AN INVESTIGATION OF SCHOOL WALKABILITY IN DIFFERENT NEIGHBORHOOD CONTEXTS IN ANKARA WITH THE PROPOSED GIS TOOL

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

SİMGE REYHAN

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
GEODETIC AND GEOGRAPHIC INFORMATION TECHNOLOGIES

FEBRUARY, 2022

Approval of the thesis:

AN INVESTIGATION OF SCHOOL WALKABILITY IN DIFFERENT NEIGHBORHOOD CONTEXTS IN ANKARA WITH THE PROPOSED GIS TOOL

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

AN INVESTIGATION OF SCHOOL WALKABILITY IN DIFFERENT NEIGHBORHOOD CONTEXTS IN ANKARA WITH THE PROPOSED GIS TOOL

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February 2022, 121 pages

Children walking to school contributes to the daily required physical activity recommended by health guidelines and makes them less prone to obesity and mental health problems. Urban form characteristics such as distance, density, diversity that have the potential to encourage children to walk to school are essential for the public health and livability of cities. The main aim of this study is to analyze and compare the school walkability in the different neighborhoods to understand the role of neighborhood design in children's walking behavior. Three neighborhoods were selected from Ankara: Bahçelievler (traditional neighborhoods with garden apartment houses), İşçi Blokları (mixed-use neighborhoods of 1970s with low- and high-rise apartments) and Kuzeykent neighborhoods (contemporary high-rise mass housing developments), all of which represent different urban form characteristics. The study proposes a new model based on Geographic Information System (GIS) to measure school site walkability for decision makers to perform urban computations more accurately and easily. School walkability toolbox is created with the Model Builder tool of ArcMap Software. The toolbox contains following models: pedshed ratio, building density, land use mix (based on ground floor and based on building), traffic exposure, NDVI based greenness score. Building data (includes floor number and land use), road data (includes road width), and Sentinel 2 data (Band4 and Band8) are collected and prepared as inputs of the toolbox to measure school walkability. The output of each model in the prepared toolbox is the result of the measurement equation. Results show that Bahçelievler neighborhood encourages children to walk to school more compared to İşçi Blokları and Kuzeykent neighborhoods, respectively. In terms of parameters, while the highest values varied between İşçi Blokları and Bahçelievler neighborhoods, Kuzeykent neighborhood has shown the lowest performance in all parameters except building density. Results argue that over the years, because of the urbanization policies, compared to children living in the pre-1990s of Ankara (where one could see mixed-use neighborhoods with both low- and high-rise apartment buildings), today's children are more likely to live in neighborhoods that less support school walkability in Ankara. The study highlights the importance of planning decisions on school sites to encourage children's walking to school. This understanding may help urban planners to create more healthy and livable neighborhood environments for children.

Keywords: School Walkability, Built Environment, Urban Form, Geographic Information System (GIS), Ankara

ÖZ

ANKARA’DA FARKLI KENTSEL FORMLARDAKİ MAHALLELERDE OKUL YÜRÜNEBİLİRLİĞİNİN ÖNERİLEN GIS ARACIYLA İNCELENMESİ

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Ocak 2022, 121 sayfa

Çocukların okula yürüyerek gitmeleri, sağlık yönergeleri tarafından önerilen gerekli günlük fiziksel aktiviteye katkıda bulunur ve obezite ve ruhsal sağlık sorunlarına daha az eğilimli olmalarını sağlar. Çocukların okula yürümelerini teşvik etme potansiyeline sahip mesafe, yoğunluk, çeşitlilik gibi kentsel form özellikleri, halk sağlığı ve yaşanabilirlik açısından önem taşımaktadır. Bu çalışmanın temel amacı, mahalle tasarımının çocukların yürüme davranışındaki rolünü anlamak için farklı mahallelerdeki okul yürünebilirliğini objektif verilerle analiz etmek ve karşılaştırmaktır. Ankara’dan, farklı kentsel form özelliklerini temsil eden üç mahalle seçilmiştir: Bahçelievler Mahallesi(geleneksel, bahçeli apartman mahalleleri), İşçi Blokları Mahallesi (1970’lerin az katlı ve yüksek apartmanlı karma kullanımlı mahalleleri) ve Kuzeykent Mahallesi (çağdaş yüksek katlı toplu konutlar).Çalışma, karar vericilerin kentsel hesaplamaları daha doğru ve kolay bir şekilde yapabilmeleri için okul çevresinde yürünebilirliği ölçme amacıyla Coğrafi Bilgi Sistemine (CBS) dayalı yeni bir model önermektedir. Okul yürünebilirlik araç kutusu, ArcMap yazılımının Model Builder aracı ile hazırlanmıştır. Araç kutusu çeşitli modeller içerir. Bunlar yaya alanı oranı, bina yoğunluğu, zemin kata dayalı karma arazi kullanım indeksi ve binaya dayalı karma arazi kullanım indeksi, trafik maruziyeti, NDVI tabanlı yeşillik skorudur. Bina verileri (kat numarası ve arazi kullanımı içerir), yol verileri (yol genişliğini içerir) ve Sentinel 2 uydu verileri (Band4 ve Band8) toplanır ve okulun yürünebilirliğini ölçmek için araç kutusunun girdileri olarak hazır hale getirilir. Hazırlanan araç kutusundaki her bir modelin çıktısı, ölçüm denklemlerinin sonuçlarıdır. Çalışma, Bahçelievler Mahallesi'nin çocukları okula yürüyerek gitmeleri için, İşçi Blokları ve Kuzeykent mahallelerine göre daha çok teşvik ettiğini göstermektedir. Parametreler açısından en yüksek değerler İşçi Blokları Mahallesi ile Bahçelievler Mahallesi arasında değişirken, Kuzeykent Mahallesi yapı yoğunluğu dışındaki tüm parametrelerde en düşük performansı göstermiştir. Sonuçlar, yıllar içinde değişen kentleşme politikaları nedeniyle, 1990'lı yılların öncesinde yaşayan çocuklarla karşılaştırıldığında (hem düşük hem de yüksek katlı apartmanlara sahip karma kullanımlı mahallelerin görülebileceği mahalleler), günümüz çocuklarının Ankara'da okul yürünebilirliğini daha az destekleyen mahallelerde yaşama olasılığının daha yüksek olduğunu gösteriyor. Çalışma, çocukların okula yürüyerek gitmelerini teşvik etmek için, okul çevresindeki planlama kararlarının önemini vurgulamaktadır. Bu anlayış, şehir plancılarını çocuklar için daha sağlıklı ve yaşanabilir mahalle çevrelerini oluşturmalarına yardımcı olabilir.

Anahtar Kelimeler: Okul Yürünebilirliği, Yapılı Çevre, Kentsel Form, Coğrafi Bilgi Sistemi (CBS), Ankara

To my mom

ACKNOWLEDGMENTS

I would like to express my gratitude to my dear advisor Yücel Can Severcan, for always being supportive and enlightening throughout the research. His positive attitude made this process much better for me.

I would like to thank my co-advisor, Zuhal Akyürek, for her valuable contributions. I would also like to thank the examining committee, Prof. Dr. Ela Babalık, Asst. Prof. Müzeyyen Anıl Şenyel Kürkçüoğlu, Prof. Dr. Arzu Erener and Assoc. Prof. Serkan Kemeç for their suggestions and comments.

I would like to give special thanks to my greatest supporter during this thesis, and my favorite person in my life, my mother, Suzan Reyhan. I am grateful for his endless love and patience.

I am thankful for their support of my sister, Sinem Baki, and brother-in-law, Ömer Baki. I would like to thank my nephew Poyraz for entertaining me during breaks. I hope he will be walking to school in the future.

I owe special thanks to Bihter Kizilca, Esra Gürel, Şevval Çavuşoğlu, and Övünç Ertunç for their supportive and warm friendship that are always with me. I am also very grateful for the existence and encouragement of Gizem Demirkol when I need her.

I would like to thank my dear colleagues from GEOSYS for the pleasant and warm atmosphere they created.

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INTRODUCTION

1.1 Problem Definition

Obesity has become a growing problem in the world, reaching pandemic levels (Blüher, 2019). According to World Health Organization, since 1975, global obesity has almost tripled. Being overweight or obese increases the risk of cardiovascular diseases (like heart and vessel diseases), asthma, diabetes, some cancers, and poor mental health (Bischoff et al., 2017). Childhood obesity is an important public health issue. Simmonds et al. (2016) emphasized in their systematic review (includes countries from Europe, Asia, and America) that nearly 55% of obese children (7-11 ages) remains obese in adolescence, and 80% of obese adolescents (12-18 ages) remain obese in adult age.

Changing world conditions and policies have impacts on children's obesity levels as well as adults. In Turkey, similar to the trends in the world, Health-Related Physical Fitness Report (2017) shows the rate of overweight and obesity in children (10-14 ages) was 30.1%. Additionally, overweight and obesity rates in children (7-8 ages) was 20,8% in 2009, and it increased to 24,5% in 2016 (T.C. Sağlık Bakanlığı, 2019). In Ankara, where the study focuses, the childhood obesity rate is 1.5 times more common than national estimation (Yardım et al., 2019).

Limiting energy intake and providing adequate physical activities in daily life ensure the prevention of obesity on the individual level. However, individual precautions are not enough to prevent obesity (Feng et al., 2010). A review of the public health and planning literature shows that urban form is an influential factor in physical activity and health-related outcomes in society (Ewing et al., 2014; Frank et al., 2004; Prince et al., 2012; Sallis et al., 2016). The fact that walking is a type of activity influenced by environmental characteristics suggests that creating more walkable places may prevent obesity.

Children actively commuting to school are able to meet the required physical activity level (Tudor-Locke et al., 2002). In fact, recent findings suggest that in some countries like Hong Kong, walking to school can be the only physical activity of children (see Karsten, 2015). In such contexts, because of their obligations (e.g., extracurricular activities, domestic responsibilities), children have limited out-of-school time, leaving them no free time for other types of physical activity that can take place in public spaces. Children who walk to school prone to be more physically active and less overweight and obese (Cooper et al., 2005; Drake et al., 2012; Heelan, 2002). Traveling by walking to school has not only health but also ecological, social, and cognitive benefits. Therefore, it is important to create built environments that support children to walk to school for healthy generations, a sense of community, and livable places for residents from all ages. There are many projects across the globe that encourage children to walk to school. Some of these are implemented by governmental institutions (e.g., Safe Routes to School from the United States and Transport, Environments and Kids (TREK) from Australia). Parallel to these implementations, there are a growing number of scientific studies that investigate the role of these implementations on children’s travel behaviors (Boarnet et al., 2005; Trapp et al., 2012).

After World War II, a variety of issues, including the promotion of low-density, low mixed-use, and non-compact developments, caused to decrease in residents’ walking behavior. Especially after the 1970s, parallel to the scientific developments in the field of public health, urban planning and design started to put greater emphasis on the importance of creating walkable neighborhoods. Car-free city initiatives in Italy, Home Zone initiatives in Europe, New Urbanist developments in the United States, and more recently 15-minutes city project in Paris are just a few examples of how cities aimed to encourage walking through urban planning and design policies at different scales.

The reason for the effort to create a walkable environment is not only obesity but also other factors such as mental well-being, economic development, environmental pollution, and social cohesion. Walking contributes to the physical and mental well-being of people (Ferdman, 2019; Spokane et al., 2007). Walkability creates economic value. A better pedestrian environment leads to more commercial activity. According to Burden & Litman (2011), people who walk spend more than people who travel in their vehicles for a day. Walking is a basic form of transportation. People can save on transportation costs in walkable areas instead of using public transport or driving their cars (Litman, 2003). Furthermore, driving is one of the most significant parts of an individual's carbon footprint (Speck, 2018). Walkability decreases car usage and thus causes less environmental pollution. Walkable environments also contribute to the sense of community by providing the potential of interactions between people and places (Wood et al., 2010).

As in many other cities across the globe, the macroform of Ankara has leap frogged into peripheral areas. Over the years, the design of the neighborhoods in Ankara has been formatted according to the changing planning approaches. This thesis focuses on the role of neighborhood design in influencing children's school travel behavior.

1.2 Objective of the Study

The main aim of the study is to assess and compare the school walkability of three different neighborhoods that reflect different design traditions in Ankara based on an analysis of various meso-scale urban form variables. It asks: Based on their urban form characteristics, how walkable are the school areas in traditional neighborhoods with garden apartment houses, mixed-use neighborhoods of 1970s with low- and high-rise apartments and contemporary high-rise mass housing developments for children? Which neighborhoods perform better or worse regarding their school walkability and why? To answer the above-mentioned main research question, the thesis asks the following additional questions to construct a geographic information system (GIS) based model to help authorities assess school walkability:

1. What methods do we have to measure the walkability of neighborhoods?

2. What are the most appropriate objective variables in meso-scale for measuring school walkability for authorities having limited data sources, research budgets, time, and skill?

3. How can walkability measures be incorporated into a GIS tool for measuring school walkability?

These three questions provided a base for the author to conduct the literature review.

Scholars have used different methods to evaluate school/neighborhood walkability. They either focused on perceived walkability (which is usually obtained from surveys) and objective walkability, which is obtained from audit or GIS tools (Ikeda et al., 2018; Kerr et al., 2006; Molina-García et al., 2020; Timperio et al., 2006). There are many different approaches for measuring objective walkability with GIS tools. Davison and Lawson (2006) emphasized that there is no coherency in the methodological approaches used in walkability studies. Furthermore, according to them, researchers require more advanced designs to measure walkability while quantifying the built environment (Davison & Lawson, 2006). This study provides an extensive literature review of the methods used for objectively measuring the built environment. Thereafter, based on this review, it proposes a GIS-based school walkability index tool.

Existing studies on walkability, by and large, examined this concept by linking various urban form variables to children's school walking rates (Giles-Corti et al., 2011; Ikeda et al., 2018; Schlossberg et al., 2006). Most studies were conducted in the developed countries, and hence, for example, examined the role of the new urbanist neighborhoods in the United States in the ordinary public's neighborhood walkability (Al-Hagla, 2009; Gallimore et al., 2011; Napier et al., 2011). In many of these studies researchers obtained publicly-available and readily accessible GIS data –an opportunity which enabled them to collect self-reported data to answer more complex questions like the relationship between children's walking behavior and objectively measured neighborhood form characteristics. In many parts of the developing world, including Turkey, this is not the case; researchers lack the opportunity to access updated and publicly available GIS data. This issue requires researchers to invest their time in editing the existing data in order to update it, replace the missing data with field data, and make it ready for analysis. Thus, editing large-scale maps is a daunting task for researchers in developing countries, especially for those who have limited time and financial capital.

1.3 Contribution of the Thesis

To the best of the author's knowledge, this is the first study that compares different planned neighborhoods in Turkey based on their meso-scale urban form characteristics (like land use mix and greenness index) and the potential of these characteristics to encourage children's school walking. This understanding may help urban planners not only to change the existing land use and urban design policies in existing developments but also shape the planning decisions of future developments to increase children's walking to and from school. For example, in neighborhoods with low connectivity levels and land use mix and greenness indices, planners may use the scarce government resources to invest in policies that encourage the development of tree-canopy streets with commercial, cultural, and recreational uses. The qualities of existing urban regeneration projects can be better assessed regarding their potential to encourage school walking. Additionally, in a context where the number of mass housing projects increases annually, the results of this thesis may help urban planners and decision-makers understand whether they are on the right track regarding the creation of healthy societies.

Another contribution of this thesis is the proposed GIS tool for decision makers, local governments, and NGO members who make policies and interventions in school districts to improve walkability. This tool aims to provide automation of the analysis and therefore provide time-saving, convenience, and effectiveness on urban computations. Moreover, within the scope of the thesis, the base map of all three selected neighborhoods is created with features of street pattern, building, and land use and presented. With these up-to-date base maps, researchers having limited time will be able to ask new research questions in future research. Complex research questions that combine self-reported data with objective data can be answered in a shorter time.

1.4 Structure of the Thesis

This thesis is composed of five chapters, including the introduction. Figure 1.1 presents the structure of the study. In Chapter 2, walkability definition, history of walkability concept in urban planning, the characteristics of walkable environments are introduced. Walkability studies from different fields such as transportation, health, and urban planning and their different methodological approaches are described in the historical process. Data types used to measure the walkability of the built environment, and their pros and cons are reviewed. Detailed information about GIS based approaches for measuring walkability is discussed in this section. Thereafter, the school walkability framework and meso scale urban form characteristics relationship with school walking are focused. Chapter 3 focuses on the methodology of the study. To create the planning framework of the study, the planning history of Ankara and neighborhoods, which are selected according to their urban form characteristics are described. Secondly, GIS data preparation is also included in this chapter. After that, the proposed GIS tool to measure school walkability with ArcGIS Model Builder is explained. Content of the selected parameter models, namely, pedshed ratio, traffic exposure from the road network, residential density, land-use mix, and normalized difference vegetation index (NDVI), are described step by step. Chapter 4 includes the results of the analysis. The chapter highlights the neighborhoods that perform better or worse regarding their school walkability. In Chapter 5, the thesis is concluded with a summary of the study. It contains a discussion of results, implications, and limitations of the study, and suggestions for further research.

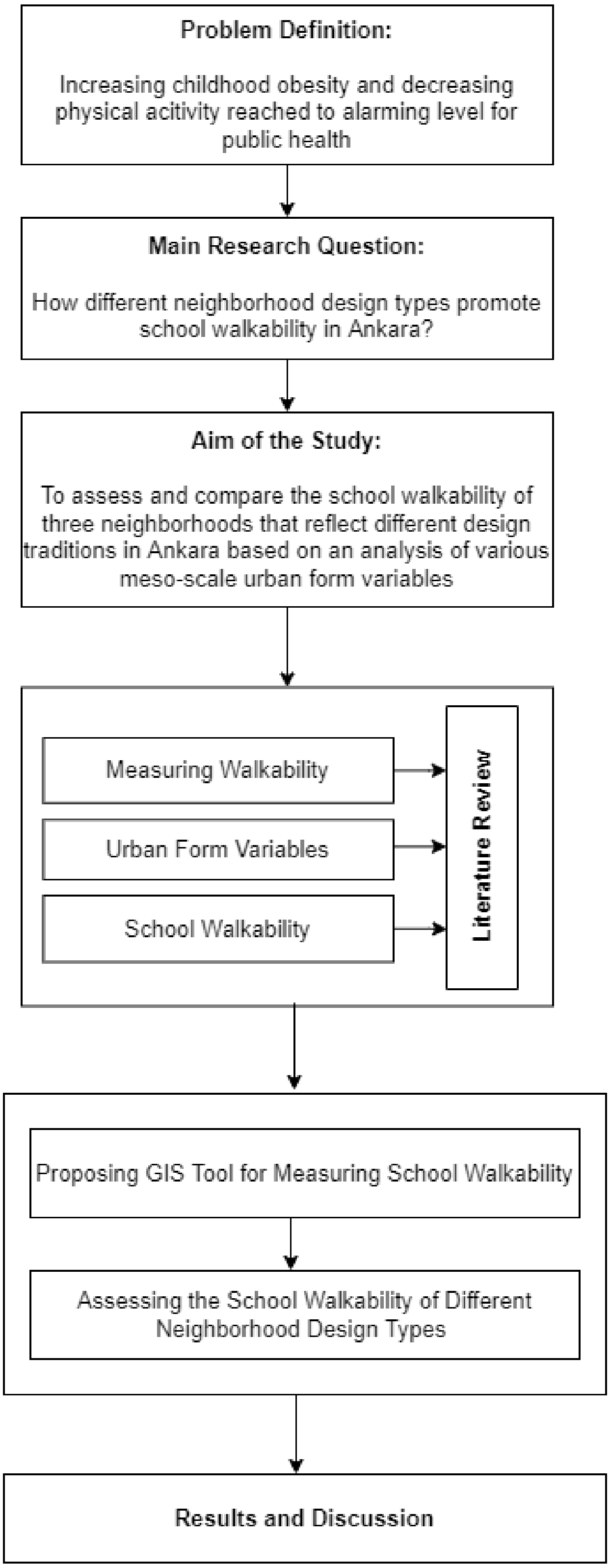


Figure 1.1. Structure of the study

CHAPTER 2

LITERATURE REVIEW

This section contains literature research on walkability concept and school walkability. First walkability definition, its history in urban planning context and main characteristics which are used to measure walkability in neighborhoods will be explained. Also, the review of studies from the walkability literature with different fields and their different methodological approaches will be discussed. Secondly, data types (objective data and perceived data) which are used to measure walkability, their data sources (how they are obtained) and their pros cons will be discussed.
This part also focuses on different methodological approaches that use GIS tools to measure walkability. Thirdly, school walkability and its importance in terms of children's health, cognitive development and social interaction are explained. After that, the general framework including factors which affect the school walking behavior are emphasized. Finally, the urban form characteristics and their relationship with school walking rates are investigated to determine parameters that are used to measure the school walkability in Chapter 3.

2.1 Neighborhood Walkability

2.1.1 The Concept of Walkability and Walkable Neighborhoods

Walkable environments are places which are traversable (i.e., places which enable residents to move without barriers), compact (places which have short distances between destinations), safe (places where crime rates and perceived safety issues are low) and visually pleasing (i.e., places having visually pleasing infrastructure, architecture and landscape elements) (Forsyth, 2015). According to ideal walkable neighborhood definition of Talen and Koschinsky (2013), they have urban form that supports pedestrian mobility, have diversity in the social, economic and land use context, have equal access to facilities, high-quality public spaces, and support environment and human health. In addition, walkable environments support not only walks for transportation such as work and shopping, but also for recreation and health (Southworth, 2005). Walkability is used to measure the extent to which the built environment supports people to walk (Wang & Yang, 2019).

2.1.1.1 The History of Walkable Neighborhoods in Urban Planning

Walking was a necessity for cities before industrialization in the absence of motorized transportation (Southworth, 2005). It was the main transportation mode in the cities. The configuration of street networks and residential units, and the location of uses in the urban macroform were influenced based on people's walking needs and behavior.

With Industrial Revolution, the invention of mechanical tools and steam engine caused big changes in cities. Overcrowding, pollution, poor infrastructure of water supply and sewerage, and poverty were some of the problems of 19th Century cities (Corburn, 2012). These unhealthy conditions of urban areas resulted in the widespread outbreaks of diseases. Urban planning as a profession emerged in these conditions to provide healthier environments and social justice. During this period, major planning theories emerged, and walkability became one of the main concerns of planners and architects in the context of public health. Urban utopians have revealed the ideal city approaches aiming walkable city such as Ebenezer Howard's Garden City Movement and Clarence Perry's Neighborhood Unit (Guan et al., 2019; Talen & Koschinsky, 2013).

After the industrialization, because of the widespread usage of automobiles, car-oriented developments began to prevail in cities, and they became barriers for pedestrians (Southworth, 2005).With the Post-War II era, the rise of suburban developments, segregation of land uses, low density, long block length, and long distances to destinations resulted in the decline of walkability in cities (Randall & Baetz, 2001). Especially after the 1980s, through new urban planning approaches such as New Urbanism, Transit-Oriented Development, Smart Growth, LEED-ND (Leadership in Energy and Environmental Design Neighborhood Development), which was based on sustainability, walkability has again become one of the main focuses in cities (Napier et al., 2011; Sim, 2016; Zook et al., 2012).

2.1.1.2 Measurable Characteristics of Walkable Neighborhoods

As a way of quantifying the built environment, walkable neighborhoods contain some measurable characteristics. In the following sub-sections, each of these characteristics of urban form are introduced.

2.1.1.2.1 Density

Density is one of the key characteristics of walkable neighborhoods. It refers concentration of people and places (Dovey & Pafka, 2020). Density broadly refers to compact neighborhoods with short walkable distances between origin and destinations (Leslie et al., 2007). Dense areas are more likely to provide better public transportation (Cervero & Kockelman, 1997). Common variables used to measure density are the number of dwellings per area (residential density), number of people per area (population density), and number or total area of buildings per area (building density) (Feng et al., 2010).

2.1.1.2.2 Diversity of Land Uses

Diversity means the variation of land use functions. Diversity of land-uses provides people more destinations to walk. Additionally, it enables the proximity of distance between destinations (Leslie et al., 2007). Dissimilarity index, entropy index, mean entropy index are used to measure land-use mix as diversity (Brownson et al., 2009).

The most common is entropy index, which is the ratio of land uses (e.g., residential, retail, public, offices, industrial, health, and recreations) to total land area. The result score is between 0 and 1, which refers to the homogeneity and heterogeneity of the land respectively (Cervero & Kockelman, 1997). In addition, land use mix is diversified by horizontal and vertical land use. Vertical land use mix means including different uses on the floors in the same building, for instance, first floors are used for retail and upper floors are used for residential or office purposes. Horizontal land use mix means single land use entry for each building. In most of the walkability studies, land use mix index is limited to use horizontal land use mix because each parcel is assigned to a singular land use in their data (Lovasi et al., 2012; Sallis et al., 2016). According to Torun et al. (2015), ground floor land use is a critical factor for the vitality, safety, attractiveness and so walkability of neighborhoods since ground-level uses are the part where walking people interact most. Uses such as stores, cafes and restaurants, rather than banks, offices, parking garages support the public realm, and hence encourage people to walk for going from one place to another (Gehl, 2010). Evidence shows that uses that attract the attention of people vary based on personal characteristics like age and gender. As an example of land uses that attract children’s attention, Moore and Young (1978) mention in their study that, children (8-12 ages) draw their homes, vegetation areas, pathways and community facilities, open spaces and streets respectively as their favorite places where they spend free times. Many studies that investigate children’s preference places show that children like to be in places where they interact with nature, and where they can play and socialize (Castonguay & Jutras, 2009; Freeman, 2010; Severcan, 2018).

2.1.1.2.3 Connectivity

Connectivity refers the quality of connections of street network (Handy et al., 2003) It is used to measure how easily one can travel from an origin to a destination in a street network (Feng et al., 2010). More intersections, smaller blocks, fewer cul-de-sacs, and fewer main roads mean higher connectivity (Southworth, 2005) High connectivity refers to shorter distances and directness between destinations and multiple alternative routes (Saelens & Handy, 2008). Molaei et al. (2021) investigate the common ten variables to measure connectivity. These ten variables and definitions are shown in Table 2.1.

Table 2.1 Connectivity Measures (Source: Molaei et al., 2021)

Variables	Definitions	Equations
Intersection density	• The ratio of intersections in a unit area. • A higher number means more intersections that lead to more connectivity.	$\frac{number\ of\ intersection}{unit\ area}$
Street density	• Total length of streets per unit of an area. • A higher density is equal to a higher connectivity.	$\frac{total\ lenght\ of\ streets}{unit\ area}$
Block density	• Total number of blocks in a district divided by its area. • Higher block density means smaller blocks and, as a result, higher connectivity.	$\frac{total\ number\ of\ blocks}{unit\ area}$
Cul-de-sac density	• The number of all cul-de-sacs per square km. • The fewer cul-de-sacs, the more intersection, and the higher connectivity	$\frac{number\ of\ cul\ de\ sacs}{unit\ area}$
Average block length	• Total length of links should be divided by the number of nodes in an area • There is an inverse relationship between the average length of streets and connectivity	$\frac{length\ of\ links}{number\ of\ nodes}$

Table 2.1 (continued)

Average block section	• Maximum distance between any two points on the perimeter of a block • The minimum block section means better connectivity	maximum distance between any two points on the perimeter of a block
Connected node ratio	• Proportion of real nodes to the total of all nodes calculated by dividing the number of three-way and four-way intersection by the sum of all nodes. • The maximum ratio is 1 representing a more connected street network	$\frac{number\ of\ real\ node}{all\ nodes}$
Link node ratio	• The number of streets (links) to the total number of real nodes. • Link node ratio of 1.4 or more is a desirable target for urban planners in the term of connectivity of street .	$\frac{the\ number\ of\ links}{the\ number\ of\ real\ nodes}$
Alpha index	• proportion of the number of real circuits to the highest possible number of circuits • This feature of geography studies ranges from almost 0 for poorly connected networks to about 1 for higher connectivity	$\frac{\#Links - \#Nodes + 1}{2(\#Nodes) + 5}$
Gamma index	• ratio of the number of streets in the network to the maximum possible number of streets between intersections • The higher ratio for the gamma index results in better connectivity.	$\frac{\#Links}{3(\#Nodes - 2)}$

Ellis et al. (2016) mention different connectivity measures (intersection density, link-node ratio, pedestrian route directness, pedestrian shed, metric reach, and directional reach). Intersection density and Link-Node Ratio are seen as parameters for large areas, Pedshed and Pedestrian Route Directness are used for the origin-destination route measure, and lastly, metric and directional reach parameters aim to measure the possibility of route options and directions. The result shows that intersection density and metric reach have better performance than others to measure connectivity. Also, these scholars propose the usage of footpath instead of the road centerline data since footpath is a more proper way to evaluate the pedestrian connectivity. According to them, the usage of up-to-date and complete footpath data increases the accuracy of the walkability index. Road line data may not be appropriate for the neighborhoods which have differences with unformal paths, parks, pedestrian bridges, underground paths, greenways. It is better to use footpath for the decision-makers who evaluate and improve the pedestrian infrastructure if they have up-to-date and complete data (and safe pedestrian crossings on each road intersection). The results show that, while intersection density and the metric reach have the most correlation with the self-reported physical activity, the least correlated one is Pedestrian Route Directness. Moreover, the 10 minutes walking buffer (1000 meter) is more correlated with physical activity than 5 minutes walking buffer (500 meter) for connectivity measures (Ellis et al., 2016). However, Cruise et al. (2017) found that road line-based data has better performance in association with walking rates in the study comparing the footpath data and road line data while measuring the walkability indices. They mentioned the foot path data is an acceptable alternative to measure walkability index (Cruise et al., 2017).

2.1.1.2.4 Proximity

Proximity to facilities is one of the most critical factors for walkability of neighborhoods. Because distance between origins and destinations affect people's transport mode choices. Closer proximity between non-residential uses provides compactness and, therefore, people are willing to walk rather than using cars (Saelens et al., 2003). The walkable neighborhoods are expected to have facilities and services (schools, parks, stores, restaurants, pharmacies, bus stops, health center) within a 10 minutes walking distance (which is approximately 800-1200 meters) (Zuniga-Teran et al., 2017). Furthermore, walking distance may vary depending on ages. Alves et al. (2020) argued that primary services should be located in 500 meters and secondary services should be in 800 meters distance for elderly people. Rodríguez-López et al. (2017) investigated threshold distances for children and adolescents to walk to school. They find that the threshold distance was 875 meters in children and was 1,350 meter in adolescents (Rodríguez-López et al., 2017).

2.1.1.2.5 Micro Scale Design

Design refers to micro scale built environment elements. These elements are related with the qualities of streetscapes and include path quality, path context, safety, attractiveness and aesthetics of the place (see Table 2.2). Ewing and Handy (2009) developed a framework to identify design quality elements (imageability, enclosure, human scale, transparency and complexity) and their related physical built environment items in street(e.g., number of people, major landscape features, proportion of street wall, long sight lines, proportion sky ahead, proportion first floor with windows, public art), that affect individual’s reactions(sense of comfort, sense of safety and level of interest) and thus, walking behaviors. Additionally, although distance is a very critical feature that affect walking, Guan et al. (2019) emphasize that walking behavior is more affected by the visual interest of the built environment on the way rather than distance.

Table 2.2 Street Level Design Elements (Source: Aghaabbasi et al., 2018; Mcnally, 2010; T. Pikora, et al., 2003; Southworth, 2005)

Street Level Design Elements	**Definitions**	**Variables**
Path Quality	Path quality is related with the pedestrian infrastructure in the streets.	• Maintenance • Continuity • Sidewalk Width
Path Context	Path contexts features include characteristics that increase the pleasantness of pedestrian environments.	• Street Trees • Street Furniture • Cleanliness
Safety	Safety feature refers to enable safety environment in the context of personal and traffic.	• Lighting • Signs • Crossing • Traffic calming elements • Vehicle parking
Attractiveness and aesthetic	Attractiveness and aesthetic feature refer to people's level of interest.	• Landmarks • Destinations • Buildings Form • Benches

2.1.2 A Review of Studies on Walkability

2.1.2.1 History of Walkability Studies

Transportation studies were the first that examine the topic of the built environment and walking behavior. Measuring the built environment has become common with the 3D's, which are density, diversity, distance (Cervero & Kockelman, 1997). The transportation field focuses on walking as a mode of transport with variables such as pedestrian volume, capacity, demand, trip origin/destination (Hess et al., 1999). Research from the health literature focuses on walkability to investigate the built environment, physical activity, and health outcomes such as obesity and overweight (Frank et al., 2004; Prince et al., 2012). Researchers from urban planning field mainly aim to understand how different planning and design approaches affect people's walking behavior. They investigate walkability and relationship between urban form, walking level, microscale design dimensions, quality of place, ecologic, and sustainable development (Barros et al., 2017; Ewing & Handy, 2009; James et al., 2017; Zuniga-Teran et al.,20177).

2.1.2.2 Methodological Approaches in Walkability Literature

There are commonly two different purposes of the walkability research. The first is to develop methodological approaches to measure walkability. The main goal of these studies is to determine the indices, audit tools, and frameworks to quantify the built environment. Walkability index (L. D. Frank et al., 2010), Walk Score (Duncan et al., 2011), Space Syntax Walkability (Koohsari et al., 2016), Agent-based walkability model (Yin, 2013) are examples of such studies. The aim of other studies to investigate the relationship between walkability and various variables. These variables are air quality (Marshall et al., 2009), urban form (Zuniga-Teran et al., 2017), green spaces (Zuniga-Teran et al., 2019), streetscape features (Ewing et al., 2016), environmental justice (Łaszkiewicz & Sikorska, 2020), demographic features (Wen & Kowaleski-Jones, 2012), Body Mass Index level (Lovasi et al., 2012), and real estate value (Zhang et al., 2019). Most of these studies use logistic regression to explore the walking behavior.

2.2 Measuring the Walkability

2.2.1 Data Types

Walkability studies need high-quality measures to evaluate the relation between the built environment and walking behavior (Brownson et al., 2009). So far, these studies have measured the walkability of the built environment with various data types. The measures of walkability can be categorized as objective data which is based on physical environment measures (not self-reported or vary from one social group to another) and perceived data which is based on individuals' assessment of the environment. Perceived data is generally used to understand how residents of a neighborhood perceive the built environment. It is obtained from individual's assessments which include, but are not limited to, questionnaires, and interviews. Objective data are usually based on observational and computational methods. Audit data are gathered from the systematic observation tool which is developed for certain purposes such as measuring the built environment. The other objective data is obtained using the GIS databases. Databases, that are exist or created for this purpose, are a very useful way to evaluate the walkability objectively.

2.2.1.1 Perceived Data

Data included people's perceptional assessments is one of the main data for built environment and physical activity studies. They are usually gathered from interviews and self-administered questionnaires. They generally include checkboxes and scale rating questions. Obtaining such data is time-consuming and costly (Sabzali Yameqani & Alesheikh, 2019). Statistical analysis such as test-retest, interclass correlation is used to evaluate the reliability. GIS or audit data can be compared with the perceived data to measure the validity of perceived measures (Brownson et al., 2009).

2.2.1.1.1 Tools for Collecting Perceived Data

There are some audit tools developed to measure the perceptions of residents systematically. One of the most frequently used is "Neighborhood Environment Walkability Scale (NEWS)". It includes 68 questions about perceived characteristics of neighborhoods to use in physical activity research, particularly walkability studies. The measured characteristics are residential density, land use mix–diversity, land use mix access, street connectivity, walking/cycling infrastructure, aesthetics, pedestrian traffic safety and crime safety (Cerin et al., 2006).

Kirtland et al. (2003) developed a survey tool named "Perceptions of Environmental Supports Questionnaire" to measure the environment that supports physical activity. It assesses the environment based on two different scales which are neighborhood level (10-minute walk from home) and community level (20-minute drive from home). Neighborhood items are access (existence of sidewalks and public recreation facilities), characteristics (rating to be walkable), barriers (crime safety, motorized traffic), social issues (neigborhood members) and uses. Community items are included to access (using recreation facilities, parks, swimming pool), for barriers (safety of public recreation facilities) and social issues (recreational/physical activity clubs, programs) (Kirtland et al., 2003).

Another audit tool is "Systematic Pedestrian and Cycling Environmental Scan (SPACES)." It contains both subjective, audit and GIS data. Instrument collects data that asses the neighborhood in the street level. It includes evaluation categories for streets which are functional, safety, aesthetics, destinations. The subjective assessment examines the attractiveness and difficulties based on observer' perceptions (Pikora et al., 2002).

2.2.1.1.2 Studies That Involve Perceived Data

There are many studies which use perceived data to examine the relationship between walking behavior and built environment (see, Cerin et al., 2007; Humpel et al., 2004; Sugiyama et al., 2014; Zuniga-Teran et al., 2017). Most of these studies aim to investigate the correlation between walking behavior and perception of built environment. These studies also show that individuals' needs, and motivations determine the type of walking. Humpel et al. (2004) listed these types as neighborhood walking, walking for exercise, walking for pleasure, and walking to get to and from places. Different dimensions of the built environment have different effects on different walking types. For example, while aesthetic has a positive correlation with walking for exercise, safety and accessibility have a positive correlation with walking for pleasure. Sugiyama et al. (2014) focus only the recreational walking. To evaluate the association between the perceived built environment and walking, they used survey data from 12 different countries conducted with participants in 18-66 age range. Perceptions about the environment are categorized as residential density, land use mix-access, street connectivity, infrastructure and safety, aesthetics, safety from traffic, safety from crime, few cul-de-sacs, and no major barriers. They found that perceptions about residential density, land use mix, connectivity, aesthetics, safety from crime, few cul-de-sacs, proximity to parks are positively related with recreational waking (Sugiyama et al., 2014). Also, Humpel et al. (2004) mentioned that aesthetic has the most correlated feature with walking. Perceived unsafety of environment caused to be less prone to walking for recreation. Furthermore, they generally found a consistent correlation between the different countries (Humpel et al., 2004). That study, which is conducted in different countries, and which found that the built environment is mostly similarly associated with walking, showed that a generalization can be made in this regard. Zuniga-Teran et al. (2017) developed a Walkability Framework about walkability categories (connectivity, density, land use, traffic safety, surveillance, experience, parking, green space, and community), which was later integrated into a questionnaire study. They searched the relation between Walkability Framework and two main types of walking which are recreation and transportation. They showed that Walkability Framework has remarkable correlation. Traffic safety and land use from the categories are effective for walking of both purposes (Zuniga-Teran et al., 2017).

There is a great deal of literature investigating the relationship between objective and perceived assessments. Cerin et al. (2007) searched the correlation between objectively measured with GIS walkability and perceived walkability which is obtained by abbreviated Neighborhood Environment Walkability Scale (Chinese NEWS-A). They measured household density and intersection density for objective walkability. Their study showed that people who lived in objectively high walkability neighborhoods perceive high residential density, land-use mix diversity, access to services, street connectivity, infrastructure, and safety for walking (Cerin et al., 2007).

Gebel et al. (2009) aim to investigate the adults’ characteristics who perceive their neighborhood differently (e.g., low perceived walkability) from the objective walkability (e.g., high objective walkability). They use the dwelling density, intersection density, land use mix, and net retail area to measure walkability objectively and, use the survey audit tool to obtain perceived data. Study shows that, first, there is a fair concurrence between objective and perceived walkability. Second, people, who live in objectively low walkable neighborhood and perceive neighborhood’s walkability as high, walk more than people, who live in objectively high walkable neighborhood and perceive neighborhood’s walkability as low. Also, among the people living in the same neighborhood, those who perceive the walkability of their neighborhood to be high tend to walk more than those who perceive the walkability of their neighborhood low (Gebel et al., 2009).

Furthermore, Gebel et al. (2011) examine the differences in perceived and objective measures of walkability and their effects on changes of walking and body mass index (BMI) level in four years. They found that people who live in objectively high walkability neighborhoods, and have incompatible perception (low perceived walkability) decreased walking levels and increased BMI levels more than those who have compatible perception (high perceived walkability). These studies present the importance of intervention aimed at enhancement on people’s perception (Gebel et al., 2011).

2.2.1.1.3 Pros and Cons of Perceived Data

There are some arguments about using perceived data for measuring walkability. This type of data varies according to people's ability to understand the environment, past experiences, characteristics, culture, and also mental health (Ewing & Handy, 2009). Hence, residents might perceive the environment differently even they live in the same neighborhood (Brownson et al., 2009; Gebel et al., 2009). This also means that the sample size becomes important in any study that aims to obtain self-reported data: the smaller the sample size is the less generalizable and valid are the gathered data. Time and financial capital constraints of researchers have a negative influence on the sample size of the research. Extreme environmental conditions including disasters and pandemics also negatively affect the field research.

Secondly, some items which are used for collecting the data are difficult to evaluate perceptually. For example, the features about connectivity such as path quality and intersection density all over the neighborhood may not be completely interpreted by residents (Van Lenthe & Kamphuis, 2011). Furthermore, some items such as sidewalks are more valid than items like safety because of the objective existence in the meaning of perceptual assessment (Brownson et al., 2009).

Thirdly, parameters used to calculate the walkability may not be appropriately evaluated because of individuals' lack of awareness of the built environment measures (Boarnet, 2003). Residents who walk more, know their environment more too. That's why some perceived barriers of walkability can be associated with higher walking level (Gebel et al., 2009). Also, people who walk more, have compatible perceived measure with objective measure (Gebel et al., 2009). Also, unawareness can be caused of the duration term of the residents. The ones, who reside long duration in the neigborhood, can be more aware and familiar of neighborhood physical features (Van Lenthe & Kamphuis, 2011).

Moreover, people may reduce the physical activity according to their inaccurate low perceived walkability despite of objectively high walkable neighborhoods (Van

Lenthe & Kamphuis, 2011). Therefore, the interventions that aim to improve the perceptions about the built environment may result in increased walking.

2.2.1.2 Objective Data

2.2.1.2.1 Audit Tool Data

Audit tools are developed to measure the environment based on direct observations. Main purposes of developing audit tools are increasing the quality of research (by increasing validity) and supporting the decision making of local governments. The built environment is assessed by the observer while walking according to audit tool which includes items about environment that likely to affect the walking behavior. Observer evaluates the neigborhood according to a structured form with ratings or checkboxes (Brownson et al., 2009).

I. Audit Tools

One of the earliest audit tools is Systematic Pedestrian and Cycling Environmental Scan (SPACES). Pikora et al. (2002) developed the tool to collect objective features data in street level. The feature categories include functional items about path surface, streets and traffic, safety items about personal and traffic, aesthetics items about streetscape and views, destination items about facilities. Tool also contains subjective assessment of observer’s perception.

Day et al. (2006) mentioned that there are some shortcomings about using SPACES to measure the features about planning and design. Researchers may need more detailed information about these features. Therefore, they developed one of the most used audit tools, Irvine-Minnesota Inventory. There are four categories which are accessibility, pleasurability, perceived safety from traffic, and perceived safety from crime (Day et al., 2006).

Besides the objective measures by the audit tools, some research focuses on the objective assessment of perceived qualities which is also named as urban design qualities (Ewing & Handy, 2009). They define five different urban design quality which are imageability, enclosure, human scale, transparency and complexity, and the physical features of these categories. According to them, urban form features such as land use mix and density are not enough to clarify the relation between walking behavior and built environment (Ewing & Handy, 2009).

Because field-based person audit is time-consuming and costly, researchers focus on the feasibility of using Google Street View, which is a new method to collect data easily (Lee & Talen, 2014; Rundle et al., 211). Rundle et al. (2011), collected the data items, which is categorized as aesthetics, physical disorder, pedestrian safety, motorized traffic and parking, infrastructure for active travel, sidewalk amenities, and social and commercial activity, from field and street view. Most of the items collected from Google Street view have conformity with the field observation, excluding the items that includes small and temporary features. Also, Google Street View has some limitations, such as the lack of existence of data on some streets and the not being up-to-date (Lee & Talen, 2014).

II. Pros and Cons of Audit Data

Audit tool as a data gathering method helps researchers to measure more specific features such as urban design and architectural features (Brownson et al., 2009). It provides detailed information to researchers or local governments that may not be in the GIS databases (Boarnet, 2003).

Audit tools do not limit the research with the existing data. They enable researchers to collect new information in the field that might not exist in databases. However, since data is collected by individuals, it is a labor-intensive and time-consuming method. If researchers have time constraints, rather than focusing on large neighborhood areas they usually conduct their studies on parts of the neighborhood.

Also, the observer needs to be trained. The raw data need to be ready to use (Brownson et al., 2009).

2.2.1.2.2 GIS Data

GIS data are one of the most used data sources in physical activity and walkability studies to measure the built environment objectively (Kerr et al., 2006; Sallis et al., 2016; Wen & Kowaleski-Jones, 2012). It is an effective tool in the processes of identifying the postal addresses of the study participants and measuring the walkability of their neighborhoods based on their physical environmental characteristics. The geocoded and publicly accessible census data on GIS is one of the frequently used data types for studies in USA and Canada (Lawrence D. Frank et al., 2004). Also, the street network data (Wen & Kowaleski-Jones, 2012) and land use data (Dygryn et al., 2010) can be obtained from the local government GIS databases.

I. Commonly Used Parameters for Measuring the Walkability of Neighborhoods in GIS

Most of the indices used for the walkability assessment in GIS are based on residential or building density, land-use diversity (including retail floor area ratio), proximity (distance to facilities), connectivity, and safety of urban environments (as measured by traffic safety or neighborhood crime ratio) (Feng et al., 2010; Dygryn et al., 2010; Liao et al., 2020; Lovasi et al., 2012; Marquet et al., 2020; Reisi et al., 2019). As mentioned before, researchers generally tended to examine these characteristics of neighborhoods due to the accessibility of the data source.

II. Pros and Cons of GIS Data

GIS enables the assessment of the whole of the large neighborhoods and also, comparison of the many neighborhoods in different locations (Brownson et al., 2009). It would be less costly, more time efficient, more effortless way from other data collection methods if the data already exist in GIS. Additionally, Gebel et al. (2009) search the association between walkability measured by perceived data(derived from the Neighborhood Environment Walkability Scale) and walkability measured by GIS data(dwelling density, intersection density, land use mix, and net retail area), and find fair general agreement between them. Considering the time for collecting perceived walkability data from individuals, that shows the convenience of GIS data if it is ready for use. However, the objective measures by GIS have some inadequacy about the micro-scale design elements (Talen & Koschinsky, 2013). Measuring with GIS limits the analysis to the information in the databases without the design aspects (Boarnet, 2003). Also, GIS data does not have a standard form, and so the data in different databases might have some compatibility problems (Moudon & Lee, 2003). According to Boarnet (2003), there may be deficiencies in the existence of the GIS data in some regions and also the accessibility of the data. In this case, the researcher has to produce the data him/herself. Getting ready to GIS data for analysis is a time-consuming process (Brownson et al., 2009).

2.3 GIS Based Approaches to Measure Walkability

2.3.1 Walkability Index

Researchers developed composite indices, which include a number of urban form variables, to objectively measure walkability. These indices comprise of an equation containing the weighted variables. Most common variables are presented in Table 2.3.

Table 2.3 Common variables of Walkability Index (Source: Brownson et al., 2009; Feng et al., 2010; L. D. Frank et al., 2010; Leslie et al., 2006)

Variable	Description	Relationship with Walkability
Net residential density	The ratio of the number of residential units to the land area in total	More dense neighborhoods tend to have mixed use, shorter distance and higher accessibility
Intersection density	The ratio of intersection to land area	More intersection densities bring more connected street network and so accessibility
Land use mix	Retail, entertainment, office and institutional uses to land uses in total	Diversity caused more pedestrian mobility because of the multiple destination
Retail floor area ratio	The retail building floor area footprint divided by retail land floor area footprint.	Retail opportunities are sensitive for modelling pedestrian activity

Frank et al. (2005) developed a composite walkability index which includes land-use mix, residential density, and street connectivity. They mentioned that the self-reported measures of built environment are not detailed enough for the decision-makers. The best-fitted weights of the built environment's factors are determined according to variations of the measured physical activity with an accelerometer of the residents. Street network buffer is used rather than straight-line buffer because street network buffer indicates the resident's actual accessibility. They also defined the "Neighborhood" as 1 km network distance area from person's home anc (1) computations within this area. The equation (1) is;

$$Walkability\ Index = [(6\ x\ z\ score\ of\ land\ use\ mix) + (z\ score\ of\ net\ residential\ density) + (z\ score\ of\ intersection\ density)] \quad (1)$$

Afterward, Frank et al. (2010) made improvements on walkability index. They mentioned that the walking behavior is affected by building setbacks. Therefore, the floor area ratio is added to the equation. It is explained that even though some variables are known to have a correlation with physical activity, such as sidewalks, street trees, the index does not contain these variables due to limitation of availability. The equation (2) is ;

$$Walkability\ Index = [(2\ x\ z\ score\ of\ intersection\ density) + (z\ score\ of\ net\ residential\ density) + (z\ score\ of\ retail\ floor\ area\ ratio) + (z\ score\ of\ land\ use\ mix)] \quad (2)$$

Leslie et al. (2007) adapted the Walkability Index, which is suitable for Australian neighborhoods. Dwellings data for dwelling density, road line and intersection data for connectivity, land use data, zoning data and shopping centers data for the net retail area are used (Frank et al., 2010; Leslie et al., 2007).

Moreover, there are different studies that deal the composite walkability index with different weights of parameters (Reisi et al., 2019; Tsiompras & Photis, 2017). Tsiompras and Photis (2017) developed a walkability index according to respondents' survey, which is about their walking trips. This index differentiates from Frank's Walkability Index by containing variables that have a negative effect on pedestrian walkability. These are pathways with smaller than 1 m, pathways with poor surface, pathways with obstacles on the surface. As the general parameters of walkability index, their index includes population density, proximity to destinations, intersection density, and land use mix (Tsiompras & Photis, 2017). The equation (3) is;

$$
\begin{aligned}
&Walkability\ index \\
&\quad = \left(0{,}22\ x\ z\ score_{connectivity}\right) + \left(0{,}26\ x\ z\ score_{land\ use\ mix}\right) \\
&\quad + \left(0{,}38\ x\ z\ score_{proximity\ to\ destination}\right) \\
&\quad + \left(0{,}14\ x\ z\ score_{population\ density}\right) \\
&\quad - \left(0{,}1x\ 0{,}4\ x\ z\ score_{pathway\ width<1}\right) \\
&\quad + \left(0{,}24\ x\ z\ score_{pathway\ in\ bad\ condition}\right) \\
&\quad + \left(0{,}35\ x\ z\ score_{pathway\ with\ obstacles}\right)
\end{aligned} \tag{3}
$$

2.3.2 Space Syntax Walkability Index

Koohsari et al. (2016) emphasize challenges about the accessibility of the data required for the Walkability Index. Space Syntax-based walkability (SSW) index is developed due to its potential for ease of measuring walkability. The equation (4) is;

$$
\begin{aligned}
&Space\ Syntax\ Walkability \\
&\quad = z[z(gross\ population\ density) + 2\ x\ z(integration)]
\end{aligned} \tag{4}
$$

The index includes the Density, Diversity, and Design concepts. Gross population density and Street Integration is used as the components of equation. Integration means how easy it is to traverse topologically from street to street. The calculation is based on the number of segments (parts of street based on intersections), not distance. Gross population density means the ratio of number of residents to the area. The index is less data-intensive because of there is no need to have parcel-level land use data or retail floor area data. They specify the walkability that is measured with data which is easily available. The results of the study show that, the SSW index is highly correlated with Frank's Walkability index having four components so that the SSW can be used instead of Walkability Index (Koohsari et al., 2016).

2.3.3 Walkscore

Walk score was developed as a web-based tool to calculate walkability of the neighborhood for the real estate sector in U.S.A. The measurement is based on the accessibility of destinations. The data is obtained from open sources such as Google and Open Street Map. The destinations are commercial and public uses such as schools, stores, markets, restaurants, recreational facilities, cinemas and theatres (Carr et al., 2010). Neighborhood walkability is calculated based on the straight-line distance to amenities. The amenities in the 5 minutes walking distance are scored maximum and 30 minutes walking is the limit (WalkScore, n.d.) (https://www.walkscore.com/methodology.shtml).

There are many studies using WalkScore as a way of measuring walkability (Marquet et al., 2020; Zhang et al., 2019). They, also aim to find the correlation between WalkScore and other measuring methods including objectively measured walkability (e.g.,street connectivity, residential density, access to public transit provisions, and crime) and perceived neighborhood walkability(e.g., perceived sidewalks, street lights, traffic, high crime, unattended dogs, hills) (Carr et al., 2010; Duncan et al., 2011). According to Duncan et al. (2011), there is a significant correlation between WalkScore and objective measures, which include amenities density, route directness, intersection density, residential density, and population density within 1600 meters street network buffer. It is shown that correlation is less strong in buffer with 400 meters and 800 meters. However, they mentioned that WalkScore is easy and free to use and publicly available. Also, there are some arguments that only distance-based walkability measures are lack of design dimensions (Talen & Koschinsky, 2013). Moreover, limitations of WalkScore are that the destination's area is ignored as measuring, and also that algorithm uses the straight-line distance rather than street network distance (Duncan et al., 2011).

2.3.4 Impeded Walkability Analysis

Schlossberg (2006) focuses on a tool that contains quality, proximity, and connectivity variables to measure the neighborhood walkability. The tool uses GIS for quantitative and visual assessments. These quantitative measures are street network classification, pedestrian catchment area (i.e., pedshed) and intersection density. The impedance concept which provides separation of environments pedestrian-oriented from car-oriented and implies the restriction for pedestrian to walk is the main focus of the measures. These impedance roads are the major roads. Street classification analysis is based on the minor roads and major roads and their density and ratio. Pedestrian catchment area ratio and impeded version are calculated. The ratio is calculated by the straight-line buffer to the street network buffer. For the intersection analysis, intersection and cul-de-sac densities, their ratio, and the impeded version of ratio is calculated. Cul-de-sac refers the barriers for pedestrians. In addition to that, the impeded intersection has a significance on physical activity because when the minor road intersects the major road, it might be a barrier for pedestrians. Also, the study focuses on the visualization of the walkability because it provides the understanding of some aspects that might be spatially overlooked when it is calculated quantitatively (Schlossberg, 2006).

2.3.5 Spatial Design Network Analysis

Cubukcu et al. (2015) used the Spatial Design Network Analysis tool, which is a GIS extension, to measure the street level walkability as an alternative model. Walkability calculation is based on betweenness and centrality which is obtained from the street network and also, accessibility to destinations from land-use data. Destinations consist of commercial uses, public transportation stops, schools, and green areas. Betweenness means the number of roads that pass a street segment. Centrality means calculation of averaging difficulties on going from street segment to all possible destinations.

2.3.6 Eco-Friendly Walk Score

Some research focuses on the green area and their effects on walking behavior (James et al., 2017; Marquet et al., 2020; Lwin & Murayama, 2011). Lwin and Murayama (2011) aimed to develop an eco-friendly model which calculates walkability based on urban green areas. The calculation includes the remote sensing data which is obtained from Advanced Land Observing Satellite to determine green space, GIS datasets which are street network, facilities, buildings, and also Web-GIS for the interactive calculation. Three different models are developed to measure the greenness in buffer area based on an origin, block area, and route areas from origin to destination (Lwin & Murayama, 2011).

2.3.7 Density Map Based Walkability

Telega et al. (2021) developed a new approach to measure the walkability based on the raster data. They use the open data source (OpenStreetMap) to obtain the vector data such as public transport stops, parks and recreations, amenities (culture and entertainment), retail facilities and pavement network. Kernel Density and Line Density tools are used to interpolation of density values from the point and line data. It creates density raster data of vector features. After density raster layers are obtained, raster reclassification is used for creating the new walkability density map. They mentioned that that new approach is simple in the meaning of data and easy to use.

2.4 School Walkability

Decreased physical activity levels of children has become the main concern of public health and urban planning for decades. There is voluminous literature that has examined children’s active commuting to school (Christiansen et al., 2014; Gallimore et al., 2011; Ikeda et al., 2018; Molina-García et al., 2020; Schlossberg et al., 2006; Timperio et al., 2006). Walking is the most basic and easy form of physical activity for people of all age, and school walking for children is an important opportunity to achieve the necessary physical activity level (Cooper et al., 2005). Research which investigates the school walking and health outcomes show that children who walk to school tend to be more physically active and less overweight and obese (Cooper et al., 2005; Drake et al., 2012; Heelan, 2002).

Traveling by walking to school has not only health but also ecological, safety, social and cognitive benefits. Walking is an environmental-friendly mode of transport. Therefore, encouraging walking to school provides less using cars and reduces traffic-related air pollution (Frank et al., 2006). Cars, where parents drop their children off at school, result in polluted air around the school and children being exposed to it. Alvarez-Pedrerol et al. (2017) studied the relationship between cognitive development and air pollution exposure in school routes. They find that the air pollutants are related to the children's reduction in working memory growth. In addition to that, walking to school reduces the traffic congestion around school environment caused by the parents who take their children to school (McMillan, 2005). Thus, traffic safety is improved along school street and the risk of child pedestrian injury is declined (Giles-Corti et al., 2009).

Webb Jamme et al. (2018) emphasized the eyes on the street and their effects on walking to school. Study shows that children need more people on the street to feel safe while walking. They also mentioned that the behavior of parents who drive their children to school due to danger of stranger, leads to less people in the street and therefore, desolation. Hereby, when children walk to school, it increases the eyes on the street and reduces the perceived danger (Webb Jamme et al., 2018).

Walking to school has some contributions on the social development of children. Malone (2007) mentioned the generation called "Bubble Wrap Generation" which defines the fragile children who are protected by parents due to over-concerns and changes in environments. This results in children not interacting with the environment where they live, lack of social and environmental abilities at individual level; and lack of safety in community at society level (Malone, 2007). The roads to school are the potential social interaction places for children (Demirel Etli & Yamaçlı, 2015). Research shows that these places that support children's socialization are public realms including streets, parks, courts, cafes & restaurants, stores, and public buildings (Sancar & Severcan, 2010). Also, McAllister (2008) emphasized that green areas contribute children to feel free in movements and feel independent while socialization which improve the social skills of them. Furthermore, walking to school instead of traveled by car contributes to children's awareness of their neighborhoods. According to Webb Jamme (2018), walking to school has positive effects on sense of community which imply to the individuals feeling that being a part of a group and belonging (McMillan & Chavis, 1986) and also the sense of place which means the relationship between people and place. Thus, urban planners and designers need to put greater emphasis on sustaining the places that support children's socialization and place attachment in their walking to school.

Cognitive capacity is improved by walking to school. Moran et al. (2017) explore the relation between objective routes of home-school and cognitive maps which refers to spatial knowledge and mental representation. The study shows that the children who walk to school draw cognitive maps more accurately (Moran et al., 2017). In addition, although there is no research that specifically studies the association between school walking rates and academic performance, there are many research that shows a positive relation between performance at school and physical activity (Castelli et al., 2015; Donnelly et al., 2016).

Although, private school trend is increasing and children from affluent families attend school away from the neighborhood (Giles-Corti et al., 2011), especially low- and middle-income children are still educated in their neighborhood schools (Ozbil et al., 2021). Therefore, neighborhood designs and urban forms that support school walkability are vital for healthy generations, sustainable urban development, and high liveability habitats for residents.

2.4.1 Factors That Affect School Walking

Children’s travel behavior to school has a complex framework. Figure 2.1 presents the conceptual framework of the school travel decision. It is important to understand that differentiation of factors that affect school walking from other physical activities of children (e.g., outdoor leisure physical activity, physical activity at school hour, physical activity at home, active transportation to activities) because of its different motivation (Mitra, 2013). There are many studies which aim to investigate the relationship between walking to school and variables that can influence this walking behavior (Christiansen et al., 2014; Ikeda et al., 2018, Molina-García et al., 2020). Urban built environment and how they are perceived by parents and children are some of the main determinants of the choice of transport mode. Policy context, geographical (or natural environmental) features, social environment and household features (like parental restrictions and income) are some other factors that determine children’s school travel decision.

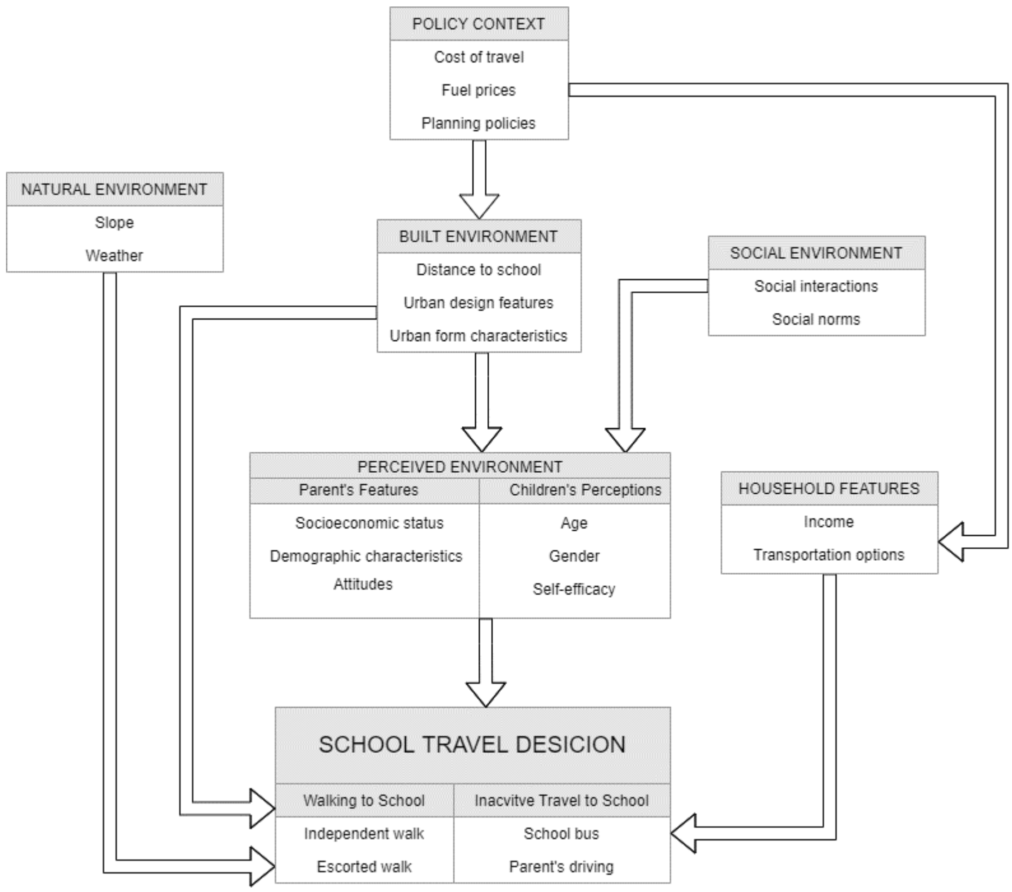


Figure 2.1. Conceptual Framework of School Travel Behavior (McMillan, 2005; Mitra, 2013; Panter et al., 2008)

McMillan (2005) emphasizes that one of the key decision-makers of children's travel behavior to school is parents until a certain age. Kerr et al. (2006) found that the most related factor with active commuting to school is parental concerns (e.g., crime safety, traffic safety, inadequate pedestrian infrastructure, long distance) rather than perceived environment variables and objective walkability. Also, they mentioned that children are five times more likely to walk to school when their parents have less worries (Kerr et al., 2006). Timperio et al. (2006) mentioned that parent's perception about few numbers of children in neighborhood, lack of lights, and crossings are negatively associated with school walking. In addition to that, Napier et al. (2011) found a positive correlation between active commuting to school; and shorter distance home-school routes, and less perceived barrier by parents and children. Furthermore, research from Istanbul, the perception of parents about sidewalks and shade-casting street trees shows a significant relationship between school walking of children (Ozbil et al., 2021).

Physical built environment effects on school walking are evaluated by different approaches. Some studies focus on the meso scale urban form characteristics in neighborhood level, others focus on the micro scale design features on the street level. Micro scale school walkability measures contain street level pedestrian infrastructure, safety, comfort, aesthetic, pleasurability (Gallimore et al.,2011; Seagle et al., 2008). Lee et al. (2008) developed an audit tool for measuring walking school suitability. The tool includes speed limit on a street, street lanes, sidewalk existence and condition, street lights, intersection conditions, and traffic volume. Lee et al. (2020) search the relation between audit-based school walkability (e.g., land use, density of sidewalk, density of street light, cleanliness, surveillance items) within 1.5 km buffer from school and children's walking to school. They found a positive association between before-school physical activity. Molina-García et al. (2020) searched the best performance model of walkability index for active commuting to school by using macro and micro environmental features including traffic lanes, crossings, traffic calming features, streetscape features, aesthetic features. The most fitting walkability index for children's walking behavior to school who live in urban areas contains the number of regulated crossings, positive streetscape characteristics, and crossing quality. Larsen et al. (2009) found a positive relationship between street trees as an aesthetic quality and school walking.

Another factor, which is a primary subject discussed in this study, is urban form characteristics as barriers and facilitators of built environment to school walking. Children's active commuting to school may be more responsive to environmental factors than adults' responds to their environments. In the following section, the built environment parameters based on urban form which are used to objectively measure school walkability and their associations with school walking behavior in the literature are explained to provide a better understanding of school walkability. It also forms the base for the proposed school walkability tool.

2.4.1.1 Distance

Distance which is the product of the urban form, is one of the strongest estimators of the likelihood to walk to school (Harten & Olds, 2004). Long distance between home and school is the biggest barrier to walking to school, and it is negatively associated with walking to school (Larsen et al., 2009; Macdonald et al., 2019; Timperio et al., 2006). Schlossberg et al. (2006) claimed that children who live shorter distance than 1 mile (1.6 km) is most likely to walk to school. More than 1.5 mile (2.4 km), children do not tend to walk to school anymore. Ikeda et al. (2018) mentioned that the number of children who walk the distance 1.3 km-2.3 km is 1/3 less than who walk the distance within 1.3 km. Also, they found that the 2.3 km as walking threshold to school. (Ikeda et al., 2018). Rodríguez-López et al. (2017) investigated threshold distances for children (7-11year-olds) and adolescents (12-18year-olds) to walk to school. They found that the threshold distance was 875 meter in children, and was 1,350 meter in adolescents. Harten and Olds (2004) found that %90 of trips is made by walking and cycling when distance at <0.25 km, 75% at 0.4 km, 50% at 0.9 km, 25% at 2.0 km, and 10% at 3.2 km for 11-12 ages children.

Distance types are another important variable while calculating the walkability. Chica-Olmo et al. (2018) examined which distance type has best performance on predicting active commuting to school. They compared the Euclidean, walking, Manhattan and driving-network distances (Figure 2.2). While Euclidean distance is the shortest distance, driving distance is the longest due to one-way roads. They found that Euclidean distance and the walking distance is better predictor walking behavior on home and school route (Chica-Olmo et al., 2018).

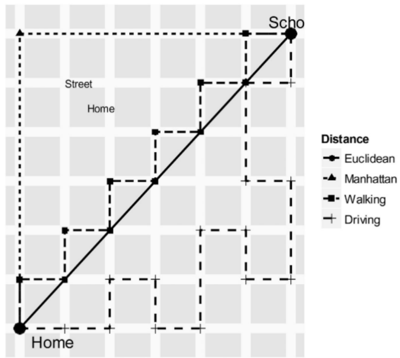


Figure 2.2. Graphical representation of four types of distances (Chica-Olmo et al., 2018)

2.4.1.2 Connectivity

2.4.1.2.1 Intersection Density

Intersection density is a very common parameter for measuring connectivity. It refers to pedestrian opportunities for route selection and higher intersection density means smaller blocks and shorter distances between origin and destination (Larsen et al., 2009). Different cases from same scale are represented in Figure 2.3. Many studies strengthen the evidence that there is a positive relationship between intersection density and school walking (Ikeda et al., 2018; Molina-García et al., 2020; Schlossberg et al., 2006). Schlossberg et al. (2006) investigated the intersection density in 0.25 mile (400 meters) and found a positive relationship between active travel and intersection density. Also, Ikeda et al. (2018) found that within 1 km buffer, the children who live in highly connected neighborhood walk to school three times more than those who live in the low-connected neighborhood. Although it is generally calculated by the number of three-way or four-way intersections to buffer area, Braza et al. (2004) calculated the intersections density by dividing the number of intersections by the lengths of the road in the 0.5 mile (800 meters) buffer to find the number of intersections per street mile. However, they found no correlation between intersection density per street mile and school walking.

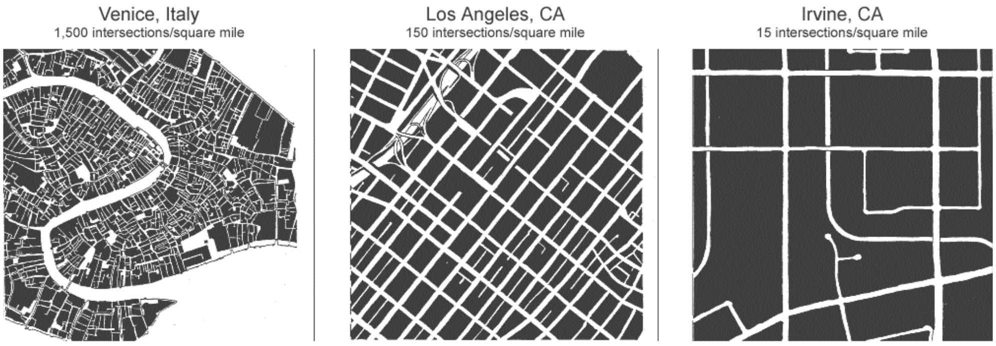


Figure 2.3. Street maps with intersection density at same scale (Source: Ewing,1999)

2.4.1.2.2 Pedestrian Route Directness

Pedestrian route directness (PRD) is a route-based connectivity analysis. It indicates the shorter and direct routes between school and home. It is calculated by dividing the shortest network distance between home and school by the straight-line distance between them. Dill (2004) mentioned that, although PRD bring subjectivity to studies because it is measured for each route, it is not a feasible method when there are many units to measure the connectivity between two points. Therefore, it is challenging to use to make policies for urban planning (Dill, 2004). Campos-Sánchez et al. (2020) mentioned that Pedestrian Route Directness has a positive relationship with school walking for children (7–11 years old) and adolescents (12–18 years old). On the contrary, Timperio et al. (2006) and Panter et al. (2010) found a negative association between PRD and school walking respectively, 5-6 ages and 9-10 ages. The negative relation results of some studies might related that more direct routes may increase car use and traffic exposure. Therefore, children may avoid using these routes to walk to school because of safety concerns (Ikeda et al., 2018).

2.4.1.2.3 Pedshed

Pedshed is the ratio of road network-based area to Euclidian distance-based area. It refers the efficiency of street layout for walking access. It is used to measure the walkable catchment area of a specific key destinations such as centers, schools, bus stops and stations (Figure 2.4). The pedshed ratio close to 1 means the more connected network. Giles-Corti et al. (2011) developed the school-specific walkability index which includes 2 km pedshed and traffic exposure variables. They found that children age 10–12 years attending primary schools, walk to school two times more when the pedshed is high (where the traffic exposure is low) (Giles-Corti et al., 2011). Moreover, Trapp et al. (2012) used the school-specific walkability index and they found that the odds of school walking in boys aged 10-13 years is higher in high connectivity measured by pedshed. Christiansen et al. (2014) used school-specific walkability index constituted of measures of pedshed, traffic exposure and residential density and found positive relation with index and active travel to school. Bejleri et al. (2011) compared the pedshed and the version of pedshed adjusted by facilitator and barriers for school walkability. These barriers are major roads, and lack of sidewalks, and facilitators are formal and pedestrian paths, crossing guards and rear entrances to school. They emphasized that, the adjusted by facilitators and barriers version of pedshed provide more accurate representation of walkability for children (Bejleri et al., 2011).

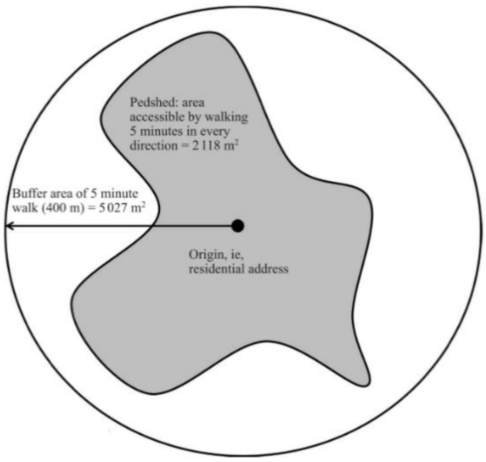


Figure 2.4. Pedshed (Source: Ellis et al., 2016)

2.4.1.3 Density

Residential, population and building density measures are commonly used variables for measuring walkability. High density neighborhoods result in short route distance between school-home, since these neighborhoods create a compact environment. Because more schools are needed to be sufficient for the high number of students unlike the sparse population of sprawl schools. Thus, it provides walkable distance and less car dependency for school transportation. Density of population refers to potential for urban vitality and safety in streets for children (Campos-Sánchez et al., 2020; Webb Jamme et al., 2018). Braza et al. (2004) found a positive association between population density within 0.5 mile (800 meters) from school and walking to school. Christiansen et al. (2014) added the residential density as a third component to the school-specific walkability index and found a strong relationship between walking and index in 2 km Euclidian buffer. Molina-García et al. (2020) found the positive association in urban area and negative association in rural area for children's active transportation to school and residential density. Kerr et al. (2006) investigated Frank's walkability index (includes residential density as a component), and children's transport behavior to school. They found that children walking to school rates are more in the high walkability neighborhoods (Kerr et al., 2006). In contrast, some research find a negative relationship between residential density and walking to school (Campos-Sánchez et al., 2020; Ikeda et al., 2018; Macdonald et al., 2019). It may be the result of the high residential density is associated with the high-level of traffic (Larsen et al., 2009). Also, in the short distance, residential density may not be an important factor that affects the choice of transport mode for children (Campos-Sánchez et al., 2020). Addition to that, to create walkable environment for children, density should be combined with the mixed uses. Thus, the potential of number of people may results in the vitality and safety in the streets with high diversity in land uses (Jacobs, 1961).

2.4.1.4 Land Use Mix

Mixed uses in streets are seen as natural surveillance for safety as Jacob (1961) mentioned that concept of eyes on the streets in his book in her book The Death and Life of Great American Cities. Addition to that, mixed uses such as shops, markets, open spaces, cultural buildings rather than only residential use can make the streets more attractive for children. There are various results for the land-use diversity and active commuting to school for different age groups. Although it is thought that greater diversity in walking distance provide destinations that children can walk, and therefore positive relation with general physical activity level, Schlossberg et al. (2006) mentioned that land use mix is ineffective for the choice of travel mode to school where destination is the school. Ozbil et al. (2021) investigated the active school transportation of children aged 12–14 from Istanbul and they found that the retail density is negatively related to it. Similarly, studies from Los Angeles and Helsinki show that high land use mix (residential, commercial, office, and institutional) are associated with lower walking rates to school (Broberg & Sarjala, 2015; Su et al., 2013). Su et al. (2013) mentioned that more land uses cause the complexity and overcrowded in the routes to school, and these may be barrier for children walking to school. Moreover, Broberg and Sarjala (2015) emphasized that selected land uses in their study for the measuring land use mix may not be relevant for the children walking behavior. Many studies use the land uses such as commercial, institutional, office, governmental which have impacts on adult's but not children's mobility, and this can cause the inaccurate results (Broberg & Sarjala, 2015).

However, Larsen et al. (2009) found a positive relationship between land use (recreational, agricultural, residential, institutional, industrial, and commercial) in 1.6 km buffer around school and walking to school. They emphasized that high land uses diversity may be more attractive for children (Larsen et al., 2009). Moreover, Campos-Sánchez et al. (2020), found land-use mix (residential, industrial, retail, office, public service and recreational) in school neighborhood are positively related to adolescents' (12-18 years old) school walking and negatively related to children's (7-11 years old) school walking in Spain. Similarly, Molina-García et al. (2020) searched the relation between built environment and urban and rural children and adolescents in Spain. They found a positive relationship between the land use mix (residential, retail area, public services) and urban adolescents who are walking to school (Molina-García et al., 2020). Dias et al. (2019) found the positive association between land use mix and active travel to school of Brazilian adolescents (14-20 ages) in buffer of 0.5 km and 1 km.

2.4.1.5 Greenness

Louv (2008) mentioned the term of nature deficit disorder which refers the problems that occurs especially in children due to lack of connection with nature. It shows the importance of greenness for children's health. Green areas are related with increased physical activity likely because reducing exposure to noise, traffic, pollution, high temperature and improving the aesthetic and attractiveness (Lu, 2018; Lwin & Murayama, 2011; McMorris et al., 2015). Although there are many studies that investigate the physical activity in young ages and its relationship with parks, greenness, recreational areas, there are few relationship studies between objective measurement of urban greenness and school walking. Physical activity studies show that the density and proximity of urban green areas are correlated with greater physical activity (Frank et al., 2007; Norman et al., 2016; Roemmich et al., 2006). According to Klompmaker et al. (2018), NDVI has the strongest association with physical activity among measurement of greenness. Almanza et al. (2012) used the Normalized Difference Vegetation Index (NDVI) to research the greenness (e.g., gardens, parks, grassland) exposure of children and moderate-to- vigorous physical activity (MVPA) and they found positive association between them. Cottagiri et al. (2021) found that children (11-14 ages) whose school located in high dwelling density area are more likely to walk to school when NDVI based greenness is high. Additionally, Larsen et al. (2009) found that street trees are associated with active transport to school for children aged 11 to 13 years in London. Dias et al. (2019) found that existence of parks are associated with active commuting to school in 0.5 km buffer for adolescents in Porto Alegre, Brazil. Van Kann et al. (2015) investigated physical activity and found significant correlation aesthetic features such as presence of parks and maintenance of green areas for 12-year-old children in the Netherlands.

2.4.1.6 Traffic Exposure

Traffic exposure refers to unsafe conditions from traffic for children. High level roads in the road hierarchy, and thus larger road width indicate high vehicle speed and more traffic exposure. Main roads are barriers in school routes for children. Timperio et al. (2006) found the busy roads (i.e., freeway, highway, or arterial road) on the school home route negatively correlated with school walking of children aged 10 to 12 years from Melbourne. Similarly, study from Helsinki show that density of major roads (i.e., length of major roads to sq km of area) are barriers on school route for 11-14 years old children (Broberg & Sarjala, 2015). Bejleri et al. (2011) removed major roads and added the facilitators such as pedestrian paths to the street network when creating pedestrian sheds since main roads seen as barriers for children to walk to school. Giles-Corti et al. (2011) combined the street connectivity and traffic exposure components to measure walkability in school neighborhoods and developed the school walkability index. Roads are classified according to hierarchical function structure, which are primary distributors, district distributors, local distributors, access roads, and then the ratio of access roads to other roads measured (Giles-Corti et al., 2011). Christiansen et al. (2014) found a significant association between active travel to school and school walkability index containing pedshed ratio, traffic exposure and residential density for the 11–13 years old children in Denmark.

2.5 Concluding Remarks

To conclude, walkability is an approach to quantify the built environment in the context of encouragement of people to walk. Extensive literature show that the walking behavior is related with built environment. Physical built environment and perceived built environment are used to measure walkability. Objective built environment not affected by the individual features containing socioeconomic status, demographics, experiences such as perceived built environment. Large sample size is an important factor validity of the study including perceived built environment data. However, it may have negative effect on research due to time consuming and financial limitation. Also, obtaining perceived data is getting challenging especially in pandemic term.

School walkability is defined as how neighborhoods promote children's walking to school rather than school bus or parents driving. This framework has a complexity because of containing a lot of factors such as policy context, social environment, natural environment, parental concerns, objective built environment, perceived built environment of parents and children affected by individual characteristics, and household features. Different scale urban form characteristics are related with the school walkability. Meso scale area includes neighborhood level characteristics, micro level includes street level design dimensions. This study mainly addresses the objective built environment measurement in meso scale which includes density of residentials/buildings, connectivity of street patterns, land use mix affecting the children's physical activity, and traffic exposure from the major roads in the buffer area of school (Figure 2.5).

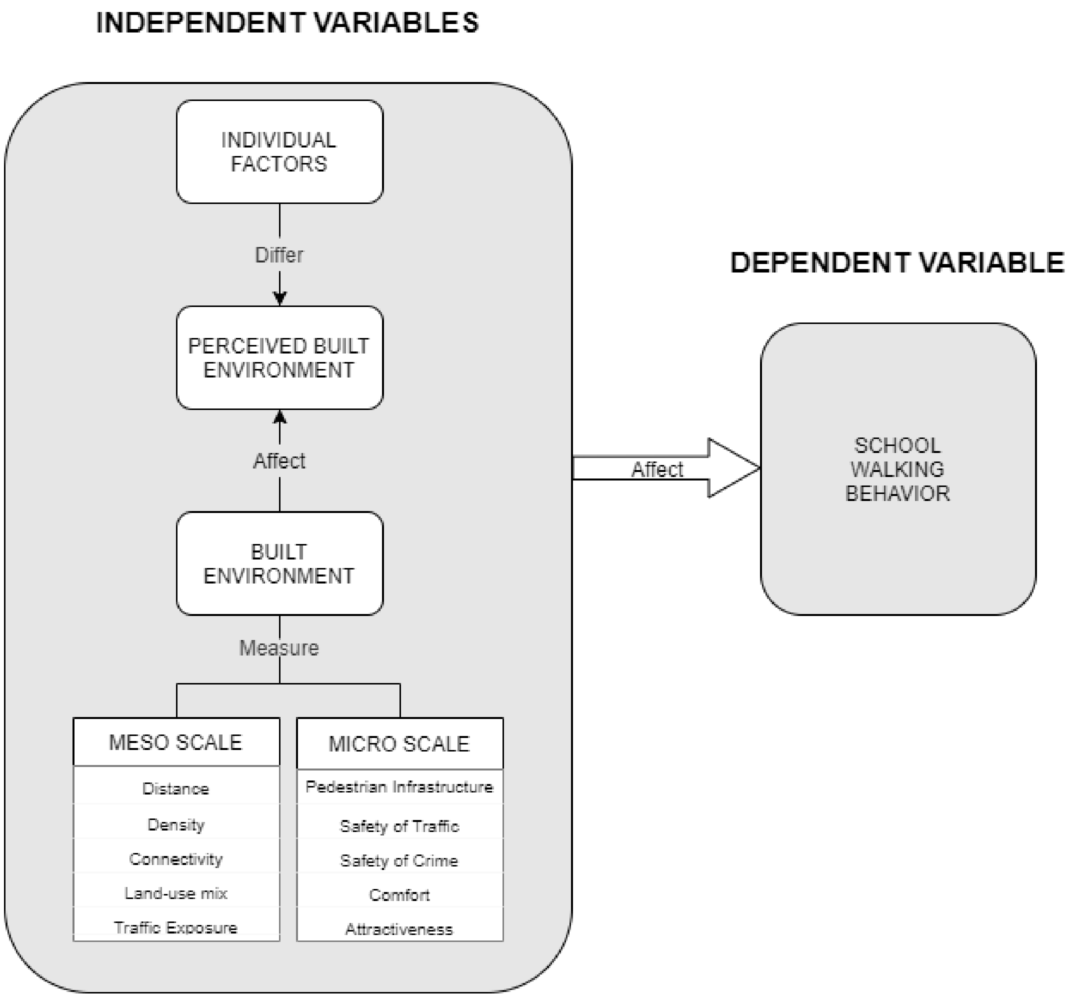


Figure 2.5. Framework of built environment and school walking behavior (produced by author)

CHAPTER 3

METHODOLOGY

This thesis asked the following major research question: Based on their urban form characteristics, how walkable are the school areas in traditional neighborhoods with garden apartment houses, mixed-use neighborhoods of 1970s with low- and high-rise apartments and contemporary high-rise mass housing developments for children? More specifically, among these three neighborhood types, which neighborhoods perform better or worse regarding their school walkability and why? To answer this research question, the thesis aimed to develop a geographic information system (GIS) based model to help municipal authorities assess school walkability.

This chapter focuses on the method of the present research study. It consists of four sections. The first one aims to provide a brief information about planning history of the context of this study: Ankara. The second part focuses on the site selection process. The history and spatial characteristics of the chosen neighborhoods in Ankara are explained – one that represent a traditional neighborhood with garden apartment houses (Bahçelievler), another that represent a mixed-use neighborhood of 1970s with low- and high-rise apartments (100. Yıl İşçi Blokları) and another that represent a contemporary high-rise mass housing development (Kuzeykent TOKİ). In the third part, data preparation process is discussed. The author provides information about data collection and data digitization process. Moreover, the author explains how the attributes of data are edited as input data of GIS model. The fourth part describes the GIS framework of the study. First, school walkability index and the parameters are identified. The author explains how each parameter is measured with the prepared Model Builder tool step by step. Furthermore, the School Walkability Toolbox, required input features to run, and output features are explained.

3.1 Planning Context of The Study

This study focuses on Ankara, Turkey. Once being a small Anatolian town until 1920s, after the foundation of the Turkish Republic, to symbolize the new Republic Regime, Ankara was declared as the new capital of Turkey in 1923.

The first plan of the city was prepared by Carl Christoph Lörcher in 1923. This plan, known as Lörcher Plan, aimed at developing a compact urban from around the railway station in the historical center, Ulus district (Günay, 2012). In the Plan, the residences were proposed to be detached houses with gardens. Within few years after the proposal of this plan, the problem of housing occurred because of the dramatic increase in population (and the plan's inability to provide a shelter for the incoming masses). Unplanned developments were mushroomed in Keçiören (located on the north of Ulus) and Çankaya (located on the south of Ulus) districts (Ankara Büyükşehir Belediyesi, n.d.) (https://tasam.org/Files/Icerik/File/5_tarihce_d.pdf_9bf7f970-2d98-404d-a5ba-c2552f254bd3.pdf).

By the end of the 1920s, a new plan was proposed for Ankara by Hermann Jansen. Jansen's Plan (1928) determined the west-south axis as the main urban growth direction. While the traditional texture of the Old City Ulus continued to exist, , Yenişehir (literally translated as the New City) Kızılay became the neighboring center with governmental buildings, public uses and housing, especially in the direction of Kavaklıdere in Çankaya (a district located in the south of Ankara) (Uğurlar & Eceral, 2012). As in the Lörcher Plan, the main housing pattern of Yenişehir was detached housing with gardens in 1925-1937 years (Baş, 2018). A similar approach was used in the design of cooperative residential housing areas like Bahçelievler, which were proposed for the middle class (Uğurlar & Eceral, 2012).

After the rapid population growth in Ankara, because of the labor force migration from rural areas, a new plan, the Yücel-Ubaydin Plan, was adopted in 1955(Günay, 2012). However, the population estimation of Yücel-Ubaydin Plan reached much earlier than expected. The failure of the Yücel-Uybadin Plan accelerated the illegal housing developments in Ankara, especially in the green belt of the city. During this period, the Property Law of 1965 (1965 Kat Mülkiyeti Kanunu) led to the transformation of the cooperative houses. Detached 1-2 storey apartment houses with gardens were replaced by apartment buildings with 4-10 floors (Geray, 2000; Günay, 2012). By the end of 1970s, there were mainly two types of housing pattern, which includes apartments and squatters in the city.

During the implementation of the Yücel-Ubaydin plan, the uncontrolled spread of the city could not be prevented. To solve this problem, a new plan was prepared by Ankara Metropolitan Area Master Plan Bureau. This plan was approved in 1982. It directed the growth towards the western corridor of the city. Additionally, it supported the development of mass housing in the fringes of Ankara, in Batıkent, Eryaman, Sincan districts. This plan played a very important role in shaping today's Ankara macroform.

After the 1980's, the administrative system was changed, and metropolitan municipality was emerged to handle the city as a whole. During 1980's because of some problems of the city, Ankara Metropolitan Municipality request a study from the City and Regional Planning Department of METU. This structural plan has objectives about macroform and transportation plan of Ankara. The plan recommended decentralized development in the north and south of the city considering the current development trends of Ankara (Ankara Büyükşehir Belediyesi, n.d.) (https://tasam.org/Files/Icerik/File/5_tarihce_d.pdf_9bf7f970-2d98-404d-a5ba-c2552f254bd3.pdf). However, due to the change of planning authority (authority of governmental institutions to make plans on different themes), the process was influenced by different planning decisions. That confusion resulted in unplanned developments in the city and partial development in fringe areas (Soylemez et al., 2018). Although Ankara Transportation Plan was approved, the, 2015 Structural Plan of Ankara is not approved.

In 2007, 2023 Plan prepared by the Ankara Metropolitan Municipality was approved. The plan was offering developments in south-western corridor, which causes land speculations in the fringe of Ankara. Central business district (CBD) of Ankara lost its functions with the dispersion. Urban redevelopment and TOKİ (i.e., Housing Development Administration of Turkey) projects have become the main discussion of planning in Ankara (Günay, 2012).

One can argue that over the years, because of the urbanization policies, compared to people living in the pre-1990s of Ankara (where one could see mixed-use neighborhoods with both low- and high-rise apartment buildings), today's people are more likely to live in less walkable neighborhoods in Ankara.

3.2 Neighborhood Selection

This thesis questions the role of neighborhood design in children's walking behavior. It assumes that neighborhoods with particular urban form characteristics are more supportive than others in promoting children to walk to school. To this end, three neighborhoods with different urban form characteristics were selected: Bahçelievler, İşçi Blokları and Kuzeykent neighborhoods. These neighborhoods were selected based on the following four main criteria: (1) All three neighborhoods have different urban form characteristics at the micro- and meso-scales (e.g., while Bahcelievler neighborhood is composed of low-storey apartment buildings with backyards gardens, Kuzeykent neighborhood houses high-rise mass housing buildings); (2) All three neighborhoods were in the fringe of the city by the time they started to be developed; (3) all the chosen neighborhoods cover a large area within the comprehensive plans; and (4) all sites contained a public secondary school. Since secondary school children are more appropriate to walk to school independently because of their age (Wilson et al., 2019), neighborhoods having a secondary school were selected for analysis.

In the next section, the planning history of these neighborhoods and their spatial characteristics are mentioned.

3.2.1 Bahçelievler Neighborhood

Bahçelievler neighborhood is a typical example of a planned development in Turkey (Figure 3.1). It represents a traditional neighborhood where one can see low-storey detached apartment buildings with gardens. The buildings are located in a grid-pattern street system as in many historical neighborhoods in the United States. The neighborhood was first proposed in Jansen's Master Plan. Many scholars like İlerisoy and Tuncel (2016), Kansu (2009), Uçar Mumcu and Özsoy (2006) argued that Bahçelievler Neighborhood's design was influenced by Ebenezer Howard's Garden City. By the time they were proposed, industrial era, garden cities were proposed outside of the large cities, which were characterized with a variety of problems like pollution and crowding. Contrary to the characteristics of such cities, garden cities were integrated with nature, and they were self-sufficient with all their functions. Bahçelievler was designed to meet the housing need in the city in the 1930s (İlerisoy & Tuncel, 2016). In Jansen's plan, the neighborhood was located on the western development corridor and at the edge of the city as a suburban settlement (Uçar Mumcu & Özsoy, 2006). The initial project was implemented by a housing cooperative called "Bahçelievler Yapı Kooperatifi". It consists of houses that each of them located in a large garden. These gardens are seen as the smallest units of the green space network in the city (Yerli, 2016). Over the years, many other cooperative houses have been established in the surroundings of Bahçelievler Yapı Kooperatifi. Different from what was proposed before, some of these cooperatives promoted the development of multi-storey apartment buildings in the neighborhood. Also, with the floor increase permissions in 1971, low-storey houses were started to be replaced by multi storey apartments with small gardens as well (Songülen, 2012). According to Geray (2000), these trends caused not only to the densification of the neighborhood but also to the erosion of green open spaces in the settlement. As Ankara's macroform grew along the southwest of the city, Bahçelievler has become one of the sub-centers of Ankara, where in addition to residential functions, one can see a variety of shops, restaurants and coffeeshops.

Figure 3.1. Bahçelievler neighborhood and 1 km buffer area of school (represented with red circle)

3.2.2 İşçi Blokları Neighborhood

İşçi Blokları neighborhood is a cooperative development from 1970's for the working class (Köse, 2013) (Figure 3.2). It is a typical example of social housing in Turkey. The neighborhood consists of two types of houses: 5 and 15 storey apartment buildings. 15 storey apartments are designed as star shaped buildings. They are clustered within 3 blocks, all of which have inner courtyards. 5 storey apartments are located around common spaces, which are used as parks, sport facilities and car parking areas. Most of these 5 storey apartments consist of 2 or 3 attached houses and, they have large backyard gardens. Also, some residents use setbacks of apartments as small gardens (Cihanger, 2018). There is a community garden (i.e, bostan) which is one of the rare examples in Ankara. There are many pedestrian pathways that connect common spaces in neighborhood. The neighborhood includes parks, schools, service buildings, commercial uses and a Bazaar. Today, İşçi Blokları neighborhood is surrounded by highways, a university campus, and neighborhoods like Çukurambar where large-scale urban regeneration projects are implemented. Due to the growth of the city along the Eskisehir Road and being located next to the Middle East Technical University campus, it is a fairly high rent area which attracts the attention of the investors.

Figure 3.2. İşçi Blokları neighborhood and 1 km buffer area of school (represented with red circle)

3.2.3 Kuzeykent Neighborhood

Kuzeykent is a well-known large-scale urban regeneration project in Ankara (Figure 3.3). Being located between the Esenboğa International Airport and the city, the neighborhood was once home to many squatter communities. In, 2005, as part of the neoliberal agenda of the government, TOKI (i.e., Housing Development Administration of Turkey) initiated a large-scale regeneration in the neighborhood aiming to replace squatter houses with high-rise mass housing buildings (Topal et al., 2019). The project is the first in the aspect that the transformation process was facilitated by a special law called .“Kuzey Ankara Girişi Kentsel Dönüşüm Projesi

Kanunu” (Gümüş, 2010). Although Kuzeykent neighborhood project consists of three stages, only the first stage has been completed so far. Uzun and Celik Simsek (2015) mentioned that, in Kuzeykent neighborhood, building density is increased 300% with the urban regeneration to finance the project. Most of the residential buildings in the area are uniform high-rise buildings which are located at higher elevations, while some are terrace houses and low-storey detached house which are located at lower elevations. The project area lacks diversity of land uses. In addition, the topographical structure of the area complicates pedestrian accessibility. There are almost no small scale neighborhoods parks. Although the green open space (Kuzey Yıldızı Park) is quite large, lack of accessibility causes the security problems in the area, and therefore the recreational area is quite desolated. Facilities in the plan of the area such as convention center, hotel and restaurant located in the recreation area have not been implemented. Korkmaz and Balaban (2020) mentioned that the emptiness in the residential units causes the lack of facilities and decreasing in economic vitality.

Figure 3.3. Kuzeykent neighborhood and 1 km buffer area of school (represented with red circle)

3.3 Data Preparation

In Chapter 2, the author mentioned about the meso-scale variables that are frequently used to measure school walkability in literature. Based on this information and the data obtained from the municipality, the author decided to focus on the following meso-scale urban form variables that are related to school walkability: pedshed ratio for connectivity, building density for density, land use mix for diversity, road width for traffic exposure and NDVI for greenness score. Building vector data containing its floor number and land use to measure building density and land use mix, road vector data containing width information to measure pedshed ratio and traffic exposure, and lastly satellite image, Sentinel 2 data to measure NDVI score are required to calculate these urban form variables. The detailed information about parameters will be discussed in 3.4.1 section.

3.3.1 Data Collection Process

1:1000 scale base maps (hereafter halihazır maps) showing the contour lines, streets, blocks, buildings and the boundaries of public amenities (like parks and bazaars) are obtained from the GIS Department of Ankara Metropolitan Municipality. Unfortunately, these maps were not up to date; they were prepared by the municipality in 1998. Since they were crafted in the Netcad Software, all the obtained halihazır(base) maps were in NCZ format. These file types can be opened in the ArcMap Software with the CAD Reader Tool. Since the study will be performed through ArcMap, once the 1:1000 scale halihazır(base) maps were obtained from the municipality, the NCZ data were converted to feature dataset which contains feature classes which are Çizgi (line), Çokgen (polygon), Münhani(contour), Nokta (point), Sembol(symbol), TaramaÇizgi(hatched line), TaramaNokta (hatched point), Yazı(text) in ArcMap (Figure 3.4).

Figure 3.4. ArcMap dataset obtained from NCZ files

The halihazır(base) maps are consist of many layers including layers related to the location of power plants. Thus, the author used only the following layers to measure determined urban form variables: buildings and roads. The buildings layer provided us information not only about the location and boundaries of each building in the neighborhood, but also about the location of mosques, residential buildings, schools, government buildings and construction sites. Similarly, the roads layer is categorized according to type such as asphalt road, dirt road, pathway. All of them were stored in "Çizgi" (line) layer as polyline geometry. Also, information that gives the layer name of the object which is created in Netcad software (e.g., building, road, parks, sport facilities, infrastructure) is located in "KATMAN" field of "Çizgi" (line) layer (Figure3.5).

ÇANKAYA_HH_Çizgi

OBJECTID	SHAPE *	KATMAN	SINIF	VTKODU	SUBTYPE	ADI	UZUNLUK	SEMBOL	KALINLIK	RENK
5	Polyline Z	EGRI_5M	3001		7		0	DUZ	1	34
12	Polyline Z	YOL_TOPRAK	3202		7		0	DUZ	1	143
13	Polyline Z	YOL_TOPRAK	3203		7		0	DUZ	1	143
14	Polyline Z	YOL_TOPRAK	3202		7		0	DUZ	1	143
15	Polyline Z	DUVAR	1019		7		0	DUZ	1.5	12
16	Polyline Z	DUVAR	1019		7		0	DUZ	1.5	12
17	Polyline Z	SEVUST	1806		7		0	DUZ	0.5	4
18	Polyline Z	PARKBAHCE	1421		7		0	DUZ	1	34
19	Polyline Z	PARKBAHCE	1421		7		0	DUZ	1	34
20	Polyline Z	PARKBAHCE	1421		7		0	DUZ	1	34
21	Polyline Z	PARKBAHCE	1421		7		0	DUZ	1	34
31	Polyline Z	EGRI_5M	3001		7		0	DUZ	1	34
33	Polyline Z	YOL_TOPRAK	3203		7		0	DUZ	1	143
34	Polyline Z	YOL_ASVALT	3201		7		0	DUZ	0	17
35	Polyline Z	YOL_ASVALT	3201		7		0	DUZ	0	17
36	Polyline Z	YOL_TOPRAK	3203		7		0	DUZ	1	143
37	Polyline Z	YOL_TOPRAK	3202		7		0	DUZ	1	143
38	Polyline Z	YOL_TOPRAK	3202		7		0	DUZ	1	143
39	Polyline Z	SEVUST	1806		7		0	DUZ	0.5	4
40	Polyline Z	SEVALT	1805		7		0	DUZ	0.5	4
41	Polyline Z	SEVUST	1806		7		0	DUZ	0.5	4
42	Polyline Z	SEVUST	1806		7		0	DUZ	0.5	4
43	Polyline Z	SEVUST	1806		7		0	DUZ	0.5	4
45	Polyline Z	KALDIRIM	3204		7		0	DUZ	1.5	250
47	Polyline Z	KALDIRIM	3204		7		0	DUZ	1.5	250
48	Polyline Z	KALDIRIM	3204		7		0	DUZ	1.5	250
50	Polyline Z	DUVAR	1021		7		0	DUZ	1.5	12

1 (0 out of *26600 Selected)

Figure 3.5. Attribute Table of çizgi(polyline) layer

For the NDVI calculation, open-source Sentinel 2 Level-2A data are downloaded from Copernicus Open Access Hub. Sentinel 2 (Band4 - bandwidth 31 nm and Band8 - bandwidth 106 nm) is selected because they have higher spatial resolution(10m) compared to other frequently used Landsat8 (30m) and MODIS (250m) data and is seen more suitable for the urban context greenness measurement due to the probably higher accuracy than others (Shuvo et al., 2021; Labib & Harris, 2018; Markevych et al.,2017). Data from 11 May, 2021, with cloud cover less than 10% are obtained. The data from May were selected because it is suitable for greenery observation.

3.3.2 Data Digitization Process

The maps obtained from the municipality were not up to date; when compared to the existing situation, the author observed that there were many missing features like buildings and roads in the halihazır(base) maps obtained from the municipality.

In order to make the obtained data up to date, firstly, in all of the three chosen neighborhoods, a 1000 meters buffer is generated around the selected secondary schools. This distance represents the maximum distance that a child can walk from home to school; based on the literature review, children are more likely to travel to school by motorized transport. The roads that are located in this buffer area were digitized as a single line to represent the centerline of the roads. Satellite images were used for the detection of missing/inaccurately drawn features. Afterwards, service areas based on the 1000-meter network distance of the schools were created by using roads. Since the analysis will be carried out in service area, building and road data in these service areas of the neighborhoods were studied.

To use existing buildings in the halihazır (base) map, the buildings in the service area were obtained by the “Clip” tool. Since buildings are stored as polyline geometry in halihazır(base) maps, closed polyline objects were converted with the “Feature to Polygon” tool in ArcMap to use them as polygon geometry. Although there were parcels in the halihazır(base) maps, most of the building were missing. Missing buildings in the service area of schools were digitized as polygons from the satellite images in the İşçi Blokları and Bahçelievler neighborhoods. Because Kuzeykent district was started to be built-in mid, 2000s, there were only squatter’s houses in the data from 1998. All the new buildings and roads of Kuzeykent service area of school were digitized from satellite images (base map of ArcMap, data source Maxar). This digitization process was a very labor-intensive process for the researcher since all the buildings and all the roads were digitized from scratch. Halihazır(base) maps from municipality, and digitized roads and buildings of neighborhoods (within buffer area and service area of school) by author are shown in Figure 3.6.

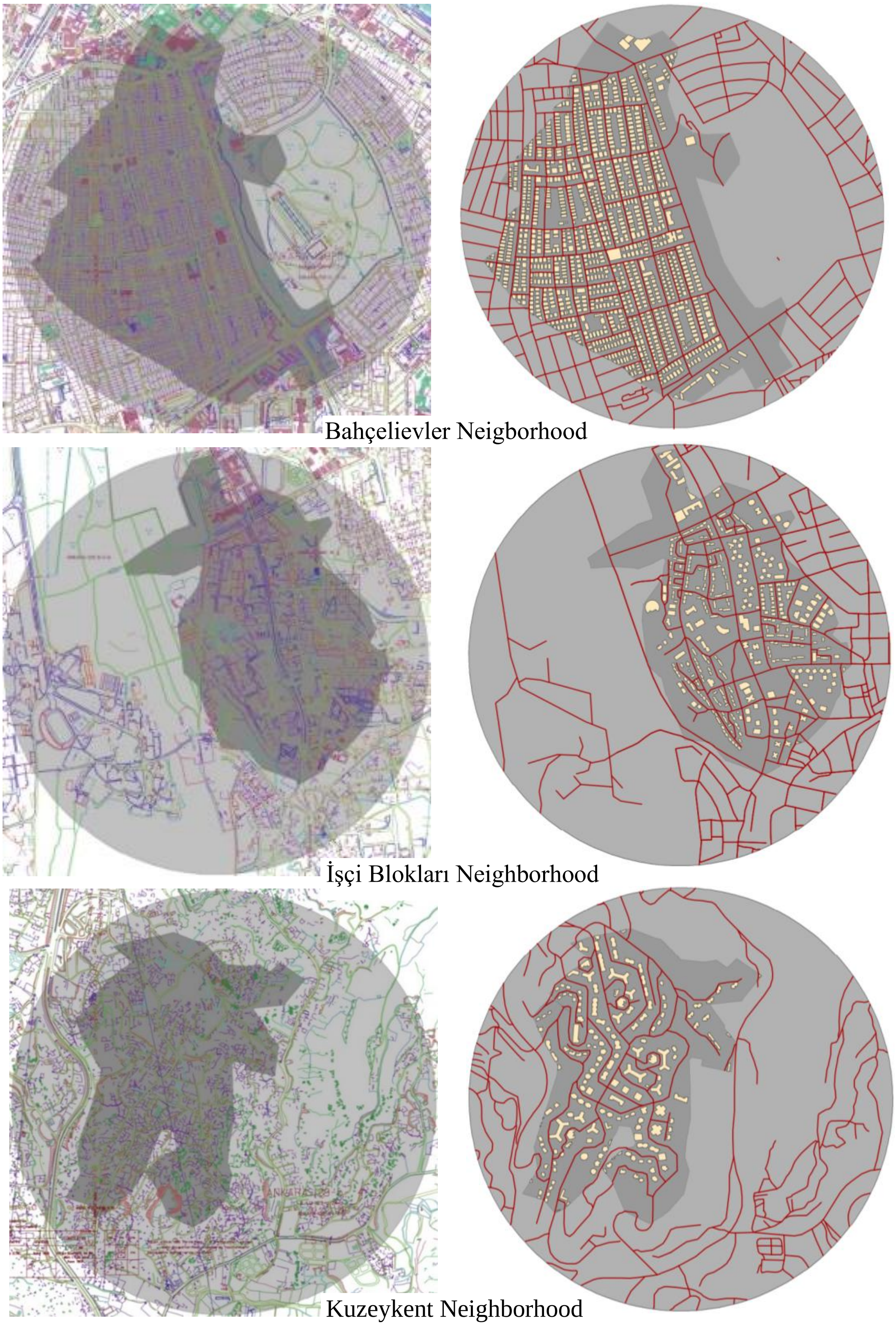


Figure 3.6. Data from municipality (left) and final digitized data by author(right). Grey shaded areas represent school service areas

3.3.3 Data Attributes Editing Process

The road degree(width) information is not available in the data obtained from the municipality. Therefore, Google Street View and satellite imagery (basemap of ArcMap, data source Maxar) are used to obtain road width information. Width information of the road is stored in the “WIDTH” column. The column, “Length“ is added to the road layer. “Calculate Field” tool with the expression “!shape.lenght@KILOMETERS!” is used to obtain the lengths of the roads.

The land use data in halihazır(base) maps are stored in the “KATMAN” field of “Çizgi” layer as BINA_CAMITURBE (mosques), BINA_INSAAT (construction sites), BINA_MESKUN (residential buildings), BINA_OKUL(schools), BINA_RESMI (government buildings) (Figure 3.7). However, much of the information regarding the land use of buildings were missing in the halihazır(base) maps. Additionally, these maps did not provide any information regarding the number of floors in the buildings at all. Therefore, in addition to field trip observations, publicly accessible online sources such as Google Street View and E-imar Sorgulama from the municipalities’ websites (https://imardurumu.cankaya.bel.tr/imardurumu/index.aspx) were used to obtain such missing data. By using these three techniques, the ground floor land use of building, the general land use of building and floor number of buildings were collected.

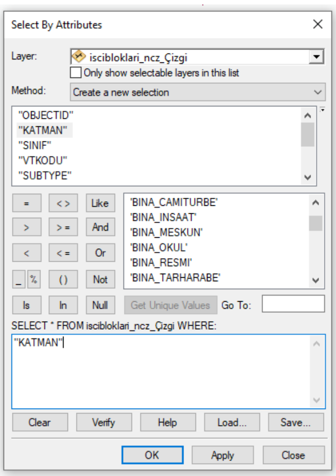


Figure 3.7. Attributes of “KATMAN” field of “Çizgi” layer

The uses of buildings were classified and coded as follows;

- RESIDENTIAL as RES
- COMMERCIAL as COM
- EDUCATIONAL, CULTURAL as EDU
- GOVERNMENTAL- PUBLIC INSTUTION as GOV
- RESIDENTIAL MIX as RESMIX
- NON-RESIDENTIAL MIX as NONRESMIX
- HEATH as HEA
- RELIGIOUS as REL
- OTHER (BUSSINESS, OFFICES, BANKS, WEDDING HALL) as OTH

The uses of ground floor of buildings were classified and coded as follows;

- RESIDENTIAL as RES
- COMMERCIAL as COM
- EDUCATIONAL, CULTURAL as EDU
- GOVERNMENTAL-PUBLIC INSTUTION as GOV
- HEALTH as HEA
- OTHER (BUSSINESS, OFFICE,BANKS, WEDDING HALL) as OTH

The ground floor use is located in “GROUND” column and, the general use of the building is located in “BUILDING” column. The number of floors is stored in the “FLOOR” column. The “ShapeArea” coloumn is added to Building layer. “Calculate Field” tool with the expression “!shape.area.@SQUAREKILOMETERS!” is used to obtain base area of the buildings.

3.4 GIS Framework of The Study

ArcGIS software presents many data processing tools which are known as geoprocessing tools. Automation of manipulation and analysis of data provide easiness, time saving and accuracy. ArcGIS provides some automation methods such as scripting and Model Builder. Model Builder provides the automation with workflow which includes visual diagrams without programming language. Models have variables (input and output data or value), geoprocessing tools, and connectors (ArcGIS, n.d.) (https://desktop.arcgis.com/en/ArcMap/10.3/analyze/modelbuilder/what-is-modelbuilder.htm.).

In the next section, author explains the selected parameters for index and School Walkability Toolbox which is created by Model Builder.

3.4.1 School Walkability Index

In the previous chapter, the author introduced the objective meso-scale urban form variables that may affect children's travel behavior. As mentioned previously, there is a great deal of research investigating the physical environmental factors that affect adults' walkability. Most of these studies revealed the role of meso-scale urban form characteristics like net residential density, retail floor area ratio, intersection density and land use mix in affecting adults' walkability (Ikeda et al., 2018; Kerr et al., 2006; Larsen et al., 2009). Some others developed a school walkability index for measuring children's school walkability. For example, Giles-Corti et al. (2011) developed the school site specific walkability index with pedshed ratio and vehicular traffic exposure components. As Giles-Corti et al. (2011) stated, since there is no universal and open source road volume data, traffic exposure is obtained from data based on the road hierarchy. Christiansen et al. (2014) added residential density as a third component to school site walkability index because neighborhoods having more density refers shorter walking distance to school for children.

In this study, author used school site walkability index (Christiansen et al., 2014; Giles-Corti et al., 2011; Trapp et al., 2012). Based on the literature reviewed, some meso-scale urban form variables were added to the index. Index consists of following parameters: pedshed ratio, building density, land use mix (ground and building), traffic exposure, and greenness value. It is assumed that all parameters positively and equally affect school walking. The effects of parameters on children's school walking may differ due to individual perceptions, but it is generally assumed to be positive. All parameters have same weights. Also, self-reported data will be able to more accurate weights for the parameters. Urban form variables should complement each other to create the walkable environment. Since single one of the parameters is not sufficient for the evaluation of school walkability, the index (5) was calculated as the sum of these;

$$School\ Walkability\ Index = Pedshed\ Ratio + Building\ Density\ + Land\ Use\ Mix + Traffic\ Exposure\ (inverse) + Grenness\ Score \tag{5}$$

Pedshed ratio is used to measure connectivity with the actual walkable buffer (road network based) and Euclidean buffer, as mentioned in Chapter 2.4.1.2. It shows the efficiency of street network for the walking accessibility of school site. Main roads and thus high traffic exposure is seemed as one the main barriers for school walking as previously mentioned in Chapter 2.4.1.6. School routes are on access roads increases the school walking. Most of the cities that adopt walkable community decreased minimum required street width (Handy et al., 2003; Western Australian Government Planning Commission, 2009). That aims to reduce traffic by slower vehicular speed and thus, creating attractive environment for walking. Building density is used to measure density variable because of the lack of residential density data. Density refers to potential for more people on the streets within walkable distance, but it is supposed to combined with diversity of uses to create walkable environment. Otherwise, area where the built form has high density, but low functional diversity increases car dependency. Because it cannot create destinations within walking distance. High level of diversity causes the vitality to be high. For children, it may be more enjoyable to see some uses such as commercial, cultural rather than residential in their walking to school. Also, high level of mixed uses increase the eyes on street (Jacobs, 1961), and therefore children walk in more security rather than desolated streets. Therefore, land use mix was added to index since it has potential to affect children's walking behavior (Campos-Sánchez et al., 2020; Dias et al., 2019; Larsen et al., 2009). In addition to general building land use, ground floor land use of buildings was calculated separately. Because ground floor use is where children interact actually with the building and thus contribute most to their school walking (Singh, 2016; Torun et al., 2015). In most of the walkability studies, green areas are evaluated in the land use mix calculation. However, in this study, green areas were not included in this measurement because land use mix calculation was based on buildings from the halihazır(base) map, not parcel data. In addition, the study of Klompmaker et al. (2018) found the strongest association with walking for greenness measurement as NDVI value rather than distance of the residential address to the nearest park and surrounding green space from land use database. Additionally, many scholars found higher NDVI value is related with more physical activity, lower body mass index (BMI) and more school walking (Almanza et al., 2012; Bao et al., 2021; Cottagiri et al., 2021). Therefore, NDVI was used to measure urban greenness in the neighborhoods.

Since most students in Turkey educated in the neighborhood schools which are close to their homes, the walkability of the school's service area is very important (Ozbil et al., 2021). Walkability analyses were carried out within 1000 meters of the schools. It is stated that the secondary school's service area should be within a walking distance of approximately 1000 meters in the spatial planning regulations (i.e., Mekansal Planlar Yapım Yönetmeliği). In the analysis, neighborhood refers the school's service area. Therefore, administrative boundaries of the different neighborhoods might be included in the school's service areas.

3.4.2 Models of Toolbox

To use proposed School Walkability tool, input features are required to run the models of toolbox. These inputs are: point of school, roads (including width and length attributes), network dataset, buildings (including floor, land use and shape area attributes)and Sentinel 2 data. Building and roads within the service area of school (based on road network) are used to measure walkability. Because it means the actual accessible area by walking unlike straight line buffer (Jacobs et al., 2021). These inputs are created as;

1. ”Polygon to Point” tool is used to obtain the point geometry of the building of school.
2. “Network Dataset” is a source data to use “Network Analyst Tool” which provides transport analysis in ArcMap Software. It is created from the road

polyline feature. To obtain “Network Dataset”, road data is right-clicked from the Catalog, and selected “New” and then” Create Network Dataset”.

3. Network Dataset is used to get the source data of “Service Area Layer”. Service area of school is based on 1 km network distance.
4. Roads in Service Area Layer are obtained by using “Clip” tool.
5. Buildings in Service Area Layer are obtained by using “Clip” tool.
6. Band 4 and Band 8 of Sentinel 2 Level-2A data which covers the neighborhoods are obtained from Copernicus Open Access Hub (https://scihub.copernicus.eu/).

3.4.2.1 Pedshed Ratio

To calculate “Pedshed Ratio”, buffer area which is based on 1000 meters straight line distance and service area which is based on 1000 meters network distance are used (Ellis et al., 2016; Giles-Corti et al., 2011). Higher pedshed ratio means higher connected network. In the Pedshed Ratio Model;

1. “Make Service Area Layer” tool is used to obtain “Service Area” based on 1 km network distance.
2. “Add Location” is used to add the school point to network model as “Facilitators”.
3. “Solve” is selected and then Service Area Polygon (Pedshed) is created.
4. The Service Area polygon is extracted as polygon layer.
5. “Service_Area” field is added to Service Area Polygon layer.
6. “Calculate Field” tool with the expression “!SHAPE.area@SQUAREKILOMETERS!” provide to add the square meter of Service Area to field.
7. “Buffer” tool is used to create 1 km Buffer Area from the Point of School.
8. “Buffer_Area” field is added to Buffer Area Polygon layer.

9. With the “Calculate Field” tool with the expression “!SHAPE.area@SQUAREKILOMETERS!”, provide to add the square meter of Buffer_Area to field.
10. “Get Field Value” tool is used to get the “Service_Area” field value of Service Area Polygon layer as “Service Area Value”.
11. “Pedshed_Ratio” field is added to Buffer Area Polygon layer.
12. “Calculate Field” tool with the “%Service Area Value% / !Buffer_Area!” expression is used for to get the ratio of Buffer Area and Service Area.
13. “Summary Statistics” is used to get the table of Pedshed Ratio as output.

Figure 3.8 shows content of the model.

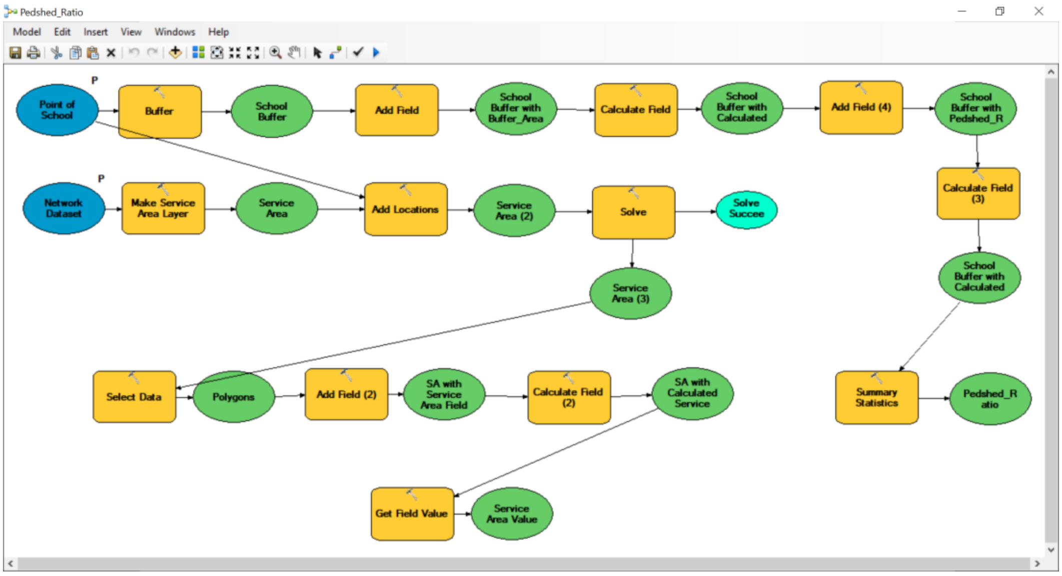


Figure 3.8. Pedshed Ratio model

Figure 3.9 shows the user interface of the model.

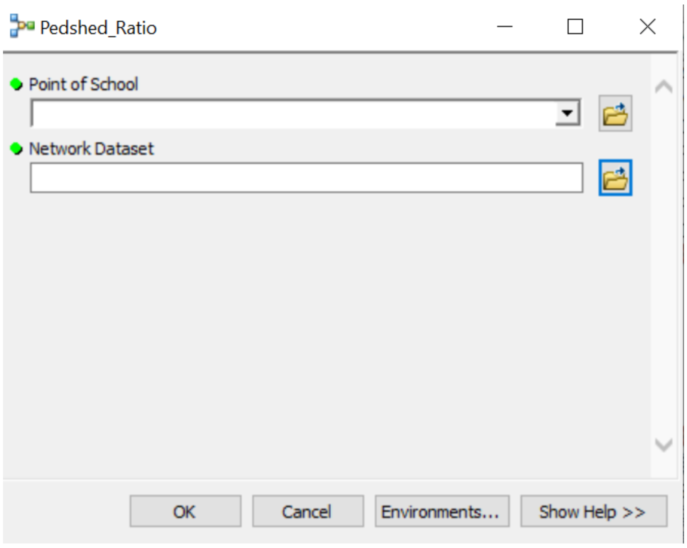


Figure 3.9. Interface of Pedshed Ratio model

3.4.2.2 Building Density

Building density is calculated as the ratio of total floor area to service area of school (i.e., the area around the school based on 1000 meters network distance)(Lin and Yu, 2011). In the Building Density Model;

1. "Floor_Area" field is added to Building layer.
2. Then "Calculate Field" tool with the expression "ShapeArea * Floor" is used to obtain floor area of the building.
3. "Dissolve" tool is used to get the Sum of the floor area of Buildings in the Service Area. In the tool, "Floor_Area" is selected as Statistic Field and "SUM" is selected as Statistic Type.
4. "Make Service Area Layer" tool is used with Network Dataset input.
5. Point of school is added to Facilities with "Add Location" tool.
6. Service Area Layer is "Solved" and Service Area Polygon is obtained.
7. "Service_Area" field is added to Service Area Polygon with "Add Field" tool.

8. “Field Calculate” with expression !shape.area@SQUAREKILOMETERS! provides the area of Service Area of school.
9. Dissolved layer (from 3rd step) and Service Area Layer are spatial joined.
10. “Building_Density” field is added to output layer of Spatial Join tool.
11. “Calculate Field” tool with expression “[SUM_Floor_Area] / [Service_Area]” provides the Building Density of the area.
12. “Summary Statistics” is used to get the table of Building Density as output.

Figure 3.10 shows content of the model.

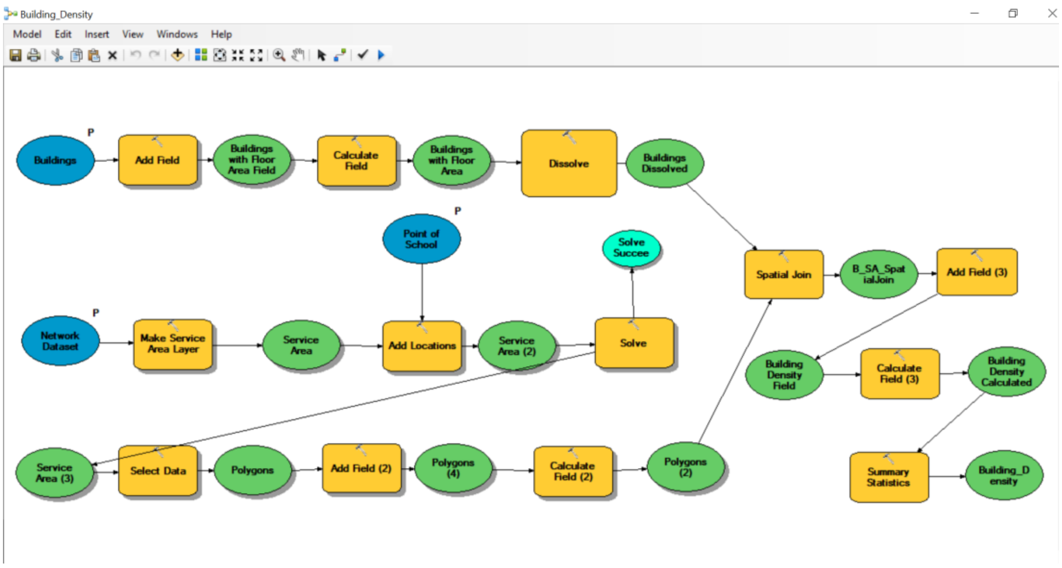


Figure 3.10. Building Density model

Figure 3.11 shows the user interface of the model.

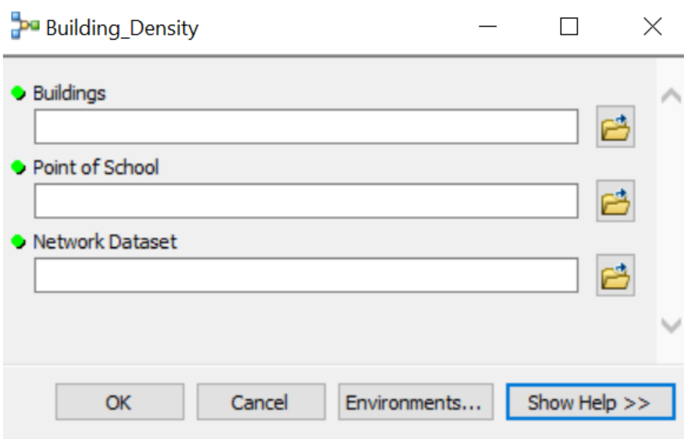


Figure 3.11. Interface of Building Density model

3.4.2.3 Land Use Mix

Ground floor land use mix and building land use mix is calculated according to Entropy Index (H) (Frank et al., 2010; Ikeda et al., 2018; Rahman et al., 2020). Entropy Index (6) represents the diversity in the land uses.

$$H = (-\sum_{i=1}^{n} P_i \ln(P_i)) / \ln N \tag{6}$$

, where H represent the entropy index, N stands for the number of land use categories, Pi represents area ratio for each land use category to the total area of all categories. The results are ranged between 0 and 1. 1 represents heterogeneity which is high level land use mix, and 0 represents homogeneity which is low level land use mix (Leslie et al., 2007). While calculating Pi for ground floor land use mix, buildings floor area of land use is divided to all buildings floor area. While calculating Pi for building land use mix, buildings floor area*floor number of land use is divided to all buildings floor area* floor number.

3.4.2.3.1 Ground Floor based Land Use Mix

In the Land Use Mix Ground Floor Model;

1. “Make Feature Layer” with Expression “GROUND= RES” provides the create layer of building which is assigned to Residential Use.
2. All the layers type of uses are created with 1st step.
3. “Dissolve” tool is used to get sum of the shape area of all buildings in the layer.
4. 3rd step is applied all the layers of uses.
5. All layers are converted into one layer with the “Merge” tool. Output layer has rows which each one is assigned to one use.
6. “Dissolve” tool is applied the layer which has all the building. Therefore, the sum of shape area of all buildings is obtained.

7. “Spatial Join” (Join Features: Dissolved Layer (Buildings Layer) and Target Feature: Merged Layer (Uses Layer)) tool is used to get the layer with columns containing sum of shape area of uses and sum of shape area of all building.
8. “Add Field” tool is used to add “Pi” field.
9. Then “Field Calculator” is used to calculate Ratio which refer to Pi.
10. “Add Field” tool is used to add “LnPi” field.
11. “Field Calculator” with the expression “math.log(!Pi!)” is used to calculate Ln Pi.
12. “Add Field” tool is used to add “Entropy” field.
13. Field Calculator with the expression “!Pi! * !LnPi! / math.log(7)” is used.
14. “Summary Statistics” tool is used to get the table with Sum of the “Entropy” field.

Figure 3.12 shows content of the model.

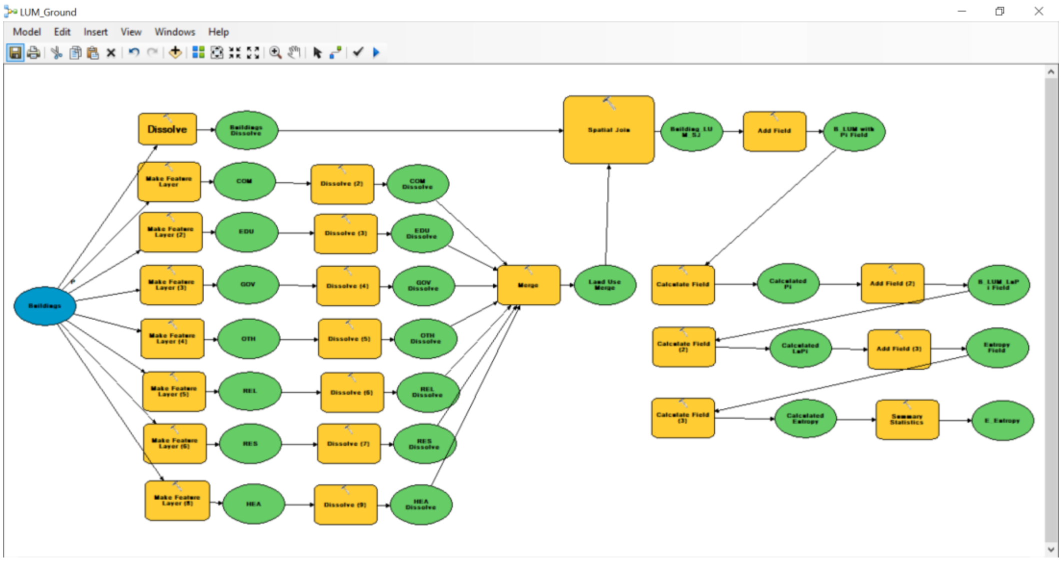


Figure 3.12. Ground Floor based Land Use Mix model

Figure 3.13 shows the user interface of the model.

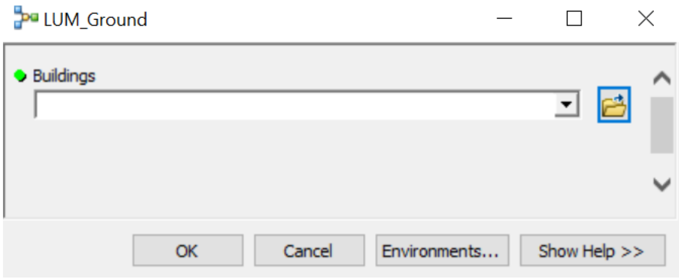


Figure 3.13. Interface of Ground Floor based Land Use Mix model

3.4.2.3.2 Building Land Use Mix

In the Land Use Mix Building Model;

1. Add Field is used to add “FloorArea” field
2. “Calculate Field” with expression “Shape Area* Floor” is used to calculate floor area.
3. “Make Feature Layer” with Expression “GROUND= RES” provides the create layer of building which is assigned to Residential Use.
4. All the layers type of uses is created with 3rd step.
5. “Dissolve” tool is used to get Sum of the Floor Area of all building in the layer.
6. 5th step is applied all the layers of uses.
7. All layers are converted into one layer with the “Merge” tool. Output layer has rows which each one is assigned to one use.
8. “Dissolve” tool is applied the layer of buildings. Therefore, the sum of floor area of all buildings is obtained.
9. “Spatial Join” (Join Features: Dissolved Layer (Buildings Layer) and Target Feature: Merged Layer (Uses Layer)) tool is used to get the layer with columns containing sum of floor area of uses and sum of floor area of all building.
10. “Add Field” tool is used to add” Pi” field.
11. Then “Field Calculator” is used to calculate ratio which refer to Pi.

12. “Add Field” tool is used to add “LnPi” field.
13. Then” Field Calculator” with the expression “math.log(!Pi!)” is used to calculate Ln Pi.
14. “Add Field” tool is used to add” Entropy” field.
15. “Field Calculator” with the expression “!Pi! * !LnPi! / mat.log(9)”is used.
16. “Summary Statistics” tool is used to get the table with sum of the “Entropy” field. In the table, Sum_Entropy field value refers to negative H of Entropy Index equation.

Figure 3.14 shows content of the model.

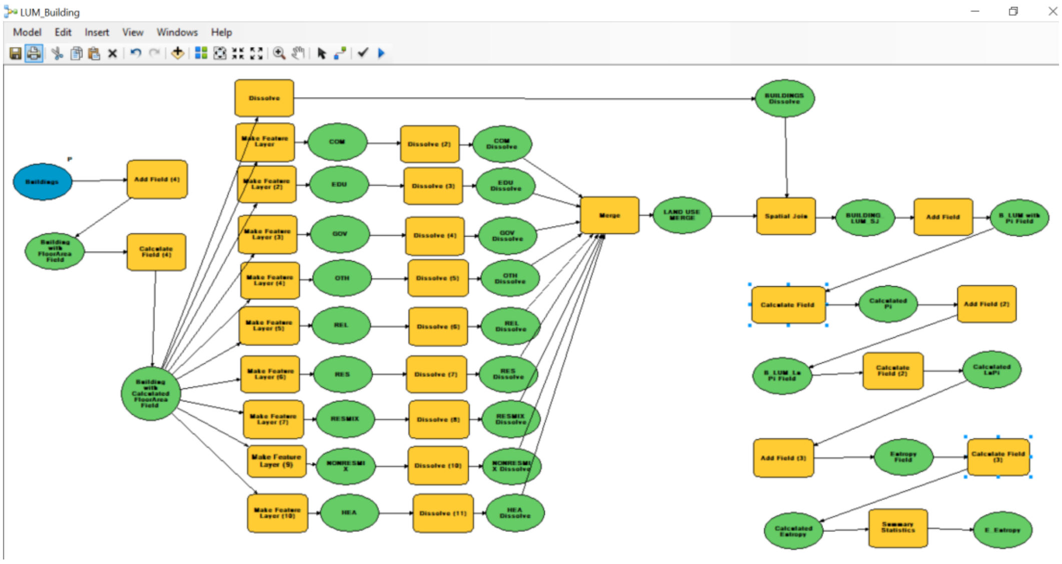


Figure 3.14. Building based Land Use Mix model

Figure 3.15 shows the user interface of the model.

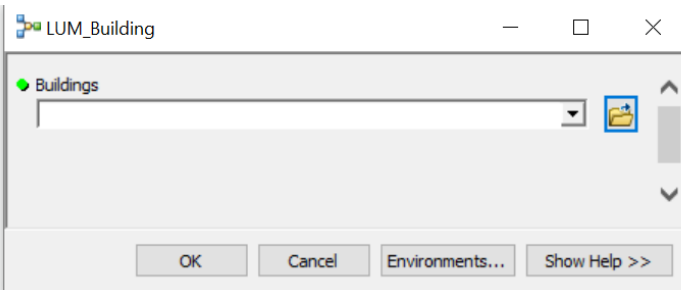


Figure 3.15. Interface of Building based Land Use Mix model

3.4.2.4 Traffic Exposure

Traffic exposure is calculated as the ratio of length of access roads to length of other main roads (i.e., primary distributors, district distributors, local distributors) in the service area (Christiansen et al., 2014; Giles-Corti et al., 2011; Trapp et al., 2012). The higher result means lower traffic exposure. Access roads are determined as the road width which is smaller than 5 meters. In the Traffic Exposure Model;

1. “Dissolve” tool is used to group the roads according to their width. “Width” field is selected as Dissolve Field. “Length” is selected as Statistic Field and “SUM” is selected as Statistic Type.
2. “Make Feature Layer” is used to select and create road layer whose width is less or equal to 5 meters.
3. Make Feature Layer is used to select and create road layer whose roads width is more than 5 meters.
4. “Dissolve” tool is used to get the sum of the length of the road layers.
5. “Spatial Join” tool provides the output layer with one row which has columns sum of main road lengths and sum of local road lengths.
6. The “Traffic_Exp_Ratio” field is added to Layer.
7. With the” Calculate Field” tool the ratio of kilometers of main roads to kilometers of local roads estimated which refers Traffic Exposure.
8. “Summary Statistics” is used to get the table of Traffic Exposure as output.

Figure 3.16 shows content of the model.

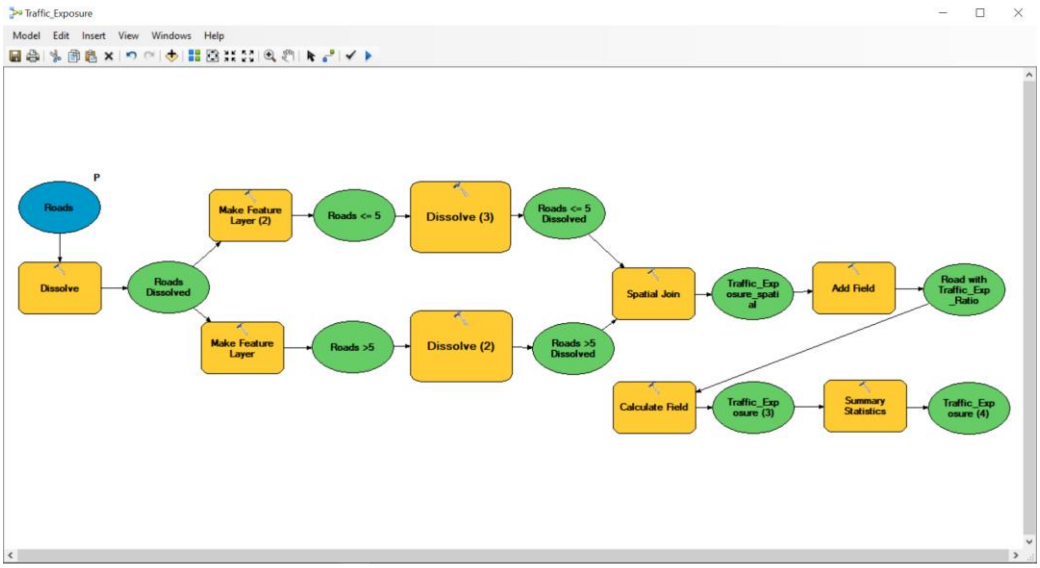


Figure 3.16. Traffic Exposure model

Figure 10 shows the user interface of the model.

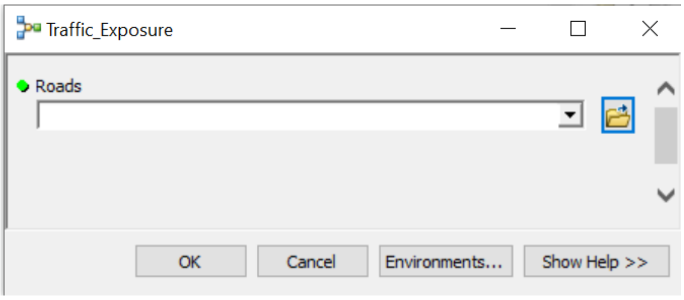


Figure 3.17. Interface of Traffic Exposure model

3.4.2.5 Greenness

NDVI is one of the most frequently used vegetation indexes (Bao et al., 2021; Sarkar et al., 2015). It is calculated by using the following formula;

$$\frac{(NIR - RED)}{(NIR + RED)} \qquad (7)$$

Where NIR and RED means near infrared and red spectral reflectance measurements, respectively. The index is ranged between -1 and 1, and higher values means higher greenness (Sarkar et al., 2015). To calculate NDVI, Band 4 (Red band, bandwidth 31 nm) and Band 8 (NIR band, bandwidth 106 nm) of Sentinel 2 data are used. Mean NDVI value in the service area of school is calculated for measuring greenness exposure of children while school walking (Almanza et al., 2012). In the NDVI based Greenness Model;

1. "Make Service Area Layer" tool is used to obtain Service Area based on 1 km distance from Network Dataset.
2. "Add Location" is used to add the school to network model as "Facilitators". The purpose of this, adding the location of school to the network model.
3. "Solve" is selected and then Service Area Polygon (Pedshed) is created.
4. The Service Area polygon is extracted as polygon layer.
5. Projections of raster data (Band 4 and Band 8) are selected same as Service Polygon Layer.
6. "Raster Calculator" tool is used to calculate NDVI. Map Algebra Expression is "Float("%Band8_Project%") – Float("%Band4_Project%") / Float("%Band8_Project%") + Float("%Band4_Project%")".
7. "Zonal Statistics" is used to get the mean value in the Service Area Polygon. Feature Zone Data is selected as polygon and input value raster is selected as NDVI layer data.

Figure 3.18 shows content of the model.

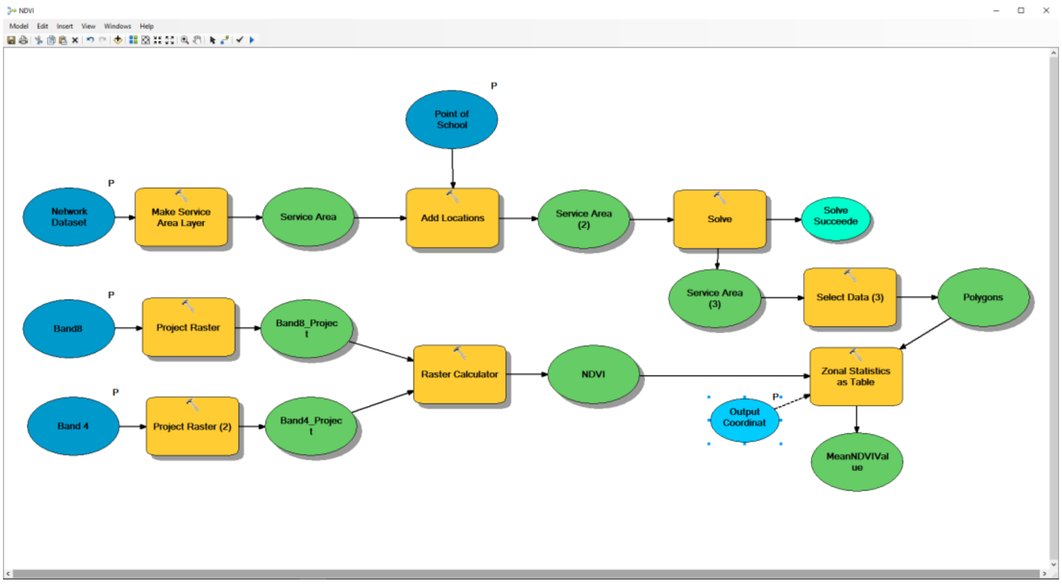


Figure 3.18 NDVI based greenness model

Figure 3.19 shows the user interface of the model.

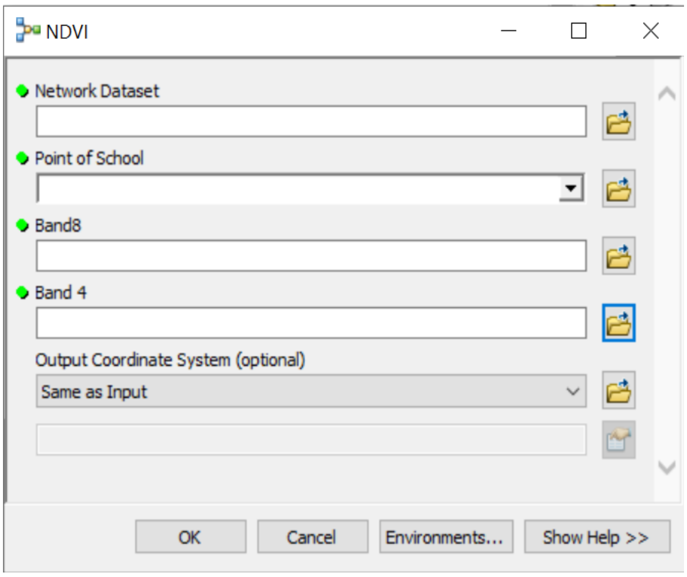


Figure 3.19. Interface of NDVI based greenness model

3.4.2.6 School Walkability Toolbox

"School Walkability" toolbox includes parameter models (Figure 3.20). The toolbox can be used by any ArcMap software user who imports the toolbox. The users have to create "SW" file geodatabase in the C folder as "C: \SW.gdb". The outputs of models are created in this file geodatabase.

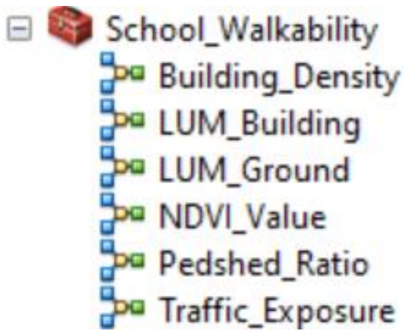


Figure 3.20. School Walkability Toolbox with models

After clicking the model, the corresponding model interface is opened. Then user choose the input features (Figure 3.21). Once the users click OK to run the model, an output table is created in the "C: \SW.gdb" in the Catalog (Figure 3.22).

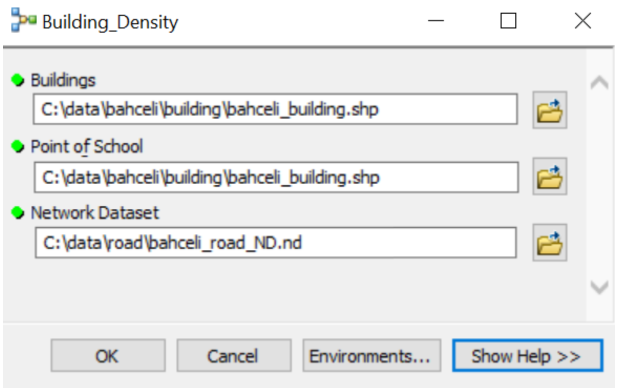


Figure 3.21. Interface of the model with inputs

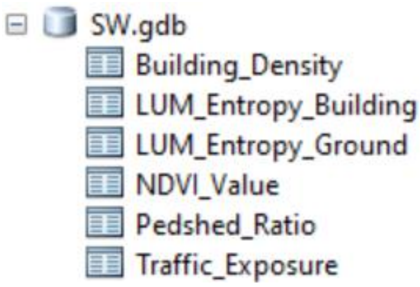


Figure 3.22. Outputs of the toolbox

3.5 Concluding Remarks

The methodological process of the study is summarized in Figure 3.23. Within the scope of the main research question, the selection of neighborhoods, data preparation and school walkability toolbox are explained. Parameters that will be included in the school walkability index are defined. Finally, the contents of the measurement models, that is, how the measurement is made through the model builder are described. The next results chapter will provide answers to the main research question of this study.

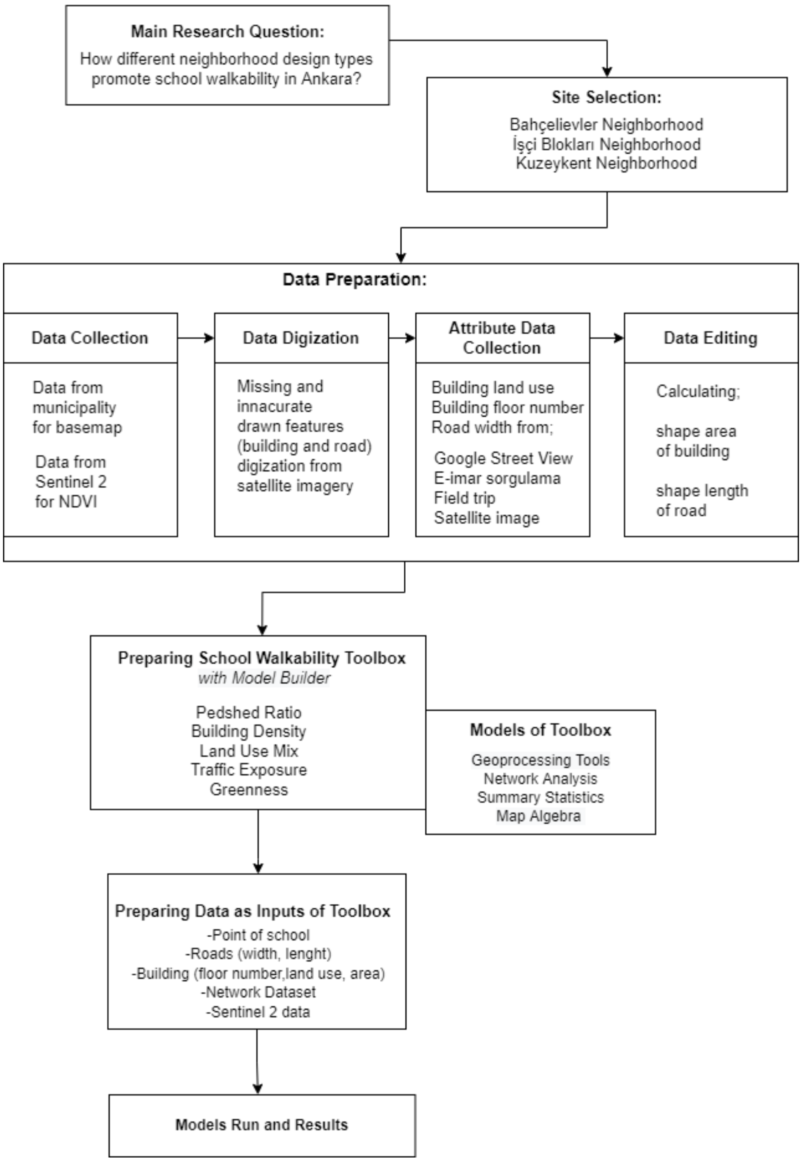


Figure 3.23. Framework of methodological process

CHAPTER 4

RESULTS

In this chapter, the author presents the results of pedshed ratio, building density, land use mix, traffic exposure and greenness score of the chosen neighborhoods. Based on these urban form characteristics, the chapter highlights the neighborhoods that perform better or worse regarding their school walkability. It also provides the composite school walkability index.

4.1 Pedshed Ratio

Pedshed ratio values range from 0 to 1 with higher values indicating more connected networks. Figure 4.1 provides the results of the connectivity analysis in the three study areas. It shows 1 km straight line based buffer area and 1 km street network distance based service area around each school (the location of the school is represented by a flag symbol). In the Figure (4.1), dark grey areas represent the service area of school, and light grey areas represent the buffer area. Red lines show roads in the service area, and grey lines show roads outside the service area. Bahçelievler neighborhood with the 0.46 pedshed ratio offers the larger area within walking distance of the school than İşçi Blokları neigborhood with the 0.32 pedshed ratio. The most recently developed neighborhood, Kuzeykent, has the lowest Pedshed ratio with 0.29.

BAHÇELİEVLER NEIGHBORHOOD	İŞÇİ BLOKLARI NEIGHBORHOOD
	
0.46	**0.32**

KUZEYKENT NEIGHBORHOOD

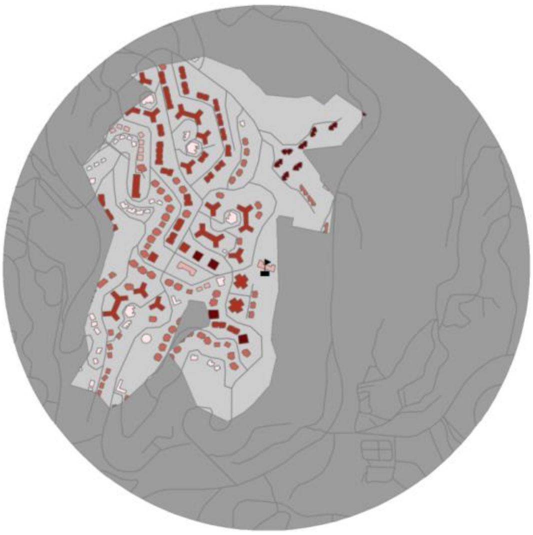
0.29

Figure 4.1. Pedshed of schools

4.2 Building Density

Building density was calculated as total floor area of buildings divided by the service area. Figure 4.2 presents all the buildings in the service area of school with the floor numbers. As the floor numbers increases, the color shades of the buildings darken in the Figures 4.2. Although the building densities in the neighborhoods are quite close to each other, the neighborhood with the highest density is Bahçelievler with 1.15, followed by Kuzeykent with 1.02, and the least dense neighborhood is the İşçi Blokları neighborhood with 0.93.

BAHÇELİEVLER NEIGHBORHOOD	İŞÇİ BLOKLARI NEIGHBORHOOD
	
1.15	**0.93**

KUZEYKENT NEIGHBORHOOD

1.02

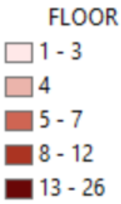


Figure 4.2. Building with floor numbers in service area of schools

4.3 Land Use Mix

Land use mix estimated by entropy index and, it is resulted in a score between 0 and 1. Higher score means higher variety in land use. Two different type of land use mix is calculated: ground level based land use mix and building based land use mix as mentioned Chapter 3.4.1.

4.3.1 Land Use Mix for Ground Floor

Figure 4.3 presents the ground level land use mix based on entropy index. While the ground level land use mix is close to each other in İşçi Blokları (0.57) and Bahçelievler neighborhoods(0.53), it is quite low compared to them in the Kuzeykent neighborhood(0.21).

4.3.2 Land Use Mix for Building

Land use mix based on buildings in service area is presented in Figure 4.4. Kuzeykent neigborhood (0.08) has the lowest land use mix index based on building. İşçi Blokları neighborhood (0.40) follows after it, while Bahçelievler (0.49) has the highest score.

BAHÇELİEVLER NEIGHBORHOOD	İŞÇİ BLOKLARI NEIGHBORHOOD
	
0.53	**0.57**

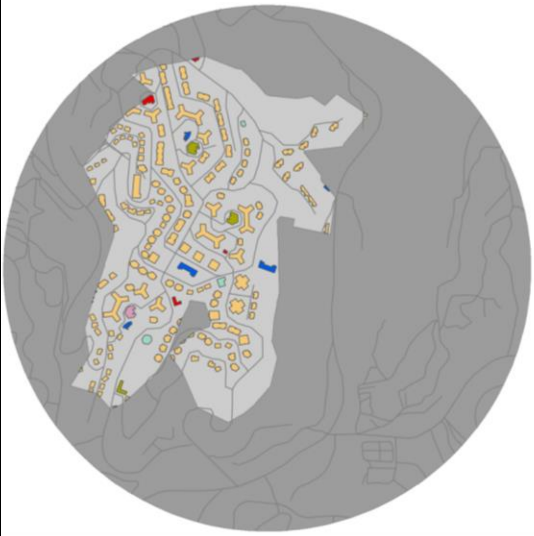
KUZEYKENT NEIGHBORHOOD

0.21

Figure 4.3. Ground floor land use of buildings in service area of schools

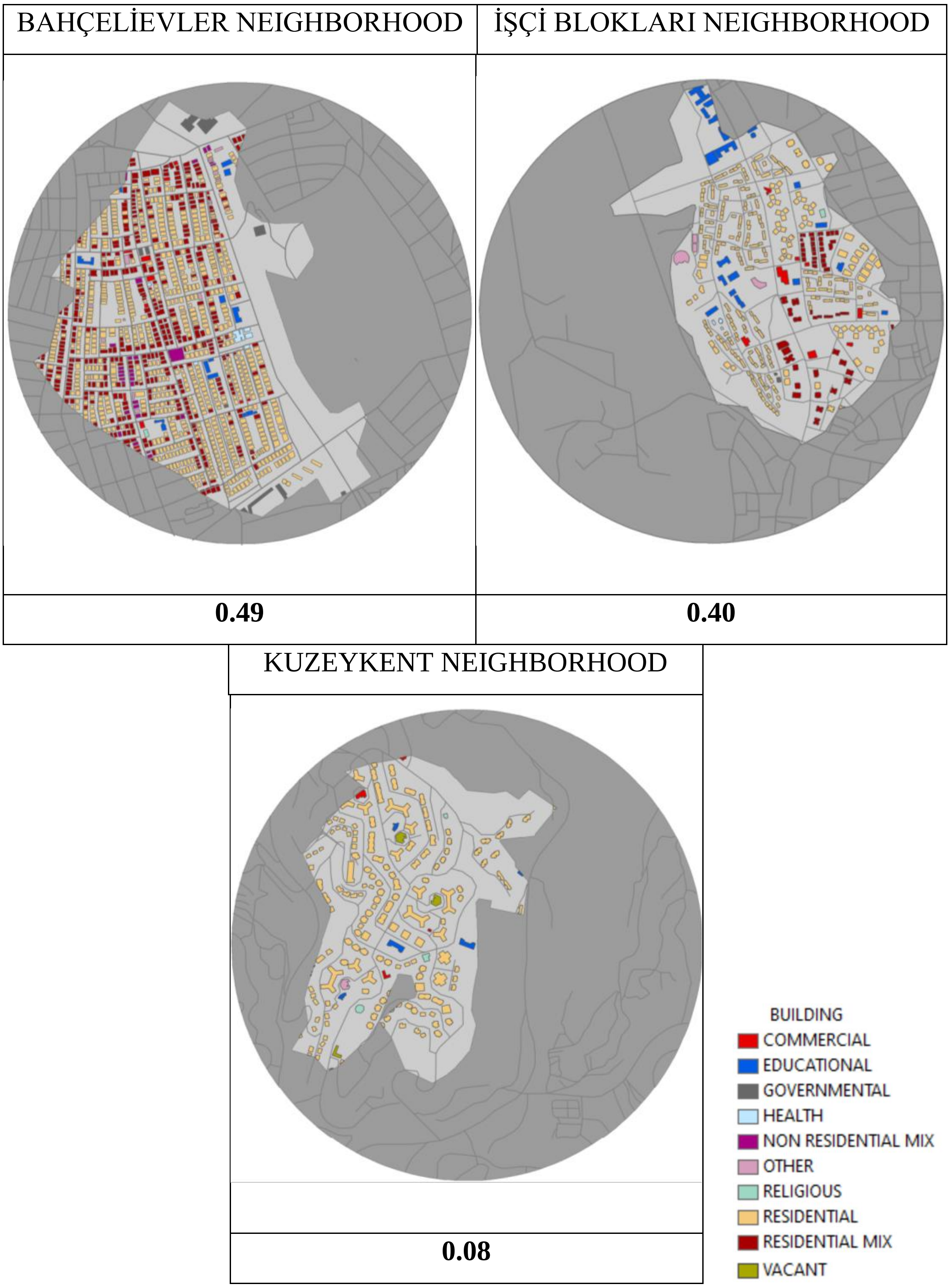
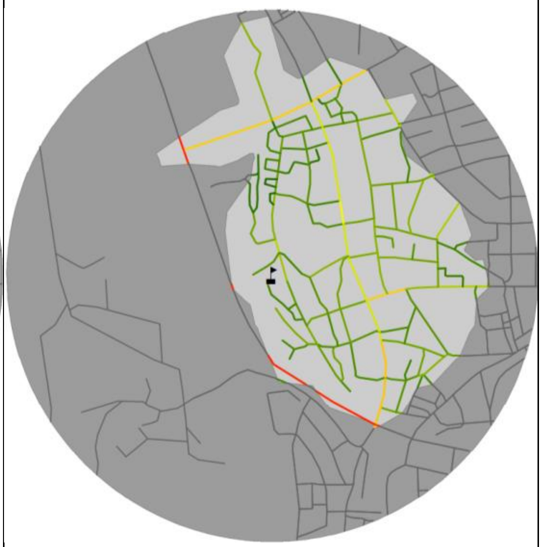
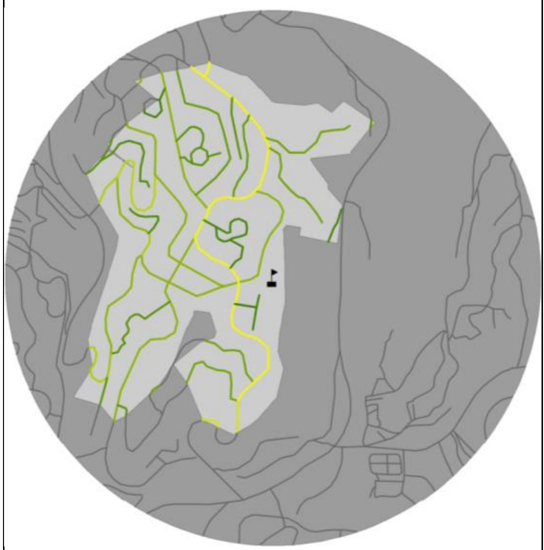


Figure 4.4. Land use of buildings in service area of schools

4.4 Traffic Exposure

Traffic exposure is measured according to the width of the road. In Figure 4.5, roads in the service area of school are classified by their widths. The width of the roads increases from green to red. Figure 4.5 shows the inverse traffic exposure value. Traffic exposure is measured as the ratio of length of minor roads to length of other main roads. Higher value means less traffic exposure (better for walkability) in the service area. İşçi Blokları neighborhood show the best performance with 0.09 rate. After that, Bahçelievler neighborhood has the 0.06 score. The performance of the Kuzeykent neighborhood is quite low compared to others with 0.01.

BAHÇELİEVLER NEIGHBORHOOD	İŞÇİ BLOKLARI NEIGHBORHOOD
	
0.06	**0.09**

KUZEYKENT NEIGHBORHOOD

0.01

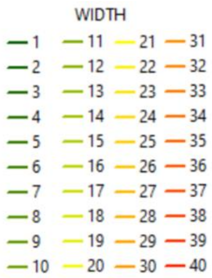
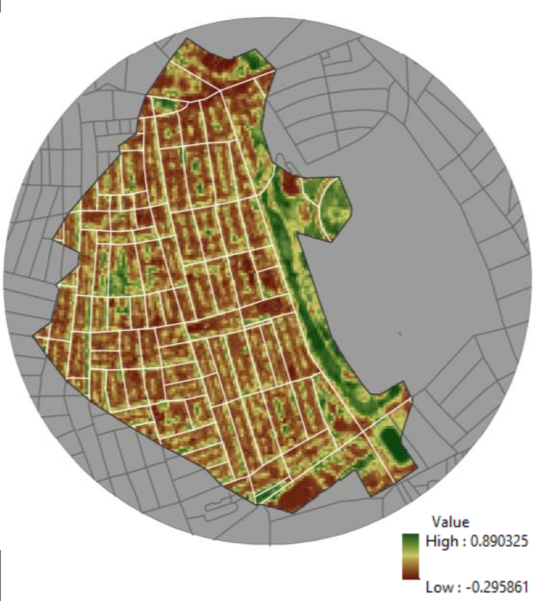
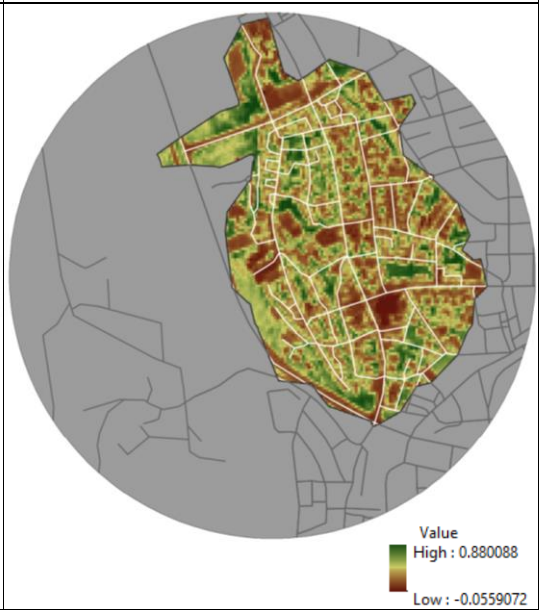


Figure 4.5. Road network according to width in service area of schools

4.5 Greenness

Figure 4.6 shows the pixel values based on Normalized Difference Vegetation Index in the service area of each school. Each value ranges from -1 to 1. High values are represented by green color and low values are represented by brown color. Figure 4.6 indicates the mean NDVI value in the service area of each school. Highest mean NDVI value in the neighborhoods is found in İşçi Blokları neighborhood with 0.34. Bahçelievler has 0.30 as mean NDVI value. Lowest value in neighborhoods is in the Kuzeykent Neigborhood with 0.22.

BAHÇELİEVLER NEIGHBORHOOD	İŞÇİ BLOKLARI NEIGHBORHOOD
	
0.30	**0.34**

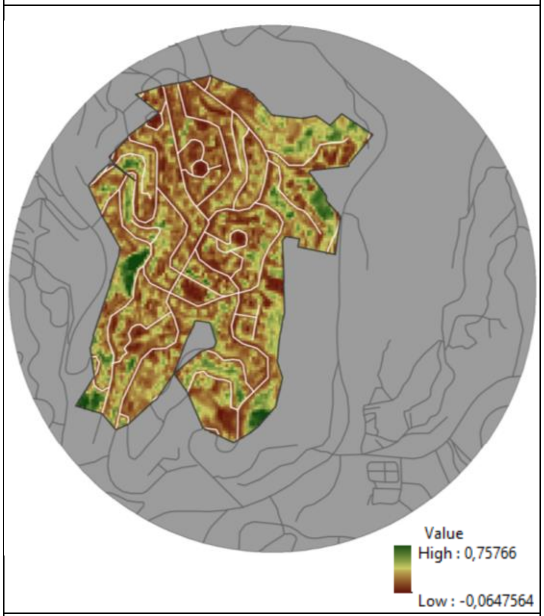
KUZEYKENT NEIGHBORHOOD

0.22

Figure 4.6. NDVI values in service area of schools

4.6 School Walkability Index

Table 4.1 presents the results of all the parameters for the neighborhoods. School walkability index was calculated as sum of the results of parameters. Two types of School Walkability are showed in the table: the one calculated with land use mix based on ground level, and the other one is calculated with land use mix based building. Bahçelievler neighborhood has the highest performance with 2.5 in the School Walkability with ground floor land use mix. It is followed by İşçi Blokları with 2.25, and the lowest School Walkability is found in Kuzeykent neighborhood as 1.75. Similarly, the highest value of School Walkability with building based land use mix is found in the Bahçelievler neighborhood. İşçi Blokları has 2.07 School Walkability with building based land use mix and Kuzeykent has the lowest School Walkability with building based land use mix as 1.62.

Table 4.1 School Walkability of Neighborhoods

	Bahçelievler Neighborhood	İşçi Blokları Neighborhood	Kuzeykent Neighborhood
Pedshed Ratio	0.46	0.32	0.29
Building Density	1.15	0.93	1.02
LUM Building	0.49	0.40	0.08
LUM Ground	0.53	0.57	0.21
Traffic Exposure(inverse)	0.06	0.09	0.01
Greenness	0.30	0.34	0.22
School Walkability (with Ground LUM)	2.50	2.25	1.75
School Walkability (with Building LUM)	2.46	2.0	1.62

*LUM: Land use mix

CHAPTER 5

DISCUSSIONS AND CONCLUSION

In this chapter, summary of the study is presented. Then, results of the study are discussed. Finally, implications of the study and suggestions for the future research are proposed.

5.1 Summary of the Study

Childhood obesity is in an increasing trend globally. Studies on this preventable disease have revealed that urban environment has an important impact on increasing or decreasing obesity (Frank et al., 2006). Children who walk to school are able to meet the required level of physical activity during a day. Studies show that encouragement of school walking for children has a potential to increase physical activity, decrease obesity level, and so enabling healthy environment (Christiansen et al., 2014; Napier et al., 2011; Ozbil et al., 2021; Sun et al., 2015).

A review of the literature on the link between urban planning to physical activity shows that urban form characteristics such as connectivity of road network, density of people/buildings, diversity of uses, distance to school have an important role in determining children's physical activity levels. In this study, the main aim was analyzing and comparing the school walkability in the different neighborhoods to understand the role of neighborhood design in children's walking behavior. While main research question was formed the understand this relation, additional questions were formed to propose a GIS based school walkability model by examining the walkability studies in the literature.

Three neighborhoods were selected from Ankara: Bahçelievler, İşçi Blokları and Kuzeykent neighborhoods, all of which represent different urban design characteristics. The chosen neighborhoods have the following common qualities: all three neighborhoods have different urban form characteristics at the meso (and micro) scales, all three neighborhoods were in the fringe of the city by the time they started to be developed, all the chosen neighborhoods cover a large area within the comprehensive plans, and all sites contained a public secondary school. Different methodological approaches of studies on walkability, and data types used to measure walkability were investigated in literature review. Parameters that are used to objectively measure school walkability in meso scale and their relationship with school walking were examined. Afterwards, the study proposed a new model based on geographic information system (GIS) to measure school walkability based on a literature review of the previously developed school walkability index and measures. Model Builder of ArcMap Software was used to prepare the toolbox of school walkability index. It contains models that measure five parameters: pedshed ratio, building density, land use mix (ground and building level), traffic exposure and urban greenness. These parameters seemed to be the most appropriate objective variables in meso-scale for measuring school walkability for authorities who have limited data sources, research budgets, and skills. How these parameters were incorporated into School Walkability Toolbox, and process of the calculations were described.

Results show that, among the chosen neighborhoods, Bahçelievler is the most supportive neighborhood regarding the potential of these neighborhoods in encouraging children to walk to school. It has high connected network, high level of density of buildings, and diversity of uses. School walkability index of İşçi Blokları neighborhood comes after Bahçelievler neighborhood. It has high diversity, low traffic exposure, high greenness score. Kuzeykent neighborhood, which is a redevelopment project located in the periphery of Ankara, shows the lowest school walkability index. This neighborhood has low connected street pattern, high traffic exposure, low greenness score. Although, the building density is high, the diversity of land use is low in the area.

To the best of the author’s knowledge, this is the first study that uses GIS to objectively measure children’s school walkability in different neighborhood types in Turkey. GIS database of walkability is prepared for school sites for all the three neighborhoods selected from the capital city of this country, Ankara. In line with the literature reviewed, the author argues that there is a strong relationship between urban form and school walkability, and that all of the chosen neighborhoods promote children’s school walkability at different levels because of their varying meso-scale urban form characteristics. Also, the proposed School Walkability Toolbox aims to provide automation of the analysis and therefore, convenience, accuracy, and effectiveness on urban computations for the decision makers, local governments, non-governmental organizations and authorities who make policies and interventions in school districts to improve walkability.

5.2 Discussion Of Results

In this section results of each parameter and school walkability index of all three neighborhood are discussed.

5.2.1 Pedshed Ratio

Pedshed ratio using road network distance and Euclidian distance was used to measure actual walkable catchment area of the school. Higher pedshed ratio values indicate higher connected networks, and so higher accessibility. Highly connected networks provide more direct and short routes, and so more encouragement for children walking to school. 0.6 pedshed ratio is seen as a target level for any center or facilities in the liveable neighborhoods by the West Australian Planning Commission (Department of Planning and Infrastructure: WA Planning Commission, 2009). All the neighborhoods analyzed in the study showed performance under the value of 0.6. Although the West Australian Planning Commission’s report shows that none of the chosen neighborhoods promote children’s walking to and from school based on their pedshed ratios, the result of this thesis shows that some of the neighborhoods may encourage children to walk to and from school more than others. Bahçelievler neighborhood encourages school walkability the most in terms of street connectivity compared to others (pedshed ratio= 0.46). Neighborhood which reflects principles of Garden City Movement, the street pattern has been conserved in 85 years (Songülen, 2012). Grid iron street pattern consisting of narrow and short streets contributes the school walkability. Also, due to low-rise buildings cause smaller block size, Bahçelievler provides more direct routes for children to walk to school. Connectivity of İşçi Blokları neighborhood (pedshed ratio=0.32) is less than Bahçelievler and more than Kuzeykent. Layout of the buildings’ locations around large common space and large backyards causes large block size and thus decreasing of connectivity in İşçi Blokları. However, there are many pathways for pedestrians between common spaces of buildings. The fact that the connectivity analysis was carried out not from the pedestrian network, but from the vehicular road network may have caused the lower connectivity performance of the neighborhood. In Kuzeykent which is located in the periphery, street pattern includes long and large width and curved streets (pedshed ratio=0.29). High-rise buildings in the neighborhood require large blocks, and these large blocks caused reducing the network connectivity. Therefore, it is least supporting neighborhood the school walk with the lowest pedshed ratio in the study areas.

5.2.2 Building Density

Building density was used to measure urban density in the area. High density means more potential for more people, more vitality, and so more perceived safety for children in the streets rather than low density as mentioned in Chapter 2.4.1.3. Low density compared to high density requires car dependency because of long distances. Bahçelievler takes advantages of proximity to city center and being a subcenter of Ankara in the context of density (building density=1.15). With permits of increasing floor, the conversion from low rise detached houses with large gardens to apartments caused increase in density of neighborhood as mentioned in Chapter 3.2.1. That also caused lack of open green space in the area which is one of the reasons of high-level building density. Building density of Kuzeykent neighborhood is very close to Bahçelievler, despite it is located in the periphery of the city (building density=0.93). Although there are low-rise detached house buildings in the lower elevations, most of the buildings are consist of high-rise buildings with 13 floors of buildings. İşçi Blokları (building density=1.02) has the lowest building density in study area because of the concentration of 5-storey buildings with large backyards gardens and clustering around large common space as mentioned in Chapter 3. Neighborhood has a collective urban garden (i.e., bostan) which is rare example in Ankara. Additionally, apart from the 5-15 storey housing pattern in the service area of school, there is 6-7 floor of apartments with small setbacks in the parcel (causes the increasing in density) which is transformed from squatter houses, and these are administratively located in the Çukurambar neighborhood boundary. The building density in Bahçelievler and Kuzeykent is very close to each other, but they do not have same effect on children's school walking. Although more density creates potential for more vitality in the street, it should be complemented with land use mix to contribute walkability. As mentioned in Chapter 2.4.1.3, in some studies more density resulted in less school walking. For example, when there are land uses that make children feel safer and interest them in the first ground floor of a high rise building, it may has a positive effect on walkability. Conversely, when it includes residential rather than commercial use in ground floor of a high rise building, it can have the opposite effect for walkability. Because it reduces the effect of eyes on the street (Webb Jamme et al., 2018). The building density of the urban area do not necessarily affect positively to the walkability capacity of the environment. Therefore, it is important to evaluate the building density together with land use mix.

5.2.3 Land Use Mix

It is accepted that high diversity in land uses means more walkable environment because it creates destinations for pedestrians in walking distance. Additionally, neighborhood with high density and low diversity results in increasing car usage rather than walking. Because people do not have activity destinations in walking distance and therefore, they need cars. Some scholars claim that land use mix does not directly contribute to the walking of a child whose destination is a school as mentioned in Chapter 2.4.1.4. However, mixed uses rather than residential uses create pedestrian flow and, so liveliness on the streets. Therefore, it is assumed that it contributes to children walk to school with more enthusiasm and also, in surveillance. The building based land use mix of Bahçelievler neighborhood show the highest value (building based land use mix =0.49, ground floor based land use mix=0.53). For children who lives in subcenter of Ankara, high diversity of uses, and therefore vibrancy in streets, can have a positive effect on their walking to school. Also, İşçi Blokları neighborhood has the highest entropy index for ground floor land use mix (building based land use mix =0.40, ground floor based land use mix=0.57). Ground floor is evaluated separately from the whole of the building, because the actual area where the pedestrian interacts with the building is the ground floor of the building (Ewing, 1999). For the children, it is attractive that the ground floor is used as commercial, cultural, recreational uses. In this regard, İşçi Blokları neighborhood supports school walkability the most. In Kuzeykent (building based land use mix =0.08, ground floor based land use mix=0.21) neighborhood, there is a design pattern in the neighborhood, which includes residential buildings clustered around the large building for common use. However, most of these buildings that was aimed as common use are vacant. The neighborhood, where mostly residential buildings are concentrated, has low performance in terms of variety of land uses. That causes desolation in the streets of neighborhood having low diversity and high density. As a result, neighborhoods least support walking to school in the context of vitality, attractiveness and safety for children.

5.2.4 Traffic Exposure

Main roads are one of the main barriers for safety of children on school walk as mentioned in Chapter 2. Larger road widths indicate increased traffic speed and more traffic exposure. For this reason, providing school route along local roads is one of the essential factors for promoting the school walking. As the total length of the main roads in the school site increases, traffic exposure increases, and school walkability decreases. İşçi Blokları is the most suitable neighborhood for children's walking in terms of traffic exposure (inverse traffic exposure=0.09). In service area of school, small width streets are in the majority. Moreover, there are many pedestrian pathways which provides safety for children in the neighborhood, but these roads were not included in the assessment because the assessment was made through the vehicular road network. In Bahçelievler neighborhood (inverse traffic exposure=0.06), which has been started to develop in 1930's, street pattern has been conserved. Most of the streets are narrow and not convenient for two-way traffic. That causes the traffic calming and more suitability for walking to school. In Kuzeykent (inverse traffic exposure=0.01), there is a street layout based on large width streets, which is more suitable for driving. Although there are a few high degree roads in the service area, traffic exposure is highest in the Kuzeykent Neighborhood because most of the streets have a large width. In contrast to places where reducing the minimum required street width to intend to create a walkable environment (Handy et al., 2003), Kuzeykent which is a new settlement is less supportive of school walkability in terms of traffic safety due to its road widths.

5.2.5 Greenness

Urban green space provides many services such as increasing aesthetic value and visual attractiveness, buffering from traffic exposure, comforting in high temperature. Therefore, it is supposed that green areas, parks, street trees on school's service area increase children's school walking. Normalized Difference Vegetation

Index is calculated for the greenness level in the service area of each school. Compared to other neighborhoods İşçi Blokları has more small scale neighborhood parks and green areas in the service area of the school (greenness=0.34). Apartments have large backyard gardens. Also, setbacks of many apartments are converted to small gardens by residents (Cihanger, 2018). İşçi Blokları is most contributing school walkability with highest mean NDVI value. Bahçelievler neighborhood (greenness=0.30) originally designed as houses with large gardens and then converted into apartments. Although most of the backyards of houses is still small gardens, some have been converted into car parks. Floor increases also led to a decrease in green open spaces in the neighborhood over the years. In the neighborhood, part of the green area of Anıtkabir (i.e., Mausoleum) is located within the service area and causing an increasing mean NDVI value and school walkability. Kuzeykent Neighborhood has the lowest score in NDVI analysis. Although the Kuzey Yıldızı Valley is a recreational green area covering a large area in Kuzeykent Neighborhood (greenness=0.22), its small part is located within the school's service area. Apart from the small parks belonging to the gated communities and gardens of few detached houses in the area, the amount of green area is very few in neighborhood. Most of the areas that have high NDVI values in the analysis, are non-recreational green areas which are reforestation of steep sloping areas which is separated from the road with retaining wall. Since this is a newly built area, the fact that landscaping has not been done yet, and the presence of empty lands around the built area reduces mean NDVI value. Landscaping and reforestation in the empty areas between the buildings, will be able to reverse the result here and contribute the school walking.

5.2.6 School Walkability Index

To create walkable environment, walkability parameters are supposed to complement each other. A single parameter is not sufficient to evaluate the walkability capacity. Therefore, school walkability index was calculated as the sum of the results of parameters. For each parameter measured in the model, although they may have adverse effects on the children's behavior individually due to different perceptions, it is assumed that they all contribute to school walking in general.

Results show that traditional neighborhood Bahçelievler encourage children walk to school much more compared to İşçi Blokları and Kuzeykent neighborhoods. While highest values in terms of parameters are ranged between İşçi Blokları neighborhood and Bahçelievler neighborhood, Kuzeykent neighborhood has shown the lowest performance in almost all parameters. Bahçelievler neighborhood obtained the highest values for school walkability parameters including: pedshed ratio with grid street pattern, building density, land use mix based on building. It is followed by the İşçi Blokları neighborhood with the highest parameter values including land use mix based on ground, low traffic exposure with majority of minor roads, and greenness score due to the amount of small scale parks, backyards gardens. Kuzeykent obtained the lowest values for all parameters except building density. High building density is a result of need for high rise buildings to finance the urban regeneration project. With its low urban greenness, lack of variety of uses, street pattern consisting of long, large, curved streets, it is the neighborhood that least supports school walking.

In the study, traditional neighborhoods with garden apartment houses (Bahçelievler neighborhood), mixed-use neighborhoods of 1970s with low- and high-rise apartments (İşçi Blokları neighborhood) and contemporary high-rise mass housing developments (Kuzeykent neighborhood) were compared in the terms of school walkability. The study demonstrates that the built environment, which is shaped by the urbanization policies, has encouraged school walking for children less over the years.

5.3 Implications of the Study and Further Research

This study highlights the importance of planning decisions about school location to encourage children's walking to school. Findings of study help to planners and policymakers in order to provide better built environment for public health. Since many of the buildings in the İşçi Blokları neighborhood have expired their time, and being potential a safety threat, a possible redevelopment project is being discussed. Redevelopment project can be evaluated in the context of improving school walkability. The thesis can guide what should be increased site-specific in redevelopment projects in the terms of school walking in old neighborhoods like İşçi Blokları. Since each school-site has different characteristics, each of them needs to be evaluated site by site. In the future, researchers could study other neighborhoods using the methodical tool included in the thesis and find out what they should pay more attention to increase school walkability. Moreover, for the existing school site, study provides foundation of interventions for promoting school walkability. New plans with better land use policies which contribute walking can be implemented. In disadvantages area according to meso-scale school walkability, other scale walkability interventions can be applied. Thus, study can guide those interventions of micro-scale design quality elements as mentioned in Chapter 2 (e.g., traffic lights, crossings, signs, sidewalks, street maintenance, street trees, aesthetic). These design elements have also crucial effect on walking behavior. In addition, most of the rapidly increasing mass housing projects in Turkey have similar designs. The thesis provides important information to planners and decision makers about the possible impact of mass housing on children's walking behavior. The fact that Kuzeykent school walkability performance is much lower than other compared neighborhoods indicates that it is failed in this context. TOKİ (i.e., Housing Development Administration of Turkey) can create a healthy, sustainable and liveable urban environment in mass housing projects by providing increasing the walking to school for children with high land use mix in addition to high density. It can provide sufficient green open spaces, better landscape designs, more connected road networks, lower road width, around the school.

There are some arguments that the chosen index parameters are correlated with each other (Feng et al., 2010). However, parameters such as land use mix and connectivity may not be systematically correlated with each other in the chosen neighborhoods since there are no strict zoning regulations in Turkey as in some other countries like the United States. Therefore, the author believes that in different contexts, researchers may observe different results.

There are several limitations in this study. The quality of the input GIS data determines the accuracy of the results. Hence, data was the one of the main concerns of this GIS based study. In Turkey, because GIS database is inadequate, author produced the related data of study field. Produced maps may have lower accuracy and precision than official data by authorities. Halihazır(base) maps provided by the Ankara Metropolitan Municipality, were from year of 1998 and there were missing buildings that were the main layer to be used. It did not contain the land use, and road hierarchy information that are required for urban calculations. Therefore, preparing the data as input feature of the model has been a very labor-intensive process. Since the data preparation is a long time-consuming process, the number of neighborhoods to be included in the study was limited. Other limitation is that most of studies in walkability literature calculate entropy index with parcel level zoning data. However, in this study land use mix is calculated in building level due to the data provided by the halihazır(base) maps in Turkey case. Therefore, recreational green areas are not included in land use mix index. Moreover, NDVI which is used for the greenness score does not provide detailed information about the type and quality of green areas. For the traffic exposure measurement, superior methods can give more accuracy. Road based analysis is computed from the vehicular road data because of the availability and ease of detection from satellite images. Instead, the use of data including sidewalks and pedestrian paths would be more appropriate for the walkability, which is a concept based on pedestrians. The other limitation of study is that all of the parameters in the proposed school walkability index are equally weighted. With the optimization of the model, the best-fitted weights of the parameters to school walking rates of children can be determined. Study was conducted in the pandemic era. Therefore, it cannot be possible to collect the perceived walkability based on self-reported data by children. Validity of the school walkability based on objective data should be tested by self-reported data. The study proposes a tool, but in order to standardization of the school walkability measurement, the tool should be combined with children's self-reported data, which is conducted by municipalities over the schools. Additionally, the author has acknowledged the fact that the raw parameters' values are summed up for the walkability index, but they should be standardized and then summed for the overall value of the index. These investigations can be incorporated into be the further of the study that uses the School Walkability Index as a base.

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