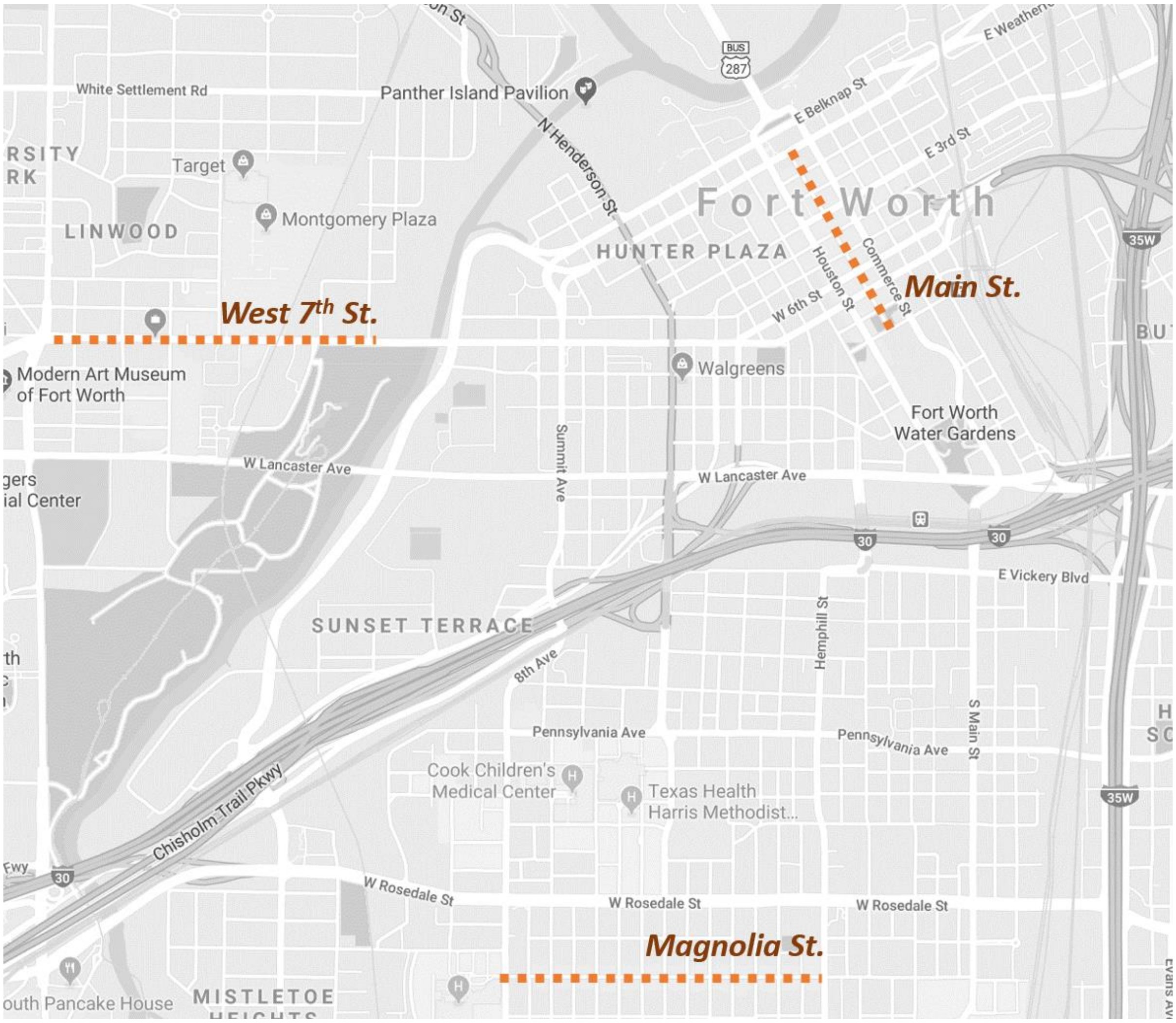

Figure 3.3a. Study Areas – Part One

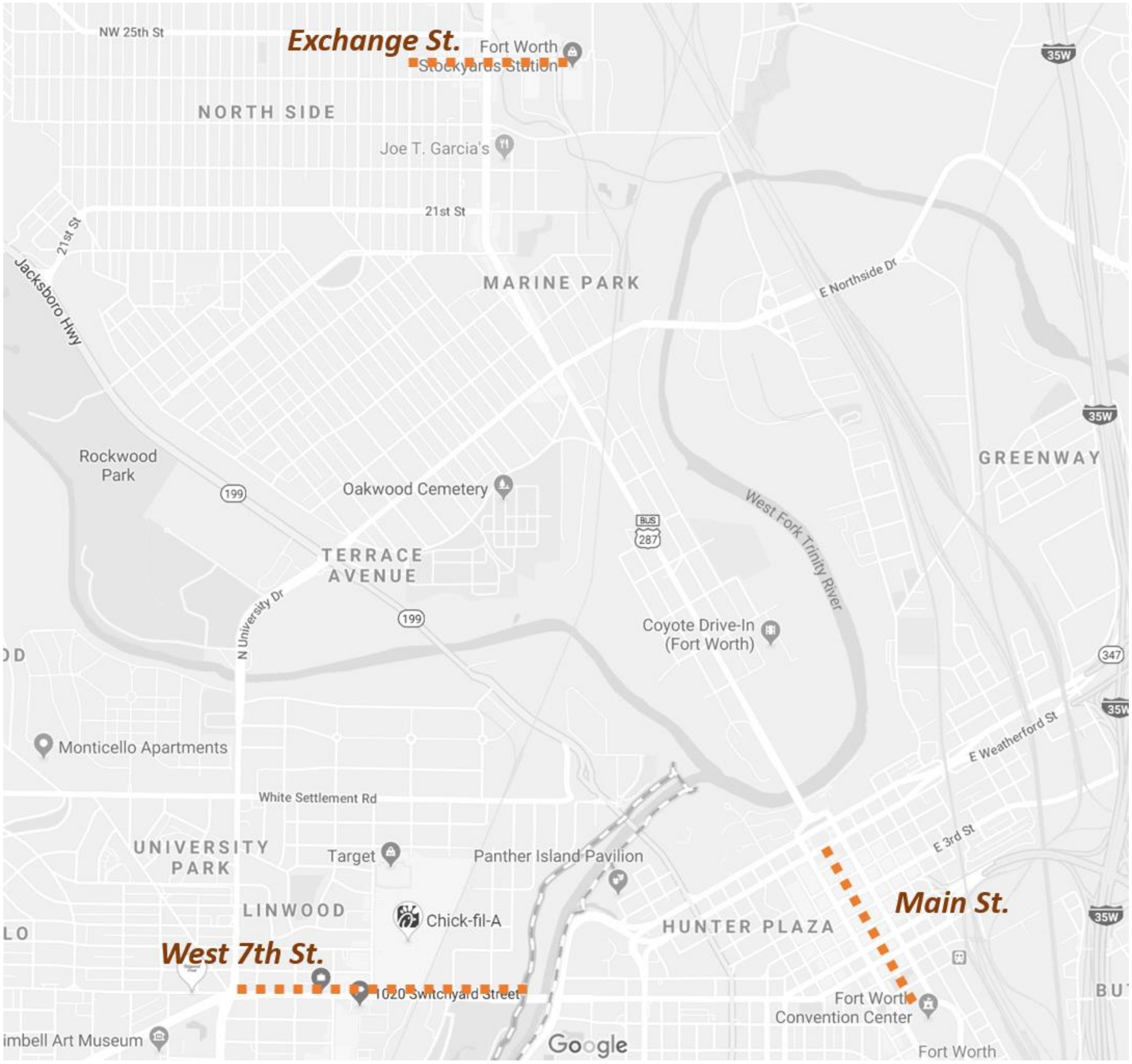

Figure 3.3b. Study Areas – Part Two

Figure 3.4. Main Street

Main Street – Main Street in the Sundance Square neighborhood in downtown area is a ½ mile-long locating between Fort Worth Convention Center and Tarrant County Court. This street consists of 8 street segments and 16 block faces. Main St. represents Sundance neighborhood in this study.

West Magnolia Street – W. Magnolia Street between Hemphill Street and 8th Avenue is a

¾ mile long and consists of 14 street segments and 28 block faces. Magnolia St. locates in the Near Southside neighborhood and will be the representative of this neighborhood in this research.

Figure 3.5. West Magnolia Street

Figure 3.6. West 7th Street

West 7th Street – West 7th Street locates west of the downtown area in the cultural district neighborhood and is a ¾ mile long, between W7th Street Bridge on Trinity River and University drive. This street consists of 16 block faces. West 7^{th} represents cultural district neighborhood in this study.

Exchange Street – Exchange Street locates in the Stockyard neighborhood. It is a ½ mile long, which consists of 16 block faces. Exchange St. represents the Stockyard neighborhood in this research.

Figure 3.7. Exchange Street

There are two definitions used to describe each study area above: length of the street and block face. The length of the street is important to factor in walkable neighborhoods. Typically quarter mile and half a mile are recognized as average walkable distances (Lee & Moudon, 2006). Walkable distance is calculated based on the pedestrian walking speed, which is 3 miles per hour and distances that people are willing to walk to get to their everyday destinations such as groceries and restaurants. Distances more than a 1.5-hour walk, which is equal to a 30-minute walk, are not very desirable (Talen & Koschinsky , 2013). This study limited the length of the study areas to the ¾ mile, which is equal to 20 minutes.

Block face is one side of the street between two intersections when the block is on the right side, and the street is on the left side. The portion of the street between each intersection is called a street segment. Each street segment has two block faces. The four study areas consist of 76 block faces total.

Chapter Four – Results & Discussion

This chapter consists of two sections. The first section is the qualitative analysis, which provides the collected data from surveys and analyzes the survey results. The second section focuses on the quantitative analysis and explains the results of the quantitative methods used in this study.

4.1 Qualitative Analysis

As discussed in the previous chapter in detail, this study used the user preference survey to determine the study area. 50 surveys were responded out of 120 distributed surveys. In addition to questions related to preferred walkable streets in Fort Worth, the survey asked people bout their perception of walkable neighborhood and smart neighborhood characteristics that make them more walkable. The first questions ask respondents the reason behind their selections. Table 4.1 shows the result of this question. The top three characteristics of these walkable streets are the diversity of land uses, well-maintained sidewalks and landscaping and trees. The next four factors are related to pedestrian safety - controlled traffic, adequate street lighting, safe pedestrian crossings, and high pedestrian activity. The higher pedestrian number is also a part of urban design qualities that was discussed in the previous chapter. Other urban design features such as attractive visuals, patios, and public arts are identified as important factors in most walkable streets in Fort Worth, TX. These were included in the statistical model for this study as independent variables.

Table 4.1
Significant Characteristics of Walkable Streets in Fort Worth, TX Determined by Users

What specific characteristics have made these streets more walkable?	
Diversity Of Land Uses	17
Wide Well Maintained Sidewalks	14
Landscaping & Trees	12
Controlled Traffic	11
Good Street Lighting	10
Safe Pedestrian Crossing	9
Other People Walking (More Eyes On The Street)	7
Events	5
Bike Lanes	4
Multiple Dynamic Storefronts	4
Public Art	3
Attractive Visuals	3
Patios	3
Good Pedestrian Circulation	3
Density	2
Bike Sharing	2
Parks	2
Local Café & Restaurants	2
Limited Parking Availability in Short Distance	2
Street Furniture	2
Public Transit	2

Another question asks respondents about the smart characteristics of walkable neighborhoods that make them more walkable. Table 4.2 shows the users' responds to these questions. The top answer among all in the list is the availability of Wi-Fi, which is an interesting response. With all developments in technology, the new generation is demanding access to the world of the internet all the time. Lighted crosswalks are the second important factor in the list, which highlights the importance of safety in walkable streets. Looking at the list of responses to this question shows the importance of safety for users. Safety-related factors such as pedestrian sensors that active lights, sensors that increase visibility and recognition of pedestrians, push to walk buttons at crosswalks, security cameras are mentioned several times in the survey results. Several respondents recognized the interactive maps that show destinations with designated walk paths and bike routes as one of the important factors to support pedestrians.

Another group of recognized factors in the responses to this question is related to smartphone applications that communicate the walkable features, bike-sharing system, and public transit system.

Table 4.2
Smart Neighborhood Characteristics for Creating Walkable Streets Recognized by Users

What Technology Based Initiatives Do You Think Can Help To Increase Walkability?	
Wi-Fi Availability	7
Lighted Crosswalks	5
Interactive Maps Of Locations, Walking/Biking Distances, Events, Parking	5
Sensors That Increase Visibility/ Recognition Of Pedestrians	3
Pedestrian Sensors That Active Lights	3
Push To Walk Buttons At Street Crossings	2
Security Cameras	2
Bike Sharing App	2
Public Transit Apps	2
Apps That Communicate Walkable Features Such As Shaded Seats, Plazas, and	2
App Based Solutions	2
Neighborhood Apps	1
Uber	1
Apps For Making Payment And No Need To Carry Money Or Card	1
Phone Charging Stations With Seats	1
Apps For Locating Restaurants And Activities	1
Solar Power Lights	1
Smart Traffic Lights	1
Sensors	1

Two other questions evaluate the knowledge of respondents with the policies and facilities that the City of Fort Worth uses to enhance walkability and facilitate pedestrian activity. The first question is very general and asks respondents to identify activities that the City of Fort Worth has done to support pedestrians. The respondents recognized Fort Worth's efforts on improving development standards to ensure diversity of land uses as the most important policy to enhance walkability. Different bike-sharing programs, increasing bike lanes, traffic managements, additional security in walkable areas, good lighting, shorter street segment, and trees and landscaping are the next important deeds. Table 4.3 summarizes responses to this question.

Table 4.3
City of Fort Worth Actions for Enhancing Walkability Recognized by Users

What Do You Think City Of Fort Worth Has Done To Facilitate Walking For Pedestrians?	
Development Standards To Ensure Diversity	9
Bike Sharing Program	5
Increased Bike Lanes	5
Traffic Management	5
Additional Security To Increase Safety	5
Good Lighting	5
Clean Streets	4
Redevelopment Of Smaller Sidewalks To Larger	4
Trees &Landscaping	3
Different Types Of Housing	2
More Public Art	2
Friendly Businesses In The Area	2
Parks	2
Closer Proximity To Destinations	1
Plaza	1
Parking Availability	1
Street Furniture	1
Planning For More Walkability	1
Crosswalk Safety	1

The second question focuses on the technologies that the City of Fort Worth has used to attract pedestrians. Many of the respondents mentioned that they are not aware of any technology being used to facilitate walking. Several of the respondents left this question, and only a few recognized the bike-sharing facilities and push to walk buttons as technologies that the City of Fort Worth has used to enhance walkability. The result of these questions shows that users are not familiar with all the efforts that The City is putting.

4.2 Quantitative Analysis

4.2.1 Measuring Neighborhood's Smartness

This study evaluated the streets of the study area based on the index of smart neighborhood characteristics related to walkability presented in Tables 3.1a and 3.1b. As discussed in the previous chapter, each street received one point for each smart characteristic, and the sum of all points is included in the model as the smart score for each block face. Tables 4.4a and 4.4b show the result of this evaluation and smart score for each street.

Table 4.4a

Neighborhoods' Smart Score

Smart Neighborhood Characteristics Related to Walkability							
Domains, Sub-Domains & Descriptions by Neirotti et al. (2014)	Smart Characteristic	Details	Score Yes = 1 No = 0	Main	Magnolia	W7th	Exchange
Natural Energy & Resources							
Public Lighting			Max.: 1	0	0	0	0
Info-Mobility	Walking in Fort Worth https://www.active.com/fort-worth-tx/walking		Max.: 1	1	1	1	1
	NCTCOG, Try Parking It Program. www.tryparkingit.com		Max.: 1	1	1	1	1
	Bike Sharing Program https://fortworthbikesharing.com/		Max.: 1	1	1	1	1
	Bike thoroughfare plan https://fortworth.bcycle.com/printable-map		Max.: 1	1	1	1	1
People Mobility	Bike Lanes		Max.: 1	0	1	1	0
	Free Valet Parking Program		Max.: 1	1	0	0	0
	Car Charging Station		Max.: 1	0	1	1	1
			Score	5	6	6	5

Table 4.4b
Neighborhoods' Smart Score

Smart Neighborhood Characteristics Related to Walkability							
Domains, Sub-Domains & Descriptions by Neirotti et al. (2014)	Smart Characteristic	Details	Score Yes = 1 No = 0	Main	Magnolia	W7th	Exchange
Living							
Entertainment	Tourist Information Center		Max.: 1	1	0	0	1
	Visit Fort Worth https://www.fortworth.com/	A comprehensive guide to events, things to do, hotels, restaurants and so on.	Max.: 1	1	1	1	1
	Social Media Activities	Apps Facebook Twitter Other Website	Max.: 4	0 1 1 1	0 1 1 1	0 0 0 1	0 1 1 1
	Diversity of Neighborhood Tours	Scooter Walking Carriage	Max.: 3	1 1 1	0 0 0	1 0 0	0 1 1
	Diversity of Events	Movie Nights Neighborhood Concerts Sport Events Art Events	Max.: 4	1 1 1 1	0 1 1 1	0 1 1 1	0 1 1 0
	Community Event Center		Max.: 1	1	0	1	1
Public Safety	Police Force	Bike Police Pedestrian Police Police Car Police Social Media Activity	Max.: 4	1 1 1 1	0 0 1 1	1 0 1 1	0 1 1 1
Public Spaces Management	Visit Fort Worth https://www.fortworth.com/	A comprehensive guide to events, things to do, hotels, restaurants and so on.	Max.: 1	1	1	1	1
Government							
Transparency	Walk Fort Worth http://fortworthtexas.gov/walkfw/	Policies, programs, and future developments for increasing walkability, ensure safety and convince, and promoting walking in Fort Worth	Max.: 1	1	1	1	1
			Score	19	11	12	15
			Total Smart Score	24	17	18	20

4.2.2 Negative Binomial Regression Model

The distribution of the dependent variables dictated the method of analysis. As discussed in the last chapter, the number of the pedestrian in each block face is the average count of four rounds of count rounded up to the closest integer. This average count of the pedestrians in each block constitutes the dependent variable, PED, and the variable mentioned in the previous section are the explanatory variables in our quantitative analysis. Poisson Regression and Negative Binomial Regression are the two models for count data. A comparison between mean and variance of the dependent variable determines which model to use. If means equal to variance, Poisson Regression is the model to use. If variance count is larger than mean, the data are overdispersed, and Negative Binomial Regression shall be used. Descriptive analysis, shown in Table 4.5, in SPSS shows the mean, variance minimum, and maximum for the pedestrian counts in this study. Pedestrian counts range from 0 to 76 for 76 street segments. The mean for the pedestrian count for this study is 9.75, and the variance is 261.550. The comparison of the mean and variance shows overdispersion and indicates Negative Binomial Regression as the best model for this study. Table 4.5 shows the results of the descriptive statistics for this study.

Table 4.5
Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
PED	76	76	0	76	9.75	16.173	261.550
Valid N (listwise)	76						

One of the most popular ways to identify overdispersion is overdispersion statistics, which is measured by the Pearson dispersion. If the Pearson dispersion (Pearson statistics divided by degree of freedom) in a model is greater than 1, the model is overdispersed (Hilbe, 2011). Table 4.6 shows the Pearson dispersion equal to 1.024 and displays the overdispersion of the dependent variable and indicates that Negative Binomial Regression is a better model for this study.

Another way to verify the better model between the Negative Binomial Regression Model and the Poisson Regression Model is to compare values of Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC). The model with lower values of AIC and BIC is the better model for predicting the dependent variable using the predicting variables (Long, 1997). Table 4.6 also provides AIC and BIC values for the Negative Binomial Regression Model for this study. The AIC value for this model is 407.057 and BIC is 432.695. AIC and BIC values for the Poisson Regression Model with the same dependent and independent variables are 446.615 and 469.922 respectively. The comparison between AIC and BIC values shows that the Negative Binomial Regression Model is a better model for this study compare to the Poisson Regression model with same predictors.

Table 4.6
Goodness of Fit

Goodness of Fit[a]

	Value	df	Value/df
Deviance	84.541	65	1.301
Scaled Deviance	84.541	65	
Pearson Chi-Square	66.584	65	1.024
Scaled Pearson Chi-Square	66.584	65	
Log Likelihood[b]	-192.529		
Akaike's Information Criterion (AIC)	407.057		
Finite Sample Corrected AIC (AICC)	411.182		
Bayesian Information Criterion (BIC)	432.695		
Consistent AIC (CAIC)	443.695		

Dependent Variable: PED
Model: (Intercept), Imageability, Enclosure, Human Scale, Transparency, Complexity, Walk Score, Smart Score, Land Use Diversity, Sidewalk Width
a. Information criteria are in small-is-better form.
b. The full log-likelihood function is displayed and used in computing information criteria.

This study estimated the Negative Binomial Regression model using the software package SPSS 21.0. Several independent variables in urban design, built environment, and neighborhood smartness categories have been tested in the model, and the best-fitted model is selected for the final result of this study. This model has a highly significant likelihood ratio chi-squares. The likelihood ratio chi-square of the model is 109.468, with 9 degrees of freedom, indicating a good fit to the data relative to a null model with only intercept terms.

For evaluating the goodness-of-fit for this model, an R-squared value used in OLS models is not valid. In OLS, the R-squared indicated the proportion of the variance in the outcome variable that is predictable by the independent variables. Here, the R-squared to determine the model's goodness-of-fit. However, the Negative Binomial Regression computes the maximum likelihood estimates and the OLS approach to goodness-of-fit is not applicable. To evaluate the goodness-of-fit in non-linear models, several pseudo R-squareds were developed. Pseudo R-squared similar to R-squared ranges from 0 to 1 with higher values showing better model fit, but they cannot be interpreted similarly. One type of pseudo R-squared is McFadden's pseudo R-squared which shows the improvement of the fitted model from null model. McFadden's pseudo R-squared is measured by 1 minus the ratio of the log-likelihood of the fitted model to log-likelihood of the null model. The ratio is revealing the degree to which the independent variables in the model improve upon the likelihood of the null model. The smaller this ratio, the higher the R-squared and the greater the improvement. The below formula shows the McFadden's pseudo R-squared (Long, 1997).

$$R^2{}_{\text{McFadden}} = 1 - \frac{\ln L^\wedge(M_{full})}{\ln L^\wedge(M_{null})}$$

Where:

$$M_{(full)} = model\ with\ predictors$$

$$M_{(null)} = model\ without\ predictors\ or\ intercept\ only$$

$$L^\wedge = estimated\ likelihood$$

Accordingly, the McFadden's pseudo R-squared for this model is calculated below:

$$R^2_{\text{McFadden}} = 1 - \frac{192.529}{247.262} = 0.22$$

The fitted model with the included independent variables improves prediction of the dependent variable, PED, roughly by 22 percent. As discussed before the McFadden's pseudo R-squared cannot be interpreted as the R-squared in an OLS model. However, it shows the improvement of the fitted model compares to the null model with intercept only.

Table 4.7 and Table 4.8 shows the description of the variables in the best fitted and the final result of the Negative Binomial Regression model for this study. Regarding the impact of the independent variables on the outcome variables, the model shows that two urban design qualities, three built environment variables, and neighborhood's smartness score are significantly related to the number of pedestrians. As discussed earlier, the Negative Binomial Regression Model uses the log linear model, so the exponential Beta coefficient interprets the relationship between predicting variables and predicted variable. The description and interpretation of the significant variables in the best fitted model are as follow:

Table 4.7
Continuous Variable Information

		N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable	PED	76	0	76	9.75	16.173
Covariate	Imageability	76	2.26	7.86	3.6442	1.15670
	Enclosure	76	-.34	4.23	1.9221	1.07326
	Human Scale	76	.99	8.93	2.9258	.96601
	Transparency	76	1.71	4.06	3.0328	.55989
	Complexity	76	4.20	9.58	6.0416	1.18075
	Walk Score	76	49	92	77.74	9.490
	Smart Score	76	17	24	19.32	2.674
	Land Use Diversity	76	.79	.89	.8468	.03795
	Sidewalk Width	76	0	50	14.22	7.289

Smart Score – The smart score ranges from 17 to 24, with a mean value of 19.32 and a standard deviation of 2.674. The results of the model shows that one unit increase in smart score increases the expected pedestrian count by the factor 1.23 or 23% (= exp[0.211]), while holding the other variables in the model constant at 0.95 level confidence. In definition of the smart score, each point/unit equals to one smart neighborhood characteristic. Accordingly, the interpretation can also read as adding one smart score characteristic increases the expected average pedestrian count by 23%.

Table 4.8

Negative Binomial Regression Model of Pedestrian Counts

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-13.740	3.7432	-21.076	-6.403	13.474	1	.000
Imageability	.242	.0829	.080	.405	8.545	1	.003
Enclosure	-.129	.1198	-.363	.106	1.150	1	.283
Human Scale	.052	.1538	-.250	.353	.114	1	.736
Transparency	.320	.2227	-.116	.757	2.071	1	.150
Complexity	.417	.1020	.217	.617	16.743	1	.000
Walk Score	-.045	.0102	-.064	-.025	19.180	1	.000
Smart Score	.211	.0490	.116	.307	18.663	1	.000
Land Use Diversity	12.679	3.1799	6.447	18.912	15.898	1	.000
Sidewalk Width	-.023	.0130	-.049	.002	3.154	1	.076
(Scale)	1[a]						
(Negative binomial)	.233	.0715	.127	.425			

Dependent Variable: PED

Model: (Intercept), Imageability, Enclosure, Human Scale, Transparency, Complexity, Walk Score, Smart Score, Land Use Diversity, Sidewalk Width

a. Fixed at the displayed value.

The two urban design variables that proved significant are imageability and complexity. Imageability ranges from 2.26 to 7.86, with a mean value of 3.64 and a standard deviation of

1.16. Complexity ranges from 4.20 to 9.58, with a mean value of 6.04 and a standard deviation of 1.18.

Imageability – One unit increase in imageability increases the expected pedestrian count by the factor of 1.27 or 27% (= exp[0.242]), while holding the other variables in the model constant at 0.95 level confidence. Imageability refers to the quality of a place that makes it distinctive, perceptible, and memorable and consists of 8 urban design features. Table 3.6 provides full description of urban design qualities and their features used in this study.

Complexity – One unit increase in complexity increases the expected average pedestrian count by the factor of 1.52 or 52% (= exp[0.417]), while holding the other variables in the model constant, at 0.95 level confidence. Complexity is the visual richness of a place that depends on the diversity of the physical environment and consists of 6 urban design features.

The other three urban design features – human scale, transparency, and enclosure – are not significant in this model.

The three built environment variables, Walk Score, land use diversity, and sidewalk width, are directly and significantly related to pedestrian activity.

Walk Score ranges from 49 to 92, with a mean value of 77.74 and a standard deviation of 9.49. Land use diversity ranges from 0.79 to 0.89, with a mean value of 0.85 and a standard deviation of 0.38. Sidewalk width ranges from 0 to 50, with a mean value of 14.22 and a standard deviation of 7.29.

Walk Score– One unit increase in Walk Score decreases the expected pedestrian count by the factor of 0.96 or 4% (= exp[-0.045]), while holding the other variables in the model constant at 0.95 level confidence.

Land Use Diversity– One percentage unit increase in land use diversity increases the expected pedestrian count by the factor of 1.14 or 14% (= exp[12.679 x 0.01]), while holding the other variables in the model constant at 0.95 level confidence.

Sidewalk Width – One unit increase in sidewalk width decreases the expected pedestrian count by the factor of 0.98 or 2% (= exp[-0.023]), while holding the other variables in the model constant at 0.90 level confidence.

The other built environment characteristics were not significant and were not included in the final model. Also, none of the direct smart variables and socio-demographic variables were significant and eliminated from the last model.

In addition to the built environment, urban design qualities and smart score, The research tried to test the neighborhood effect on pedestrian count by creating dummy variables for each street. However, the street dummies had multicollinearity with the primary research variable, smart score, and were excluded from the model. Other variables in the model were also tested for multicollinearity and there was no multi multicollinearity among predictors included in the final model.

4.3 Discussion

4.3.1 Discussion on the Survey results

As discussed in the previous chapter, four in-depth questions acquire respondents' perceptions of walkable neighborhoods. Regarding the characteristics of walkable neighborhoods, the responses are relatively in line with the built environment characteristics and urban design qualities recognized in the literature of walkability. I categorized the responses in three categories – built environment, urban design, and smart resolution. Table 4.9 shows the responses and their categorization.

The first category is the built environment. The walkability literature recognizes land use diversity (Cervero & Duncan, 2003; Frank, Schmid, Sallis, Chapman, & Saelens, 2005; Heath, et al., 2006; Saelens, Sallis, & Frank, 2003), sidewalk quality (Cerin, Saelens, James, & Frank, 2006; Kitamura, Mokhtarian, & Laidet, 1997; Talen & Koschinsky , 2013), landscaping (Adkins, Dill, Luhr, & Neal, 2012; Jackson, 2003), density ((Leck, 2006), and street connectivity (Frank, Schmid, Sallis, Chapman, & Saelens, 2005; Sundquist, et al., 2011) as attributes are physical environment related to walking. I tested the built environment variables in the quantitative model. Although there was a data availability limitation from some of the built environment variables like land-use diversity, these responses confirm the effect of such characteristics on walkability.

Table 4.9

Categorization of Characteristics of Walkable Streets in Fort Worth, TX Determined by Users

What specific characteristics have made these streets more walkable?	Score	Categorization
Diversity Of Land Uses	17	Built Environment (Land Use Diversity)
Wide Well Maintained Sidewalks	14	Built Environment (Sidewalk Quality)
Landscaping & Trees	12	Built Environment/Urban Design (Landscaping)
Controlled Traffic	11	Smart Resolution
Good Street Lighting	10	Urban Design/Smart Resolution
Safe Pedestrian Crossing	9	Smart Resolution
Other People Walking (More Eyes On The Street)	7	Urban Design (Imageability/Complexity)
Events	5	Smart Resolution
Bike Lanes	4	Smart Resolution
Multiple Dynamic Storefronts	4	Urban Design (Transparency)
Public Art	3	Urban Design (Complexity)
Attractive Visuals	3	Urban Design (Imageability)
Patios	3	Urban Design (Imageability/Complexity)
Good Pedestrian Circulation	3	Built Environment (Street Connectivity)
Density	2	Built Environment (Density)
Bike Sharing	2	Smart Resolution
Parks	2	Urban Design (Imageability)
Local Café & Restaurants	2	Smart Resolution
Limited Parking Availability in Short Distance	2	Smart Resolution
Street Furniture	2	Urban Design (Complexity)
Public Transit	2	Built Environment/Smart Resolution

The second category is urban design. Pedestrian activity(number of pedestrians), dynamic storefronts, public arts, attractive visuals, patios, parks, and street furniture are features of five urban design qualities – imageability, transparency, human scale, enclosure, and complexity) presented in Table 3.2. The five urban design qualities are tested in the Negative Binomial Regression model and the next section will discuss the result.

The characteristics under the third category are based on the policies designed to improve the pedestrian experience. They can fit under descriptions of smart neighborhood characteristics related to walkability - Transportation and Mobility, Natural Resources and Energy, and Living domains. So, I named the third category as smart resolutions.

Another in-depth question asks about technologies that can help to increase walkability. Respondents verified several technologies such as Wi-Fi availability, various apps, interactive maps, using renewable energies such as solar energy for traffic lights and street lighting, sensors, and security cameras as technologies that can support walkable streets. These features can be explained by the smart neighborhood characteristics related to walkability mentioned in Tables 3.1a and 3.1b. Although surveyors counted several technology-based initiatives that enhance walkability, the majority of them were not aware if the City of Fort Worth has used any to increase walkability. This shows the disconnection between citizens and the agencies involved in the development of smart resolutions and the application of technologies for walkable Fort Worth.

The application, size, and location of technologies that are used to enhance walkability are the reason for this disconnection. For example, people might not see sensors and surveillance cameras from a close distance, but different entities such as the Council of Governance, banks, and developers have sensors and surveillance cameras in walkable streets. However, none of these entities mentioned the technologies that they use to facilitate walking. Lack of transparency or information can be another reason for this disconnection.

Another reason can be from the users' side; although they regarded several technology-based initiatives, they did not note it in the next question, although many of them use many of them. For example, many available apps and websites communicate events, but it was not mentioned in the answers for 2nd question regarding technologies being used in the City of Fort Worth.

Although respondents did not mention phone applications and websites in the list of technologies that are used to promote walkability, there are several platforms such as apps, social media, and other websites that provide information about the walking and running events, parking, and air pollution. Figure 3.5a noted some of these platforms.

4.3.2 Discussion on the Negative Binomial results

In addition to obtaining users' perception about walkable neighborhoods, this dissertation sought to explain the pedestrian counts of each block face of the selected streets in terms of smartness, urban design qualities – imageability, enclosure, transparency, human scale, and complexity – and built environment characteristics – Walk Score, land use diversity, and sidewalk width.

The results of the Negative Binomial Regression model shows imageability is significantly related to pedestrian activity. This result is in line with previous studies related to these urban design qualities in Salt Lake City, UT, and New York, NY (Ameli, Hamidi, Garfinkel-Castro , & Ewing, 2015; Ewing, Hajrasouliha, Neckerman, Purciel-Hill, & Greene, 2016). Another urban design quality significant in this study is the complexity. This is a novel founding; because, to my understanding, this is the first study that shows a significant relationship between complexity and pedestrian activity.

However, not all of the tested urban design features have a significant relationship with the pedestrian counts. Previous studies in Salt Lake City, UT, and New York, NY, show that transparency is significantly related to pedestrian volume (Ameli, Hamidi, Garfinkel-Castro , & Ewing, 2015; Ewing, Hajrasouliha, Neckerman, Purciel-Hill, & Greene, 2016). Nevertheless, in this study, transparency does not have a significant correlation with the pedestrian count. In addition to transparency, human scale and enclosure are not significant despite the theoretic rationalization and the extensive operationalization efforts.

In the built environment category, having a higher Walk Score does not support pedestrian activity. The result of this study shows that Walk Score is significantly and negatively pedestrian activity, meaning that higher walk score, lower pedestrian number. This can be related to the scale. This dissertation collected data in micro-level - on each block face of the selected streets. On the other hand, Walk Score evaluates walking paths to adjacent amenities in 1-mile distance (30-minute walk) with amenities within ¼ mile walking distance, having the greatest contribution to the final Walk Score and lowest points to more distant amenities. These amenities are in different categories – groceries, schools, dining and drinking, shopping errands, parks, schools, and culture and entertainment. A higher walk score shows that the neighborhood supports pedestrians and provides different destinations in the walkable distance but does not necessarily show that the neighborhood has higher pedestrian activity. Also, other characteristics of the neighborhood are important in attracting pedestrians. For example, Exchange St. had the highest pedestrian activity among the four studied streets. However, the pedestrian activity in Exchange St. is limited to 4-5 street segments, and surrounding streets do not have much pedestrian activity. Although this is not the expected result, it questions if Walk Score is a good determinant of walkability. It also shows the difference between walking opportunities and actual pedestrian activity.

Another significant built environment characteristic in this model is land use diversity. Land use diversity is the indicator of land-use diversity. A high value of land use diversity shows the higher diversity of land use in a determined area. Land use diversity is the most influential variable in the model for this study, which shows the importance of the mix of land uses in attracting pedestrians, which is precisely in line with the result of the survey.

Another significant built environment characteristic in the model is sidewalk width, which is negatively related to pedestrian volume. Meaning that wider sidewalks have less pedestrian compare to narrower sidewalks. This relationship has been confirmed in several previous studies (Cervero , 2002; Tan, Wei, Lu, & Bian, 2005).

Chapter Five – Discussion, Conclusion, & Policy Recommendations

This study adds to the literature on the relationship between smart neighborhoods and pedestrian activity in different ways. First, this study reviewed smart city literature and provided a comprehensive definition for smart neighborhoods. Second, it introduced smart neighborhood characteristics related to walkability using smart city literature, walkability literature, and users' preference survey. Third, it studied the relationship between neighborhood's smartness and walkability in the neighborhood using qualitative and quantitative methods. Fourth, this study employed precise sets of methodologies to evaluate neighborhoods' smartness and collect urban design field data. Fifth, as a part of field data collection, this study counted the number of pedestrians several times in 76 block faces to ensure the accuracy and reliability of the collected data. Sixth, it used users' preference survey to understand users' perception of walkability and the role of neighborhood's smart characteristics to increase walkability. Seventh, it used concurrent triangulation approach for combining and interpreting the results of the qualitative and quantitative techniques. Eighth, the most walkable streets in Fort Worth, TX were selected by users as study areas. Fort Worth is a fast-growing American city with auto-dependent urban environments. The result of this study is generalizable to American cities with similar characteristics.

5.1 Conclusion

This dissertation has tried to understand if neighborhoods with a higher number of smart characteristics have higher number of pedestrians. In other words, this study aims to see if smarter neighborhoods have more pedestrian activity. This dissertation hypothesizes that streets with higher smart neighborhood characteristics have higher number of pedestrians. This study constructs the relationship between smart neighborhood characteristics and walkability on quality of life. While smart cities aim to enhance the quality of life, residents of walkable neighborhoods have higher physical and mental health compared to non-walkable neighborhoods. Physical and mental health are essential components of quality of life.

In the first step, this study reviewed the smart city literature to find a universal definition for a smart city. After a profound review of the literature, it found inconsistency between different definitions of smart cities. It also found out that the majority of studies focus on the technological aspects of the smart cities. Besides, the literature defines smart cities in city or larger geographical scales like region. This dissertation argues that the smartness shall not be limited to any geographical scale and defines smart neighborhood as a fraction of a smart city which aims to recognize demands, provide better services and improve quality of life.

Moreover, this study challenges the idea that cities that use technology are smart. It argues that smart cities or smart neighborhoods use innovative concepts and technology advancements to provide better services to residents and enhance the quality of life. In the second step, this study reviewed the quality of life and walkability literature. It studied the characteristics of walkable neighborhoods and defined a walkable neighborhood to be used in this study based on the literature.

On the next step, this dissertation defined smart neighborhood characteristics related to walkability based on the definition of smart city domains and sub-domains by Neirotti et al. (2014). It created an index of these smart characteristics to evaluate the study area. In the next step, this study used the user preference survey to identify walkable streets in Fort Worth, TX, as the study area to test the hypothesis. This study evaluated and scored four walkable streets – Main St., Magnolia Ave., West 7th St., and Exchange Ave. – In Fort Worth, TX, based on the smart neighborhood characteristics. These walkable streets were selected using the user preference survey, and the number of pedestrians was counted in each block face of these streets. The average of four series of pedestrian count for each block face curved to the adjacent digit and summed up for the total pedestrian count in each street.

In conclusion, this study adds to the understanding of the walkable neighborhoods in mid-size American cities. Using rigorous qualitative and quantitative data collection and methodologies, this research identifies the importance of smart resolutions in supporting pedestrian activities. The result of this study, once again, emphasizes the importance of urban design features and built environment characteristics of the street in attracting pedestrians. This study contends that enhancing walkability in a neighborhood requires a sensible combination of urban design features, built environment characteristics, and innovative technology-based and non-technology based resolutions that goes beyond adding retails and mixed uses to a neighborhood. Also, it argues that creating walkable neighborhoods does not necessarily mean higher pedestrian activity. Urban planners, designers, architects, developers shall study the regional, geographical, and cultural context of the street and neighborhood to propose policies and design solutions for creating high-quality, meaningful, friendly places that attract pedestrians and make walking more pleasant and memorable.

5.2 Policy Implications

Planners and designers can adopt the results of this dissertation to develop a comprehensive framework for improving the pedestrians' walking experience. Several policy implications can be extracted from this study. The policy recommendations are divided into three categories – built environment, urban design, and smart characteristics.

5.2.1 Policy recommendation for creating smarter walkable neighborhoods

Although this study focuses on smart neighborhoods, it recognizes smart neighborhoods as a fraction of a larger geographical scale, which is the smart city. To improve walkability in neighborhoods, a new vision for the city is required that focuses on enhancing the quality of life of residents using innovative notions and technology advancements in everyday urban life.

The results of this study urge urban planners and policymakers to come up with smart concepts using technology-based and non-technology based resolutions to create pedestrian-friendly environments that entertain users, are accessible, and provide safety and comfort. The recommendations in this section are based on the survey results in the qualitative section and the Negative Binomial model in the quantitative section.

5.2.1.1 Natural Resources & Energy

Solar energy can be used widely for street lighting, terrific lights, sensors, bike-sharing stations, and other street furniture. The street furniture can have different functions; for example, they can be equipped with Wi-Fi connectivity, traffic sensors, or weather and air pollution control sensors. Policies can be designed to enforce using multifunctional street furniture such as light poles. They can directly communicate with a central management system that analyzes the real-time information about traffic, weather, and pollution, recognizes required repairs, and can control the intensity of lights.

5.2.1.2 Transportation & Mobility

Website and phone applications that communicate the real-time information about public transportation system, times of departure and arrival, duration of the trip, stations, connections with other modes. These platforms can also show events, restaurants, bike-sharing, and other activities at each station. These platforms can get simultaneous feedback from users reporting problems and acquiring information about trips.

The result of this study also encourages policies for using clean energy in the transportation system. One example is to expand the service area of the existing electric bus line, The Dash, which operates between the cultural district and downtown, to the other areas of the city. Another policy can encourage increasing the number of electric car charging stations.

5.2.1.3 Living

Entertainments – Plazas and event centers that people can gather for public events such as concerts and movie nights can help to increase pedestrian activity in the streets. Such spaces will attract businesses and other services as well, which increases the livability of the street. Neighborhood associations and community centers can use phone applications, websites, and text message system to communicate events in a particular street or neighborhood.

Safety – based on the results of the user preference survey, safety is one of the most important concerns of users. Pedestrian-friendly environments shall prioritize pedestrians and their safety and comfort, limit the automobile traffic, and be accessible by providing different types of transportation. Such an environment shall be inclusive and provide facilities for pedestrians walking, seating, running, and people with disabilities. Ensuring the accessibility of the environment for people with disabilities is a smart resolution that can enhance the attractiveness of an environment.

One of the resolutions in this regard is to increase the number of Accessible Pedestrian Signals (APS) at all intersections that can help to increase the inclusiveness of the environment. Such buttons have integrated microphones that assess the sound level in the surroundings and raise the volume level played by the APS as required to be heard over traffic noise. Another feature is pedestrian detectors at crossings that change the traffic lights at walkable streets can increase the safety of pedestrians.

An essential step in increasing feelings of safety and security is to provide different security forces and surveillance cameras. Creating a safe environment at night is also highly related to the adequate lighting of the space. Policies shall enforce designing street lighting by professional lighting experts and with connecting each light fixture to the central management system, control the amount of light, based on the time and requirements.

Public Spaces Management – The public space management system is responsible for maintenance, cleaning, and publicizing various events. Policies such as "adopt a street/sidewalks/station" are actively taking care of cleanness and maintenances of the streets. Regarding event management, policies shall ensure the inclusiveness of the environment. Different groups, ethnicities, ages shall be able to perform their events and peaceful gatherings in the neighborhood event center and plazas.

5.2.1.4 Government

The vision for the future of the city and milestone in each sector shall be clear. Policies shall urge transparency and enabling citizens to participate in the decision-making process, recognizing their demands and sharing the final decisions and official documents. Neighborhood associations, community centers, designers and developers, City officials, and others involved in the decision-making process shall recognize this transparency. Urban planners and policymakers can take advantage of technology in collecting residents' and visitors' feedback. Phone apps, online surveys, analyzing social media inputs on the matter, real-time online community engagement platform can increase the users' input and help to recognize the demands and communicate the decision making the process and final decisions and steps toward implementation.

The City can create a central record center that keeps the record of the decision-making process that leads to new policies for enhancing walkability. Currently, there is no clear information available on the technologies being used to support pedestrians. Although after talking to the City staff, few studies have been done on pedestrian activity in the studied areas by private sectors or there are pedestrian sensors at crossings in Main Street, but there is no available record. Transparency is an important factor in identifying demands, designing policies, implementation, and enhancing services. It is also important for post-implementation evaluation, recognizing potential improvements and lessons for future projects. The central record center can also keep the predevelopment records to be able to compare before and after development. This evaluation can be used in future projects and enhance the quality of the

Overall, urban planners, policymakers, designers, and developers can take advantage of technology advancements and smart resolutions to create more walkable streets and improve the quality of life in neighborhoods. Using natural energies, improving built environment performance using real-time data, improving public transportation system controlling traffic in walkable streets, communicating events, things to do and activities, improving safety and comfort, and involving users in the decision-making process can help to improve walkability.

Also, this study encourages the implementation of smart resolutions – technology-based and non-technology based – to enhance walkability. This study suggests that a smart combination of these characteristics contributes to higher pedestrian activity.

5.2.2 Policy Recommendations for enhancing urban design qualities

The result of this study encourages policymakers to improve urban design features such as patios, public arts, landscaping, and parks to increase pedestrian activity and enhance the quality of life for residents. Imageability and complexity were significant urban design qualities in this study. Each of these qualities has several urban design features. Imageability score is a sum of scores for number of courtyards, plazas and parks, number of major landscape features, proportion of historic building frontage, number of buildings with identifiers, number of buildings with non-rectangular shapes, presence of outdoor dining, and number of pedestrians in the streets with positive contribution to the overall imageability score. Another urban design feature related to imageability is the noise level, which has a negative impact on the imageability score.

The investment in creating parks, plazas, and public spaces where can be a center for public gatherings, and events can attract more pedestrians. A major plaza and landscape feature can be a public center that goes beyond the neighborhood boundaries and be a center for the whole city, metroplex, and a place for tourists from other cities. Besides, policies that encourage diverse building forms and remarkable shapes can contribute to the overall imageability of the street. Building with unique architecture and not a regular rectangular shape is also identifiable and memorable. The signs, graphics, and building letters and symbols are also identifiers that can add to higher imageability. Outdoor dining can be very attractive to pedestrians, especially in pleasant weather conditions. Policies that encourage restaurants and cafés to have outdoor sitting areas can attract pedestrians, and more pedestrians will attract more pedestrians in the area. While empty streets do not give a secure and safe feeling, streets with higher pedestrians are more vibrant and attract more pedestrians.

The last feature in urban design qualities with a negative effect on imageability is noise level. Adding landscape buffers and trees, landscape street furniture, noise barrier separators, building materials, and transportation facilities can reduce the noise level. Policies shall encourage landscaping buffers to reduce the noise level will provide comfort for residents and pedestrians and can increase the pedestrian volume.

The other urban design quality significant in this research is complexity. The diversity of buildings and architectural details, street furniture, and public art and overall pedestrian activity contribute to the visual richness of the street. The complexity score is a sum of scores for the number of buildings, their primary and accent colors, outdoor patios, public arts, and pedestrian activity in the street. Denser neighborhoods with diversity of land-uses offer different destinations in walkable distance. They also have a higher number of residents and a higher chance of having people in the streets. Such developments have higher number of buildings, more colors, and more materials. Multi-use land-use policies and invest in denser developments that encourage higher density can help to increase complexity of the neighborhood and increase pedestrian volume.

Policymakers and urban designer can use art to increase the attractiveness of the streets. The art pieces will connect people and artists and enhance the visual richness of the neighborhood.

5.2.3 Policy Recommendations for creating a built environment that encourages pedestrian activity

The results of this research confirm the importance of built environment characteristics in increasing pedestrian activity. The land use diversity conveys the expected strong, positive relationship to pedestrian numbers. Policymakers and developers can wisely combine various land uses such as residential, commercial, offices to increase the attractiveness and vibrancy of the neighborhood. They also shall ensure the connectivity between different land uses to increase access to opportunities in walkable distances.

The width of sidewalks was significantly associated with higher pedestrian counts. Planners and policymakers can verify and enforce the appropriate width for sidewalks based on the needs of the neighborhood and vision of the city after studying and identifying the optimum width for sidewalks for pedestrians.

5.3 Limitations and Recommendations for Future Research

I acknowledge the limitations of this study. The first limitation is the scale, sample size of this study and variables in different geographic levels. The smallest scale in this study is block face, in which the dependent and majority of the dependent variables are measured. However, other variables are in the block group or neighborhood level. Although data collection in micro-scale enables a closer look at the actual pedestrian activity and recognizing effective factors, it limits the operation of variables in larger scales like neighborhood level. Although the number of block faces might be sufficient for running the statistical model at the first level, the sample size might not be large enough for the second level – neighborhood level. For example, this study counted the number of pedestrians and measured urban design features and built environment characteristics in 76 block faces, which are located in 4 neighborhoods. The smart neighborhood characteristics for this study have four counts, which is the minimum sample size for running the statistical model. The solution for this is increasing the sample size; in this case, the number of neighborhoods, which was out of the scope of this study. This study evaluated the streets that users selected. To overcome this limitation, this study tried to measure many of the variables in the block face level, including the smart score. To overcome this limitation, this study considered the same smart score for each block face of the street and included it in the model. The nested structure of the initial model was violated with this change, and I tested the variables in a Negative Binomial Regression Model in SPSS, all at the same level.

Second, for some of the variables such as transit score, the center of the block face has been used to measure the transit access score. While the center of the block face might not be the center of the activity, and it does not represent an accurate measurement for each point along the block face. However, it provides the average number for the block face in relation to transit accessibility.

The third limitation is the accessibility to data related to smart neighborhood characteristics. I discussed this study with the City of Fort Worth staff to acquire data related to the specifics of the study areas. Although many of the staff acknowledged that the data is available for selected streets, private parties own this data, and despite my requests, they were not willing to share. One example is the sensors in Main Street, which recognize pedestrian activity and can change the traffic lights accordingly. Another example was a sensor/camera-based system that records the patrons parking and destinations in Magnolia streets. The private owners of these cameras/sensors were not willing to share the data.

The fourth limitation of this study is data availability. Several built environment variables such as density and socio-demographics such as education, ethnicity, or income are at the block group level. Including them in the model would not show their actual effect and may affect the result of the study, so they were excluded from the model. However, the survey results verified the importance of these variables for creating walkable streets. In order to test these variables in a quantitative model, the study area should expand to all streets in the neighborhood. Although this is not in the scope of this study, expanding the study area is highly suggested for future studies.

The fifth limitation of this study is that this dissertation uses the most walkable street, selected by survey respondents, as representative of the whole neighborhood. The respondents of the survey lived in different areas in Dallas Fort Worth Metropolitan area and not necessarily live in the neighborhoods where these streets are. So the selected streets are streets that are mostly known regionally. These streets have higher number of pedestrians compare to other streets in their corresponding neighborhood. For future studies, this dissertation suggests expanding the study area to all streets of each neighborhood. This will provide a better understanding of the relationship between smart neighborhood characteristics and number of pedestrians.

Expanding the study area will provide the opportunity to test variables at different levels. It can provide a more comprehensive understanding of smart neighborhood characteristics. A larger-scale study requires more sources and more time, and researchers should consider it. Another recommendation is to conduct a similar study in different cities and compare the results. Further studies in larger-scale increase the reliability of the claim and increase the generalizability of the results. A further recommendation for future study is to interview and survey urban planners, designers, and experts and analyze their perception of smart walkable neighborhoods.

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