SMARTer Growth Neighborhood Design Manual: Application to Existing Neighborhoods

by

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B.Sc., Ahsanullah University of Science & Technology, 2013

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF APPLIED SCIENCE

in

THE COLLEGE OF GRADUATE STUDIES

(Civil Engineering)

THE UNIVERSITY OF BRITISH COLUMBIA

(Okanagan)

February 2020

The following individuals certify that they have read, and recommend to the Faculty of Graduate and Postdoctoral Studies for acceptance, the dissertation entitled:

SMARTer Growth Neighborhood Design Manual: Application to Existing Neighborhoods

submitted by Md Firoz Mahmood Ovi in partial fulfillment of the requirements for

the degree of Master of Applied Science

in Civil Engineering

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Abstract

Urbanization is putting immense pressure on global infrastructure. Uncontrolled rapid urbanization and motorization of cities are one of the main causes of Urban Sprawl. This sprawl alters the structure and pattern of cities, making it socially, economically, and environmentally unsustainable. Urban Sprawl is associated with traffic fatalities, physical inactivity, obesity, and increased GHG emissions. Urban planners and engineers are researching new methods to eliminate the negative impacts of urban sprawl. SMARTer Growth (SG) Neighborhood design or previously know as Fused Grid (FG) Neighborhood Design has been identified as a reliable planning technique that can effectively fight urban sprawl while making neighborhoods more sustainable and liveable. Macro-level collision prediction models were developed in this study to evaluate the traffic safety condition of the neighborhoods under study. SG was introduced to evaluate two existing neighborhoods, and macro-level collision prediction models were applied to assess the traffic safety of the existing neighborhoods and the retrofitted designs. The comparison between the existing neighborhoods and the retrofitted designs showed a 62% reduction in the total number of collisions for the retrofit design of Capri-Landmark, Kelowna, BC, Canada, and 56% reduction in the total number of collisions for the retrofit design for Gulshan, Dhaka, Bangladesh. Additionally, the suite of tools toward SMARTer Growth (SG) Neighborhood Design Manual was applied to evaluate these retrofitted designs. Based on the evaluation, the health outcomes and quality of life of the residents in the proposed retrofit designs were discussed.

Lay Summary

SMARTer Growth (SG) Neighborhood Design Manual can be prescribed to minimize the negative impacts of Urban Sprawl. This research applied the design manual of SMARTer Growth (SG) Neighborhood design to propose retrofit designs for two existing neighborhoods, one located in Kelowna, BC, Canada and the other in Dhaka, Bangladesh. To evaluate traffic safety in these neighborhoods, community-based macro-level collision prediction models (CPMs) were developed. The models were applied to compare the traffic safety of existing and retrofit designs. Additionally, the suite of tools toward SMARTer Growth (SG) Neighborhood design was applied in the retrofitted neighborhoods to evaluate health impacts, community impacts, walkability, bikeability, playability, ecological footprint, transport equity, universal accessibility, air quality, and noise.

Preface

The initial results of this research was published in conference proceeding of Canadian Society of Civil Engineers Annual Conference 2019. Md Firoz Mahmood Ovi, and Gordon Lovegrove (2019). Proactive road safety analysis of a neighborhood using Interactive High-Level Safety Planning Model (IHSPM): a case study on Capri Landmark,Kelowna, BC, Canada. 2019 CSCE Annual Conference - Laval (Greater Montreal) Conference.

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List of Abbreviations

AIC	Akaike’s Information Criterion
ARF	Accident Reporting Form
ARI	Accident Research Institute,
AT	Active Transportation
BIC	Bayesian Information Criterion
BUET	Bangladesh University of Engineering Technology
CPM	Collision Prediction Model
DMP	Dhaka Metropolitan Police
DOF	Degree of Freedom
GVRD	Greater Vancouver Regional District
ICBC	Insurance Corporation of British Columbia
MLE	Maximum Likelihood Estimation
NB	Negative Binomial
SD	Socio-Demographics
SD	Model Scaled Deviance
SG	SMARTer Growth Neighborhood Design
TAZ	Traffic Analysis Zone
TDM	Transportation Demand Management
TLKM	Total Lane Kilometers
VKT	Vehicle Kilometers Travelled

To my dear parents and brother

Chapter 1: Introduction

1.1 Background

Cities all over the world are growing rapidly and with the growth of cities, more people will either move to or be born in cities. The life of a city dweller is greatly impacted by the urban form they reside in. Cities worldwide have developed over the past few decades and their impact on the environment and society are immense. Most cities are comprised of urban centers that are surrounded by less dense housing, business, and industrial zones. Despite efforts of the Governments most large cities are expanding fastest on the peripheries, which has been termed as urban sprawl.

Urban sprawl is the result of unplanned development of the city which forces people to build houses in the periphery rather than living in the center. Sprawl gives people access to more affordable housings in the periphery, better privacy, and closeness to nature. Many families are forced or will be forced to buy affordable housing in suburban areas in the near future, which will allow sprawling. The downside of urban sprawl is evident and cannot be ignored. Even though residents in suburban areas save money on housing, the overall cost of living increases. People living in suburban areas make public transit ineffective by living far from each other. Their main mode of transportation becomes personal automobiles and they must drive farther to reach an office or school and defeating the benefits of walkable urban cores they surround. Individuals in suburban areas consume more energy and emit more pollutants than people living in denser cities (Ewing & Cervero, 2010). Low density and single-use residential neighborhoods with the traditional grid network don’t offer a variety of transportation modes, rather it makes people automobile-dependent for most of the trips. The significant increase in the demand for automobiles will contribute to excess fuel usage resulting in an increase in greenhouse gas (GHG) emissions and transportation costs. Environment Canada (2018) recognized transportation as the second-largest GHG emission sector, which was approximately 25% of the total national GHG emission in 2016.

A correlation can also be observed between sprawl, traffic crashes, safety costs, fatalities rate due to the increase in speed limits and vehicle miles traveled (Ewing, Hamidi, & Grace, 2014). This increases dependency on personal automobiles, and driving long distances from the sprawling areas results in increased traffic collisions. Urban sprawl can be also held responsible for social isolation, obesity, and unsustainable infrastructure costs (Talen, 2011).

To address these problems of urban sprawl, planners have come up with different ideas, focused mostly on making the community more compact and sustainable. These communities are expected to offer more compact and affordable housing while providing access to green spaces, public transit services, and amenities. These communities are meant to discourage the use of automobiles and encourage more active transportation. Transportation and land use are inseparable. An effective transportation system can shape the development, impact the economy, and the quality of life in a neighborhood or a city. Mixed land use and denser neighborhoods improve affordability and access to services and amenities while reducing infrastructure costs.

Neighborhoods are the building blocks of a city, and their designs impact residents' attitude towards different modes of transportation (Talen, 2011). A step toward building a more sustainable neighborhood eventually can make the city a better place for dwellers.

SMARTer Growth (SG) Neighborhood Designs, previously known as the Fused Grid Sustainable Neighborhood (FG) Design, is a recent innovation in design to deal with issues experienced in traditional neighborhood design. It is a system-based approach that promotes a more sustainable quality of life, including social interactions. Moreover, it promotes active transportation, reduces collisions, reduces emissions and noise and improves the health of residents and makes public transportation more efficient and accessible, to sum it up, it promotes sustainable quality of life.

1.2 Research Objectives

This research focuses on the application of the SMARTer Growth (SG) Neighborhood Design Manual being researched and developed in the UBC Okanagan (UBCO) Sustainable Transport Safety (STS) Research Lab, including the development and application of community-based macro-level collision prediction models (CPMs) to assess the safety of neighborhoods. The objectives of this research were three-fold:

1. Application of the SG Design Manual, including (among other aspects), the development and use of CPMs to evaluate the Capri Landmark neighborhood in Kelowna, British Columbia, Canada. Identify strengths, and areas for improvement toward SMARTer Growth (SG) Neighborhood Design Manual, for three designs: a. existing, b. the city proposed, and c. STS SG based neighborhood design.

2. Apply the SG Neighborhood Design Manual internationally, to a Dhaka, Bangladesh. Identify strengths and areas for improvement toward SMARTer Growth Neighborhood Design Manual, for two designs: a. existing, and b. STS SG based neighborhood design.

3 How well will SG Neighborhood Design Manual work when applied to two significantly different communities around the world (i.e. Kelowna and Dhaka)

1.3 Thesis Structure

This thesis is divided into six chapters. Chapter One introduces the background, objectives and thesis structure. Chapter Two presents the literature review available to find the previous works and research gaps. Chapter Three discusses the methodology used to develop community-based macro-level collision prediction models in this research. Chapter Four and Chapter Five describes the application of suite of tools toward SMARTer Growth (SG) Neighborhood design and development of retrofit neighborhood design for Capri-Landmark, Kelowna and Gulshan, Dhaka respectively. Finally, Chapter Six presents the conclusion, contributions, limitations, and recommendations for future research.

Chapter 2: Literature Review

2.1 Overview

The purpose of this literature review is to investigate the different design components of the SMARTer Growth (SG) neighborhood design manual and previous studies where traffic safety at a traffic analysis zone (TAZ) neighborhood level was evaluated.

The literature review was conducted using Compendex, Scopus, Science Direct, Google Scholar, Transportation Research International Documentation (TRID), UBC library and ASCE Library. The keywords used for each search are : traffic safety planning , neighborhood-level traffic safety, neighborhood and urban planning, fused grid and SMARTer growth (SG) neighborhood design, mixed land use, density, street pattern, sustainable neighborhood design, development and application of community-based macro-level collision prediction models, urban green space or open space, and development of retrofit community plan.

This chapter is composed of five main sections. Section 2.2 describes the basic principles of SG. In addition, it describes how each component of the design impacts travel behavior and traffic safety of dwellers in a neighborhood. Section 2.3 reviews neighborhood-level traffic safety and the development and application of community-based macro-level collision prediction models for neighborhoods. Section 2.4 describes different toolkit used to assess sustainability and health outcomes at the neighborhood level and Section 2.5 summarizes this chapter.

2.2 SMARTer Growth Neighborhood Design (SG) Manual

After investigating several historic and human-scale communities which support the sustainable quality of life for both residents and businesses, the SMARTer growth (SG) concept was formed (Grammenos & Lovegrove, 2015; Lovegrove, 2007; Nieuwenhuijsen, 2019). The SG neighborhood is the blend of vehicular transportation, non-vehicular transportation, and green spaces. SG combines two popular North American street designs; traditional grid network and the conventional curvilinear pattern of looped streets and cul-de-sacs (Grammenos & Gregory, 2004). Land use and transportation in SG are integrated in such a way that, the system reduces shortcutting and limits the trips of high-speed traffic by directing them to the perimeter, and the accessibility of the local automobile is provided through the discontinuous loop (Sun & Lovegrove, 2013). This strategy makes walking or biking across the neighborhood more convenient while making driving less accessible. In SG green spaces are constructed in such a way so the residents can access them by five minutes of walking. The focus of SMARTer growth (SG) is to make the neighborhood compact and improve access to amenities and services while promoting active transportation and maintaining quality of life. The successful implementation of the design is expected to have several positive outcomes in comparison to the traditional neighborhood designs. SG is a system-based design that combines a full suite of factors towards a holistic sustainable, quality of life for all its residents, businesses and visitors. It tends to be more complex because of the combinations of different discrete stencil components used in the design.

SMARTer growth (SG) neighborhood design principles feature different design elements. The SG sets up a geometric structure by combing both traditional grid network and the conventional curvilinear pattern of looped streets and cul-de-sacs. This fusion works as a system by adopting the best characteristics of each, while rejecting their drawbacks to create a quality neighborhood environment. The design elements aim is creating compact and dense neighborhoods with mixed land use, making the neighborhoods less automobile-dependent while improving public transit and active transportation. Also key is providing plentiful green spaces within a minute walking distance of all doors to promote a healthier community by improving social interactions.

In a SG neighborhood, pedestrian and bicyclist accessibility and safety are increased by limiting through traffic in the neighborhood area. This is done by configuring the local street in such a manner so that the non-local vehicular traffics is kept on roads located around the perimeter of the neighborhood, and the local neighborhood roads are made discontinuous to reduce vehicular activity and promote walking and biking opportunities throughout the neighborhood. Another fundamental element of SG is to construct a network of footpaths and green spaces in such a way that it ensures a continuous pedestrian and biking network with the neighborhood. The roundabout-controlled intersections and one-way perimeter arterial couplets ensure the safety and mobility of non-local vehicular trips network and bikes (Grammenos & Lovegrove, 2015).

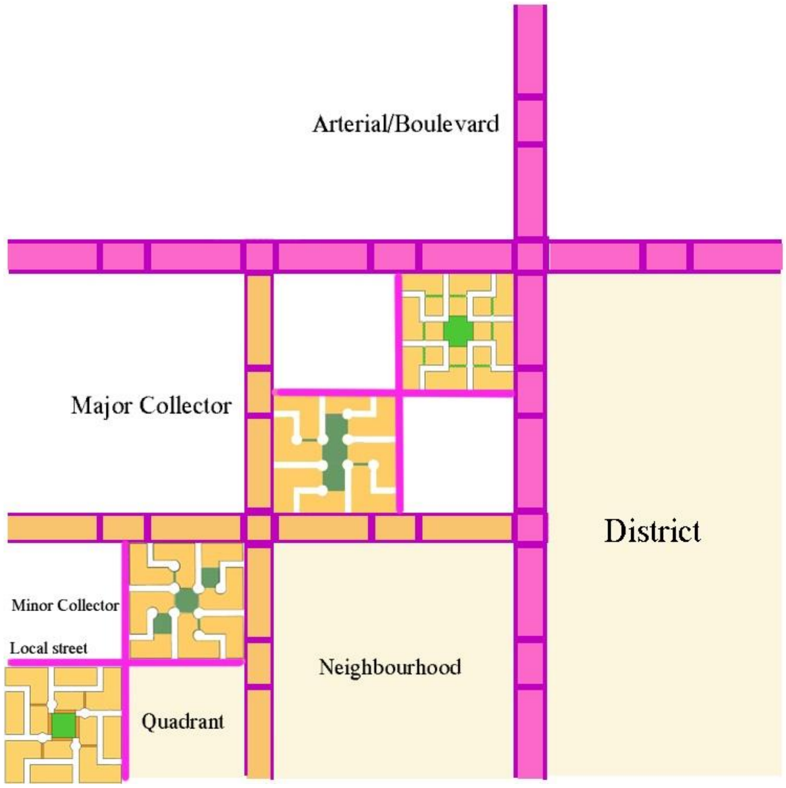


Figure 2-1: Nested hierarchy of roads in SMARTer Growth neighborhood (Sun & Lovegrove, 2013)

The SG model can be applied to neighborhoods as well as districts. The SG design is comprised of four 16-hectare modules and each module is represented by a 400-square meter neighborhood. The quadrants with local roads provide access to local traffic only and the through traffic movement is restricted by central green spaces. A continuous open space and footpath for pedestrians are constructed to provide direct access to parks, transit stops, and other services and amenities. In SG the width of collectors are 400 meters, minor arterials are 800 meters, and arterials are 1600 meters. The width of the roads, alignment, and grades are context-sensitive. To provide safety and mobility, roundabout controlled intersections and one-way perimeter arterial couplets are constructed. However, the three-way intersection is constructed where the local roads meet the perimeter roads (Grammenos & Lovegrove, 2015). The SG supports mixed land uses as it reduces commuting distances to work, school, or other services (Masoud et al., 2015). The high-density mixed-use residential areas located in between two parallel collectors or arterial roads, so that the commuting distance to reach the amenities are within five minutes' walk or bike from any point of the quadrant (Grammenos & Lovegrove, 2015). To summarize, the design components that are associated with SMARTer growth neighborhood system can be listed as 1) pedestrian or bike oriented street pattern or street network (i.e. street network, roundabout, pedestrian and bike network, etc.), 2) High land use mix and density, and 3) green spaces.

2.2.1 Transportation

2.2.1.1 Street Pattern

Among the physical components of a neighborhood, street pattern is one of the most important elements. Buildings and other construction projects are built regularly but street patterns sometimes remain the same for several decades in some cities. It's crucial to select the appropriate street network as it's quite impossible to reconstruct or modify the network, even if it's feasible it would be troublesome and costly. Retrofitting the old street network can be suggested as one of the solutions to solve the problems of today. Constructing a new street network is not a solution as it will take up space, removing the space required for other components of a neighborhood's living tissue.

The street pattern or network is one of the most important components of the SG principles. It is very important in terms of connectivity and to shape the local travel behavior (Frank et al., 2009). Streets consume approximately 1/4 to 1/3 of all public land in a city (Cervero, 1996). A well-designed street pattern contributes significantly to the quality of life, safety, and tranquility of that city, as well as promoting a healthy environment for residents.

The design of streets is dependent on the use of people. The dimensions of the streets are mostly dependent on mode choice. Streets not only serve travel functions, but the urban quality of life is also maintained by them. It is evident that a well-connected street network increases walkability and is associated with higher density which results in high proximity to activities (Frank et al., 2009). The street pattern within a neighborhood is important in terms of traffic safety as well as it improves accessibility and walkability while building sustainable communities (Wei & Lovegrove, 2012).

2.2.1.2 Different Types of Street Pattern

Street patterns in urban areas have been classified using several approaches. Marshall (2004) developed macroscopic and microscopic street networks, which is the most common approach (Marshall, 2004). The macro-level street network deals with streets that run through the city, connect a sizable portion of the city, and provide mobility in and out of the city. The micro-level street network supports travel in between the neighborhood blocks as these streets are not continuous throughout the city. Marshall (2004) fused four kinds of city-wide street network types (straight, tributary, spiral, and lattice) with the two types of neighborhood street networks (tree and framework) to portray the road order in a city (Wesley E. Marshall & Garrick, 2010; Wesley Earl Marshall & Garrick, 2011; Rifaat, Tay, & de Barros, 2012).

In another approach, different types of roads in a neighborhood are combined to form a pattern. These newly formed street patterns were classified into five different categories. They were gridiron, fragmented parallel, wrapped parallel, loops and lollipops, and lollipops on a stick (Southworth & Ben-Joseph, 1997).

The gridiron was first introduced in the early 1900s (Alexander et al., 1977), widely into the suburban neighborhood and became popular for neighborhood design (Girling & Helphand, 1996). In a gridiron pattern, several parallel streets cross each other at right angles to form a grid (Alexander et al., 1977; Rifaat et al., 2012). Gridiron patterns consume a larger area than the other patterns. The infrastructure costs for streets are dependent on the length and width of the street, the width of the block, and the width of the pavement. Infrastructure costs in a gridiron pattern are higher than other patterns. However, the orthogonal geometry increases access points, walkability, decreases the lengths of trips, and provide more route choices (Southworth & Owens, 1993; Rifaat, Tay, & de Barros, 2012).

The fragmented parallel pattern was presented in the 1950s (Alexander et al., 1977). This pattern rebuilt the neighborhood blocks into long, narrow square shapes and L-shapes. The similarity between the fragmented parallel pattern and the grid network is that in both cases the road length is similar. However, the fragmented parallel pattern reduces the number of neighborhood blocks, traffic flow, access points, interconnectivity, and route choices through a neighborhood (Rifaat et al., 2012). Significant reduction in pedestrian accessibility and increased automobile dependency was also evident in the fragmented parallel pattern in comparison to the gridiron pattern (Southworth & Owens, 1993).

The loops and lollipops pattern was first introduced in 1970 and the aim of this pattern was to make neighborhoods more tranquil by reducing the number of vehicles traveling through residential areas thus reducing traffic and noise (Gallion & Eisner, 1986). The street pattern consists of many loops and cul-de-sacs. The main issues of this pattern was lesser connectivity than the traditional gridiron pattern and to reach anywhere both the pedestrian and vehicle need to exit cul-de-sac through collector streets. The neighborhood is quieter and safer for children because the network limits vehicular connectivity in residential areas, reduces access points, and increases vehicular movement in the arterials; however, this pattern demonstrates reduced pedestrian accessibility as they must walk more to reach their destination (Southworth & Owens, 1993).

The lollipop on a stick street pattern also known as cul-de-sacs or dead-end street was first introduced in 1980. It was created by separating cul-de-sacs from through roads. This pattern became quite popular, as it consumed less land than the traditional gridiron pattern; however, this pattern increased pressure on traffic compared to the traditional gridiron and reduced interconnectivity, pedestrian mobility, intersections, route choices, and access points considerably (Southworth & Owens, 1993). Though this pattern is ineffective in handling heavy traffic, most communities prefer this pattern to maximize privacy (Asabere, 1990).

2.2.1.3 Transportation Issues Related to Street Pattern

The development of transportation in North America can be marked by different eras (Hanson & Giuliano, 2005). Each era gradually shaped the modern transportation planning. The eras were: walking/horsecar (up to 1890), streetcar (1890-1920), automobile (1920-1945), and freeway (since 1945). In the streetcar era, as people were more dependent on walking to reach their destination, the gridiron pattern was predominant. The initial two decades of the twentieth century can be marked for the popularity of automobiles. In that time period, the street alignments were changed, road surfaces were improved, traffic lights were added, and ultimately streetcar tracks were removed (Frank et al., 2009).

Amid the first quarter of the twentieth-century automobiles became a popular mode of transportation, so popular that it replaced the most common transportation mode walking of the middle ages. With the increase in traffic volume and velocity, the shortcomings of the traditional grid in the neighborhood were discovered and managing these high traffic volumes with the existing street network was challenging (Frank et al., 2009).

Several factors influence the failure of the gridiron pattern; the issues were easy through traffic movements in all areas; frequent, multi-conflict intersections; and monotonous form (Frank et al., 2009; F. Grammenos & Gregory, 2004). The gridiron increased vehicle accessibility; however, it was not friendly for pedestrians and bikers (VTPT, 2010). Moreover, it increased driving while decreasing bicycling and experienced safety issues at intersections (Sun & Lovegrove, 2013). The problems associated with the gridiron pattern are given below:

A. "Contributes to the dispersion of vehicular travel to all streets, even for pass-through travel purposes, and hence increased traffic impacts on neighborhoods, including:

   - Pollutant emissions due to higher automobile volumes in close proximity to residences

   - Exposure to safety risks to children at play and pedestrians from increased volume of traffic possible on all streets

B. Frequent four-way intersections also increase traffic impacts:

- Congestion, and associated increase in air pollutant emissions from frequent stops and starts, (especially as traffic volumes increase)

- Exposure to safety risk for both motorists and pedestrians due to complexity of turning movements

C. Monotony: if unaccompanied by design requirements, gridiron networks can be uninteresting in their regularity and discouraging to pedestrians"

(Frank et al., 2009, p. 17)

To avoid the problems associated with the grid, the curvilinear street pattern was recommended for districts as they do not have continuous through streets (Grammenos & Gregory, 2004). There was a significant benefit for the developer while adopting the loop and cul-de-sac street network design: it enlarged the construction area for saleable plots as streets consumed less lands eventually and it reduced the developers' infrastructure cost (Frank et al., 2009).

To meet the demand of modern transportation systems, street design standards have evolved. The new guidelines for street design call for disconnected streets rather than highly connected, hierarchical rather than non-hierarchical, and curvilinear rather than rectilinear in residential regions (Frank et al., 2009). To accommodate the higher speed traffic block sizes increased in the last one hundred years (Stephen Marshall, 2004; Southworth & Ben-Joseph, 1997). The main problem with the conventional suburban street pattern is that they have poor connectivity and in single-use, there are more cars on the collector streets making it less friendly to walk (Frank et al., 2009). The problems with the conventional suburban street pattern and loops and cul-de-sac relate to each other and are given below:

A. "Contributing to route indirectness:

   - Pedestrian routes are elongated due to dendritic (sparse) street pattern
   - Fewer choices of route for motorists

B. Increase in bicycle/pedestrian personal safety risk:

   - Pedestrian pathways, if kept separate from streets to improve their directness, have reduced natural surveillance
   - Separate pathways frequently result in mixing of bicycle-pedestrian modes without appropriate design treatments, creating conflicts and higher likelihood of collision (especially when paths meet or cross a roadway)

C. Curvilinear streets are disorienting, and thus discouraging to walking activity

D. Disconnected local access streets focus traffic onto larger classification streets closer to residences:

   - Diminished accessibility for pedestrians (larger streets to cross with higher volumes of traffic) closer to home and often between home and shopping or other destinations.
   - More difficult left turns for motorists due to infrequency of intersections, larger collector streets, and higher traffic volumes on limited number of major streets (sparse network)"

(Frank et al., 2009, p. 19)

2.2.1.4 Conflict Controls

2.2.1.4.1 Roundabout

A roundabout, or traffic circle, is one of the most important elements in a SMARTer Growth Neighborhood. A roundabout is a circular intersection without traffic signals, allows traffic flow in a counterclockwise direction around a central island, and priority is given to traffic already in the intersection (Robinson et al., 2000). To increase traffic safety several design rules are observed in a roundabout. The modern roundabouts are safer than other forms of intersections and reduce the total number of collisions and severity of collision by reducing conflicts between traffic movement (Brown, 1995; Jacquemart, 1998; Robinson et al., 2000).

The conflict points in a 4-way intersection can be decreased by up to 75% if replaced with a roundabout (Alphand, Noelle, & Guichet, 1991). Traffic in a roundabout comes from one direction that allows visual engagement between traffic and pedestrian or bicyclists. The roundabout also reduces the drivers' confusion of crossing a 4-way intersection and reduces idling time at traffic lights at intersections (Roy, Uddin, & Dey, 2018).

Roundabouts have specific design features that control traffic speed and a series of roundabout work as traffic calming effect on traffic because of their geometry. The geometric feature of a roundabout includes yield control, channelized approaches, and curvature which ensures the traffic speeds to be less than 50 km/h (30 mph). A good roundabout design helps in reducing speed and the speed is controlled through geometric features of the roundabout through a series of turning maneuvers at low speeds and not by traffic signals or impeding other traffics. Moreover, roundabouts allow traffic to take U-turn within the normal traffic flow. A good roundabout is expected to reduce the severity of collision for vulnerable road users (i.e. pedestrians and bicyclists) (F. Wei & Lovegrove, 2013), provides more reaction time, allows safer merges into circulating traffic, and makes the roundabout safer for newly learning drivers as well (Alphand et al., 1991; Robinson et al., 2000).

2.2.2 Land Use

Street networks promote mobility and accessibility by connecting all major hubs of a neighborhood or city; however, constructing all of the major hubs in a certain location of the city will increase traffic flow to that location resulting in reduced mobility and accessibility. Balancing and mixing land use is crucial for this reason. The layout of the transportation network and traffic demand are greatly dependent on the land use mix and on the distribution of sociodemographic components (Bento et al., 2005; Najaf et al., 2018).

Land use and transportation infrastructure are interconnected, and the system and characteristics of the built environment are greatly influenced by them. The transportation infrastructure impacts where development happens. Similarly, the investment in transportation infrastructure and their location is influenced by new developments such as real estates, malls, or industrial zones. The travel behavior of people in a city is greatly influenced by two components of the built environment: density and mixed land use (Cervero, 1996)

2.2.2.1 Mixed Land Use

Mixed land use, a modern urban planning concept, is one solution to mitigate urban sprawl and sprawl-related problems (Tesso, 2013). The mixture of residential, commercial and industrial zones within a certain area is defined as mixed land use (Aurand, 2010). In the medieval period and in ancient Greek and Roman cities, the urban communities featured living, working, and shopping altogether inside the city boundary (Coupland, 2005; Toynbee, 1967). Due to technological advancement in the transportation sector and changes in cultural and travel behavior in the early twentieth century, mixed land uses came to an end and residential, commercial, and industrial zones became isolated (Grant, 2007). Jacobs (1961) first argued that a balanced mix of residential, commercial, and industrial use of land may prompt a more livable and safer neighborhood (Jacobs, 1961). Postwar period planners isolated land use by implementing zoning (Calthorpe, 1993); however, 'New Urbanists' and others advocating traditional city designs believed to promote sustainable transport modes, where the distance between trip origins and destinations must be reduced (Calthorpe, 1993).

2.2.2.2 Density

Density or Urban Density can be termed as people living in a square kilometer (people/km^2) or hectare (people/$hectare^2$) of land. Urban density is an urban planning concept, which promotes high residential density with mixed land use. It is used to evaluate the livability of an urban form (Jiao, 2015). Dense cities have an urban layout that supports more sustainable transportation modes while keeping the residents within close proximity to daily amenities (i.e. school, convenience store, house, work) (Dempsey & Jenks, 2010). The main idea of this type of urban planning is to reduce the commuting time of people by reducing the distance between origin and destination. This reduces the automobile dependency for commuting across neighborhoods and eventually reduces consumption of fossil fuel and amount of traffics on highways (Boussauw, Neutens, & Witlox, 2012). The optimal density in a dense city should be high enough to provide residents proximity to community amenities; however, the density should be low enough to allow residents access to green spaces and maintain privacy (Yue, Lee, & Hart, 2016). In a dense city, active transportation (i.e. walk, bike) is more feasible and public transit is more accessible and efficient. The per capita investment on public transit is lower in dense cities, making it more justified to invest in transportation infrastructure.

2.2.2.3 Impact of Land Use Mix and Density on Traveling Behavior and Safety

Mixed land uses have many transportation benefits in a city (Cervero, 1989). If the residential, commercial, and industrial zones are mixed together people will avoid driving and become more inclined to walk to destinations. This would reduce the number of automobile trips generated and encourage the use of active transportation (i.e. walk or bike) (Frank, Grammenos, & Hawkins, 2009) in cities where offices, restaurants, and other services are close to each other. This would also promote ridesharing as many people don't need an automobile to go to their destination for mid-day activities. In a mixed-use area, trips are distributed uniformly throughout the day and week. In an industrial zone, most of the people commute during morning and evening peak hours, but if there are shops, restaurants, and other consumer services in an industrial zone the trips to these establishments will be during off-peak hours when the road capacity is more accessible (Barton-Aschman, 1983). Different studies have compared travel survey data to travel behaviors to see non-motorized travel behavior and it was found that mixed-use neighborhoods have characteristics which reduce automobile dependency in the neighborhood (Cervero & Radisch, 1996; Reid Ewing, Haliyur, & Page, 1994; Friedman, Gordon, & Peers, 1994).

Gehrke & Clifton (2017) showed in their study that transportation systems are greatly influenced by the development pattern of land and urban planning (Gehrke & Clifton, 2017). The authors believe that a walkable community will increase the dependency of people using active transportation. They studied locations in Portland and Oregon using structural equation modeling and concluded that if mixed land use, workplace concentration, and pedestrian-oriented design features applied in a community, the residents will rely more on active transportation to complete their work trips and discretionary trips.

In another study, the researchers used the 1985 American Housing survey to investigate how the presence of retail activities in neighborhoods influences the commuting choices of residents. They found out that, where residential density and vehicle ownership is controlled and if the consumer services are within 300 feet of one's residence, there are more chances that the person will either walk, bike, or take public transit. However, as the distance between house and consumer services increases, even just beyond 300 feet but less than a mile more, people are encouraged to drive to the destination.

The result of the study agrees with the research findings of Reid Ewing et al. (1994). The researchers compared work and non-work trips among the residents of six neighborhoods in Palm Beach County, Florida. The researchers found that if there are shops and other consumer services available in the neighborhood it can reduce vehicle hours traveled (VHT) per capita.

In recent years, there is an extreme scholarly discussion on how land use and density affect people's choice of choosing sustainable modes over other transportation modes. Higher density zones are where the residents have few cars, variable earnings, smaller houses, better public transit, and where the mix of land uses are balanced (Kitamura, Mokhtarian, & Laidet, 1997). Several studies have found a strong relationship between urban density and mode choice, (Pucher, 1988; Pushkarev & Zupan, 1977; Cervero, 1996) vehicle miles traveled (VMT) per household (Holtzclaw, 1990), and per capita energy consumption (Newman & Kenworthy, 1989). In one of the studies by Holtzclaw (1994), he discovered that if all the variables (improved public transit, more access points, and pedestrian-friendly environment) are constant, doubling density reduced approximately 25% to 30% driving per household. It is also evident that public transit becomes more accessible when the density is high (Cervero, 1996; Holtzclaw, 1994). Public transit stops located close to a densely populated area are more accessible within a certain boundary around the stop (Apogee, 1998). This is the fundamental idea of Transit Oriented Design (TOD). Walking and biking are also dependent on public transit (Calthorpe, 1993).

Robert Cervero (1996) found that as the density increases it increases walking and biking, especially walking as it shortens the distance between origins and destinations. However, most of the walking trips occur when the distance is within a kilometer (Antonakos, 1995). Dunphy & Fisher, 1996 compared American cities by their density and found that the total number of trips was reduced as the density increases. However, the number of trips by public transit, walk, or bike increases. Schimek (1996) studied the US 1990 Nationwide Personal Transportation Survey and found that if the income and demographics are controlled, a ten percent increase in density reduces 0.7 percent household car trips. However, if the household earnings increase by ten percent, household car trips increase three percent.

2.2.3 Green Space

Plentiful green space is a somewhat new idea yet a fundamental piece of modern urban land use planning. The term 'green space' incorporates different regions of vegetation which can be additionally utilized for recreational purposes. Plentiful green space doesn't just enhance the city environment, it increases the personal satisfaction and quality of life of the inhabitants, which was first perceived by Urban Task Force Report (Urban Task Force, 1999). To lower the stress of residents and promote good health, plentiful green space is very important in a neighborhood (Ulrich et al., 1991)

Since the nineteenth century, the significance of green space in towns and urban areas has been perceived as providing an escape from urban air pollution. An upsurge in interest to construct green spaces in cities to reduce air pollution was marked during the last decade. A few of the factors that are responsible are given below:

- "Widespread concern at the decline in the quality and condition of many parks and other urban green spaces due in part to their generally low priority in the political agenda at both national and local levels;

- Growing emphasis on the need for more intensive development in urban areas, focused around the concept of the high-density 'compact city' as the model for future cities in Europe, raising questions about the role of green space in this model;

- Parallel emphasis on the development of brownfield rather than greenfield land, and a recognition that more intensive urban development may sometimes involve the sacrifice of existing areas of urban green space;

- Increased recognition, supported by an improved evidence base, of the benefits of urban green space, and of its environmental, social and economic value to society."

(Swanwick, Dunnett, & Woolley, 2003, p. 94)

Green spaces are proven to be beneficial for both physical and mental health (Croucher, Myers, & Bretherton, 2008). Infill development help in the preservation of green land space and by preserving green space urban sprawl can be controlled and livelier communities can be adopted (Daniels & Lapping, 2005). In a precise survey of green space and obesity, Lachowycz & Jones (2011) found that people living closer to green spaces are more physically active than people living far from green spaces. Moreover, in regions with the greenest spaces, young men walked 2.3 times more and young women 1.7 times more than those living in the region with the least green space. Inhabitants living in a house that is surrounded by green space also feel less stressed (Lindberg et al., 2010).

2.3 Neighborhood Level Traffic Safety

Road traffic injuries are considered to be one of the main reasons for death each year globally. Over half of these injuries results in death and the rest result in disability following injuries. The current economic loss due to traffic crashes is approximately 3% of the global GDP (WHO, 2015). The dependency on automobiles accompanying global urbanization has made traffic safety a major challenge for urban planners and engineers. Urban areas experience higher traffic crashes than rural areas and the total cost of traffic crashes is higher than the economic impact of traffic congestion in urban areas (AAA Study, Newsroom, 2015).

Neighborhoods are the building block of a city. To make a safer city the traffic safety of the neighborhoods should be improved. In recent years evaluating traffic safety in neighborhoods has become a major concern for engineers and planners. Road safety organizations are conducting researches to reduce traffic collisions and find a way to plan neighborhood road networks while improving accessibility and mobility. It is well established that traffic collision is associated with travel behavior, and travel behavior is greatly affected by urban design (Ewing & Cervero, 2010). The way a neighborhood is built indirectly affects the road safety of the neighborhood via travel behavior such as modal choice and route choice (Schepers, Lovegrove, & Helbich, 2019). The mixed land use and density along with the neighborhood layout are very important to promote walkable, accessible, safe communities (V. F. Wei & Lovegrove, 2012) and changing the layout of existing neighborhoods greatly impacts the mode choice and vehicles miles traveled (VMT) (Ewing et al., 2014). Neighborhood land use patterns also play a vital role in promoting a sustainable form of transportation and reducing automobile dependency resulting in a reduced traffic collision frequency (Kenworthy and Laube, 1999; TDTM, 1995; Buchanan, 1963).

The SMARTer Growth (SG) neighborhood design was first developed by Gordon Lovegrove and Fanis Grammenos. The traditional grid and suburban layouts were combined to promote sustainable land use and active transportation. Five neighborhood patterns i.e. traditional grid network, cul-de-sacs, Dutch Sustainable Road Safety (SRS), 3-way offset, and SMARTer growth neighborhood design was evaluated to test the road safety of these neighborhoods. The 3-way offset and SMARTer growth neighborhood designs were found to reduce approximately 60% of the total number of collisions compared to the other alternatives (Sun & Lovegrove, 2013). To test the road safety of the SMARTer growth neighborhood design CMHC (2008) conducted research to compare the mobility and accessibility of SG with traditional grid network and cul-de-sac patterns. The patterns were evaluated using traditional transportation planning models and each pattern represented different population and employment densities. The results concluded that, in case of high population and employment density, the SG pattern would reduce the number of automobiles on the road while maintaining Vehicles Kilometers Traveled (VKT) and mobility in the neighborhood (CHMC, 2008). The 1990 fatality rate in European countries and developed Asian countries, compared to North America, show lower dependency on automobiles and higher dependency on sustainable mode split which improves road safety conditions statistically (Kenworthy and Laube, 1999). In another study, Wei & Lovegrove (2012) evaluated five neighborhood patterns: gridiron, cul-de-sac, Dutch Sustainable Road Safety (SRS), 3-way offset, and SG. They used the standard road safety analysis to evaluate these patterns and found that the 3-way offset and SG could reduce collision up to 60% compared to the rest of the patterns (Wei & Lovegrove, 2012). Masoud et al. (2015) also showed that SG design features consisting of three-way intersections, roundabouts, and having traffic calming features helps in reducing vehicle speed and conflict points and also helps in reducing collision by reducing drivers' error. The design also promotes safer and healthier communities.

2.3.1 Development of Collision Prediction Models

The safety performance of a road system is evaluated through two approaches; reactive approach and proactive approach (G. Lovegrove & Sayed, 2006). The reactive approach focuses on improving the road safety of a component of a road system based on the collision histories, whereas the proactive approach focuses on improving the safety of a component of the road system by preventing it from occurring beforehand. Future researchers focus on land use and transportation planning to improve road safety proactively while making the community more sustainable. The drive towards sustainable land use and transportation planning is expected to reduce auto dependency, which will result in a safer community. To build a safer community the decision-makers must develop more reliable proactive predictions of road safety and adopt sustainable community development patterns during community planning stages. The need for more reliable empirical tools that allow engineers and decision-makers to evaluate the level of road safety in a city or at the neighborhood level has encouraged researchers to develop macro-level collision prediction models. Research on macro-level collision prediction models (CPMs) showed the potential to conduct reliable road safety tests and application of the model to a zonal level to evaluate safety (Lovegrove 2007; Lovegrove and Sayed 2006; Sun & Lovegrove, 2013; Feng Wei & Lovegrove, 2013). The emerging research on CPMs across North America (Sawalha and Sayed 1999; Hadayeghi et al. 2003; El-Basyouny & Sayed, 2009), has led several UBC researchers to develop macro-level collision prediction models for the Greater Vancouver Regional District (GVRD). For 577 neighborhood across GVRD, 4 variable groups (Socio-Demographic, Exposure, Network, and Transportation Demand Management) were developed and these variable groups were used to develop the standard nonlinear multiple regression (generalized linear regression) model to predict mean collision frequency (Lovegrove and Sayed 2006; Lovegrove 2007). The randomness of the observed historic mean collision frequency is screened out by statistical techniques. As the traffic collision is a random, discrete, and non-negative event, regression models can provide an appropriate analysis for Poisson regression and Negative Binomial regression models. To model collision data Poisson regression and Negative Binomial regression models are ideally used. However, the Negative binomial regression is the variant of Poisson regression but provides more accuracy in collision data in comparison with Poisson models (Lovegrove & Sayed, 2006).

The development of community-based, macro-level CPMs follows the formulation in equation 2.1:

$$E\ (\Lambda) = a_0 (Z)^{a_1} e^{\sum b_j X_j} \qquad (2.1)$$

Where E (Λ) = the predicted collision frequency (3-year); a_0, a_1, b_j = model parameters; Z = leading exposure variables (e.g. vehicle kilometer traveled (VKT) or total lane kilometers (TLKM)); and, X_j = other explanatory variables (e.g. socio-demographic, economic, and network variables).

The model parameters are estimated from the maximum likelihood method and the goodness of fit of the models are measured through Scaled Deviance (*SD*), Pearson χ^2, and κ, and all statistical measures are tested at a 95% level of confidence. To compare and select the models Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC) are used and models with smaller AIC and BIC values are considered to be a good fit model. The independent variables were selected based on the t statistic value, significant improvement in model fit, intuitive associations (i.e., +/− logic), and low correlation with other independent variables. The formulation of SD and Pearson χ^2 measures are shown in equation 2.2 and 2.3 (Enderlein, 1987).

$$SD = 2\sum_{i=1}^{n}[\mathrm{y}_i * \ln\left(\frac{\mathrm{y}_i}{E(\Lambda_i)}\right) - (\mathrm{y}_i + \kappa) * \ln\left(\frac{\mathrm{y}_i + \kappa}{E(\Lambda_i) + \kappa}\right) \tag{2.2}$$

$$\text{Pearson}\, \chi^2 = \sum_{i=1}^{n}\left(\frac{\{(\mathrm{y}_i - E(\Lambda_i)\}^2}{Var\,(\mathrm{y}_i)}\right) \tag{2.3}$$

$$Var\,(\mathrm{y}_i) = E(\mathrm{y}_i) + \frac{E(\mathrm{y}_i)^2}{\kappa} \tag{2.4}$$

Where y_i = the observed collision frequency, $Var\,(\mathrm{y}_i)$ measures the variance of the observed collision frequency as per equation 2.4. The predicted total number of collisions is represented by $E(\Lambda_i)$ and κ is the model shape parameter. The value of SD and Pearson χ^2 are measured from models and compared with the standard Pearson χ^2 value at 95% confidence, if the value is smaller than the standard value the model is considered to be a good fit model (G. Lovegrove & Sayed, 2007).

2.4 Beyond Road Safety

Neighborhood planning is complicated and requires knowledge of urban and transportation planning, engineering, and environmental and social science, human behavior, and sustainability. To create a sustainable community, it is very important to preserve and improve the quality of life of residents, businesses and visitors. Since the mid-twentieth century, community planning focused primarily to improve mobility, redevelopment of the suburban area, and construct more highways to accommodate the rapid growth of automobiles. This form of planning has led to an auto-oriented society and sprawling cities. Furthermore, it discouraged the physical activity of residents by reducing the attractiveness of sustainable transport (Grammenos, Craig, Pollard, & Guerrera, 2008). Several communities have struggled to create a sustainable community while maintaining the health of residents. The effort to build sustainable and healthier communities has led several researchers to build assessment tools to evaluate the health of residents in a community and they have found a definite correlation between urban planning and physical activity (Boussauw et al., 2012; Johnson & Marko, 2008)

2.4.1 The Healthy Development Index (HDI)

The Healthy Development Index (HDI) was developed by Peel Region in Ontario, Canada to evaluate future developments with an aim to sustain the quality of life. The HDI focuses on seven elements of the built environment to evaluate future developments. The elements are associated with the land-use mix, walkability, density, proximity, connectivity, road network, and parking.

To assess a development each criteria of the development is broken down into computable measures and a score is given to each criterion and added for a final score. The weight of each criteria is given based on research and consultation from stakeholders and, based on the final score, the Healthy Development Index is measured. The way HDI and its measures were developed lets the user apply it to new developments only where the built environment characteristics can be modified or fused for further evaluation. For existing communities, HDI needs a lot of data to evaluate the neighborhood, which is both a difficult and time-consuming process. The researchers recommend HDI to apply on new Greenfield development of society to simplify and reduce the number of criteria used. The HDI cannot be efficiently applied to smaller communities as the measures cannot be tailored to fit the community's requirements. To fit existing communities, the HDI needs careful modification.

2.4.2 I-Thrive

The Interactive Sustainable Transport Safety / Healthy Development Index Valuation Tool (I-THRIVe), is a Microsoft Excel-based tool developed by UBC STS researchers to help urban planners and engineers assess benefits of sustainable development. Much of it was developed based on the principles of the Healthy Development Index (HDI) developed by Peel region and Dutch sustainable road safety principles; however, some portion of the principles were modified to enhance the HDI. I-THRIVe allows users to input the traits of the project under consideration and receive feedback "scores" for evaluation. I-THRIVe tool consists of 12 components, amongst them most of the components focus on built environment and health criteria, others focus on road safety criteria (Masoud et al., 2015).

As HDI tool does not account for an active transportation network in street connectivity, its street connectivity was modified to accommodate both on-road and off-road walkways and bikeways. Road safety criteria were based on the principles of Dutch sustainable transport safety. The criteria focuses on improving mobility of both local and arterial roads, managing and optimizing access points, constructing consistent and predictable road designs, separating lanes in roadways for motorized and non-motorized vehicles, minimizing driver errors by providing forgiving road measures (i.e. rumble strips, medians and wide shoulders), and replacing signalized intersection to 3 way intersections and roundabouts to improve safety (Grammenos et al., 2008; Lovegrove and Sayed, 2006).

2.4.3 Healthy Built Environment Linkages Toolkit

The Healthy Built Environment (HBE) Linkages Toolkit creates a link between design, planning, and health. It was developed by the Population & Public Health team at the BC Centre for Disease Control (BCCDC) under the leadership of the BC Healthy Built Environment Alliance (HBEA) steering committee members including engineers, health experts and planners. It is adopted by British Columbia and other provinces to point out the health initiatives required to initiate local government plans and to assess the impact of the built environment on residents' health. The toolkit includes health considerations in community planning and design and shows how the health of residents are impacted by the built environment. The toolkit has assisted in increasing people's awareness of their environment and in developing new community plans and policies. Five core concepts were considered to assess the health impact of the built environment and describe the correlation between population health and neighborhood designs, housing, transportation systems, natural environments, and food systems. The toolkit has an online tool which allows users to participate in the research and bring diagrams to life. It aids in applying the healthy built environment concepts into reality with the aim of promoting healthy and active living of the residents in the community. The toolkit is intended to help health professionals make decisions and promote a healthier lifestyle in a community from the planning stage. The toolkit is supposed to help planners propose solutions that support health evidence and aid local government, policymakers, and stakeholders to articulate how a planning solution can be employed which will have multiple health benefits and can be reached through multiple planning features (BC Centre for Disease Control, 2018).

2.4.4 Envision

Envision is a rating system developed in collaboration with the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design and the Institute for Sustainable Infrastructure. Envision was developed to recognize how sustainable approaches can be incorporated in planning, designing, constructing and operating in infrastructure projects. The framework is built consisting of 64 sustainability indicators. The indicators are named as credits and these credits are categorized into five groups: quality of life, leadership, resource allocation, the natural world, and climate and resilience. These indicators work together to build a sustainable infrastructure. The assessment of each project depends on the 64 credits and the project teams need to assess all of the credits carefully and to determine the challenges that need to be overcome to meet sustainability goals. Envision includes a self-assessment checklist for the infrastructure, a rating tool, a credential program for the individuals, project evaluation and verification program, and recognition program of sustainable infrastructure. Envision rates six types of infrastructure including energy, water, waste, transport, landscape, and information and can be used for any size, location, and type of infrastructure. The goal of Envision is to improve the performance of a project while making the infrastructure sustainable and resilient. Envision aids in making decisions for projects to meet sustainability criteria, however, it does not set a prescriptive measure in meeting those criteria.

2.4.5 Walkability

Walking is one of the key factors in promoting healthier and active communities. Different researches were conducted to evaluate the benefits of walking. The walkability index is a measure of how walkable a neighborhood is comparing to other neighborhoods (Frank et al., 2010). Frank et al. (2010) measured the walkability index by deriving an equation. The independent variables were net residential density, retail floor area, and land use mix and intersection density. The variables measured from parcel-based land use data, road centerlines data and census data. The floor area ratio and parcel-based land use data were critical based on the accuracy. However, based on several regression analysis the following equation was derived.

Walkability= 2*z-intersection density + z-net residential density + z-retail floor area ratio

+ z-land use mix

In this research, the walkability was measured based on the equation developed by Frank et al. (2010). The variables values were measured for both the existing neighborhood and SMARTer growth neighborhood. The values were normalized between 0 and 1, using a z score.

$$\text{Z score} = \frac{\text{Value} - \text{Min}}{\text{Max} - \text{Min}}$$

2.4.6 Bikeability

Bikeability index is a measure of how bikeable a certain area is and it discusses the comfort and accessibility of bike networks (Lowry, Callister, Gresham, & Moore, 2012). The number of people biking was proven to be depedant on the built environment they reside. Winters et al. (2013) developed a Bikeability index based on the influence of the built environment on biking. The researcher developed empirical evidence based on the opinion survey and found 4 main components of Bikeability, as follows:

Bikeability = 2 * bicycle route density + bicycle route separation
+ connectivity of bicycle-friendly streets + topography
+ destination density

In this research, the bikeability was measured based on the equation developed by Winters et al. (2013). The bicycle route density was measured from the active transportation network shapefile. The active transport network was converted to a density surface and the line density was measured from the density.

2.4.7 Playability

Neighborhood design plays a vital role in a child's growth and physical health. It aids in a child's playability, physical health, and behavior towards active transportation such as walking and biking to school and other places (Timperio, Reid, & Veitch, 2015). Childhood obesity is one of the most severe public health issues of recent times (Organization, 2012) and is associated with diabetes, heart disease, depression, and certain cancers (Lobstein, Baur, & Uauy, 2004). Increasing the physical activity of children can be prescribed to fight obesity (Saris et al., 2003). World Health Organization recommends at least one hour of physical activity each day for children including planned exercise or active play and active transport (i.e. walk and bike) (Tremblay, 2014). Physical activity of children and teenagers can be boosted by promoting active transportation to school. Active transportation to school is positively associated with increased physical activity (Cooper et al., 2006; Rosenberg et al., 2006) and improved cardiorespiratory health (Andersen et al., 2009; Voss & Sandercock, 2010); however, walking or biking to school has reduced over the past 30 years (McDonald, 2007). Over the past 10 years increasing physical activity through neighborhood design and active transportation to school has received increasing interest. Safe Routes to School (SRTS), the Walking School Bus (WSB), or the Walk to School (WTS) programs were introduced to promote walking or biking to school; however, they have gained little success. Neighborhood design can also hamper the physical activity of the residents and the unsupportive environment (i.e. low rates of active transport and independent mobility) of a neighborhood can be held responsible for creating “indoor children” (Carver et al., 2008; Timperio et al., 2015). The importance of neighborhood design to improve physical activity and reduce obesity is recognized by the World Health Organization (Organization, 2012, 2013). Neighborhood design attributes such as transportation environment, street connectivity (Aarts, de Vries, Van Oers, & Schuit, 2012; De Meester, Van Dyck, De Bourdeaudhuij, & Cardon, 2014; Giles-Corti et al., 2011; Machado-Rodrigues et al., 2014; Panter, Corder, Griffin, Jones, & van Sluijs, 2013; Rothman, To, Buliung, Macarthur, & Howard, 2014; Tappe, Glanz, Sallis, Zhou, & Saelens, 2013; Trapp et al., 2011, 2012) , proximity to school, land use mix (Aarts et al., 2012; De Meester et al., 2014; Galvez et al., 2013; Machado-Rodrigues et al., 2014), walkability scores (D’Haese et al., 2014; Echeverria et al., 2014; Giles-Corti et al., 2011; Napier et al., 2011) and residential density (Aarts et al., 2012; De Meester et al., 2014; Rothman et al., 2014; Su et al., 2013) play an important role in improving physical activity as well as encouraging children and teenagers to bike or walk to school (Panter et al., 2013; Rothman et al., 2014; Su et al., 2013; Tappe et al., 2013; Stevens & Brown, 2011; Trapp et al., 2011). Moreover, neighborhood walking and biking infrastructure and pedestrian safety impact residents and school-going children's attitudes towards active transportation.

2.4.8 Ecological Footprint

The ecological footprint is a simple indicator for measuring the effective land area required by an individual or community to produce resources and assimilate wastes they generate (Muñiz & Galindo, 2005; Musikavong & Gheewala, 2017; Stöglehner, 2003; Wackernagel & Rees, 1998). Energy is consumed in every aspect of human life, whether it is related to produce goods or disposal of waste. The ecological footprint combines direct and indirect emission and measures per capita ecological footprint (Petsch, Guhathakurta, Heischbourg, Müller, & Hagen, 2011). Neighborhood densification transforms the land use and reduces infrastructure cost and per capita ecological footprint (Chhipi-Shrestha, Hewage, & Sadiq, 2017). The location of employment, houses, and other amenities affects the ecological footprint as it is responsible for the number of trips and trip length (Muñiz & Galindo, 2005). Newman & Kenworthy (1989) studied the relation between the consumption of fossil fuel and the influence of population density and found that increasing population consumption of fossil fuel decreases. Jöst (1999) also supported Newman & Kenworthy (1989) as their research showed population growth was associated with advances in technology and reduction of per capita energy consumption. Muñiz & Galindo (2005) showed why density reduces the ecological footprint as it reduced trip distance between different destinations and made transit more effective. Cervero (1989), Ewing et al. (1994), and Chhipi-Shrestha et al. (2017) also found reduction of per capita ecological footprint was associated with increasing population density.

2.4.9 Transport Equity

Transport Equity is an important component of transportation planning as it effects (benefits and costs) the decisions of practitioners and decision-makers. Transport equity is very hard to measure and transport equity concerns regularly affect transportation planning decisions (Litman, 1999, 2003). There are different types of transport equity, different effects to consider and ways to measure the effects. Community planning should consider different ways and effects to measure the transport equity and community involvement is mandatory to identify the priorities and concerns of the residents. Transport equity affects the quality of life of people by affecting economic and social opportunities (Pereira, Schwanen, & Banister, 2017). In community planning, one decision may privilege several groups and may seem equitable. However, when different perspectives are evaluated it may seem inequitable. Transport equity decisions are taken based on the concerns of the stakeholders and communities involved (Lucas, Martens, Di Ciommo, & Dupont-Kieffer, 2019; Martens, 2019).

2.4.10 Universal Accessibility

Universal accessibility focuses on building a system that is accessible to all groups of people, regardless of their disability (i.e. speech impairment, hearing or vision loss, aging, cognitive disability) (Aragall, 2003; Zitkus et al., 2011). The universal accessible design could be defined as a system that would increase the usability and could be of great ease to people with disabilities (Iwarsson & Ståhl, 2003).

2.4.11 Air Quality

Air quality impacts human health and climate change globally. Vehicular emission is one of the major contributors to increasing greenhouse gases in the urban (Kumar et al., 2010). The exposure to air pollution tends to decrease in a neighborhood if it is located far from the major highway (Karner et al., 2010). Dense road networks in cities contribute to increasing GHG emissions (Hu et al., 2012). Increasing the land use mix and densification of population in neighborhood reduces the number of cars on the roads (Cervero & Kockelman, 1997; Crane & Chatman, 2003) and by reducing automobiles from the roads GHG emission can be reduced at a great extent (Friedman et al., 2001). Traffic calming in roads though increase the safety in the neighborhood, but it increases the idling time and speed of vehicle that emits more pollutants in the calmed area (Ahn & Rakha, 2009; Várhelyi & Mäkinen, 2001). Hu et al. (2012) showed higher density is associated with higher traffic-related pollutants. Choi et al. (2013) opposed their results and showed street with controlled vehicle activity accompanied by high neighborhood density lowered the GHG emission. Moreover, Shu, et al. (2014) showed a 20% reduction in traffic flows when there's a parallel road running with the highway.

2.4.12 Noise

Rapid urbanization contributes to increasing noise pollution. The growth of transportation demand plays a key role in urbanization and eventually increases noise pollution (De Vos & Van Beek, 2011). People living close to the highways are more exposed to noise pollution. Noise is ranked to be the second major cause of dissatisfaction in a neighborhood (Gandelman, Piani, & Ferre, 2012). The relation between air and noise pollution is strongest close to the highways (Allen et al., 2009; Foraster et al., 2011; Sørensen et al., 2012). Wang & Kang (2011) studied the relation between noise and increasing population density and found that higher population density reduces noise pollution. Their research was supported by the International Association of Public Transport (UITP) as increasing population density is associated with the availability of multi-transport modes (i.e. walk, bike and transit) (Kenworthy & Laube, 2002). The effect of greenspaces was evaluated by Margaritis & Kang (2017) and they found that green spaces reduce noise pollution if the area is located within 500 m * 500 m area. Furthermore, it was observed noise pollution increased with increasing traffic volume (Lee, Jerrett, Ross, Coogan, & Seto, 2014), road network density and reduced with increased greenspaces and decreased building coverage (Salomons & Berghauser Pont, 2012; Zuo et al., 2014)

2.5 Summary

This chapter presents the principle of SMARTer growth (SG) neighborhood design and the design components of SG. The advantages and problems associated with each design component and how each component influences traveling behavior and traffic safety of the dwellers in the neighborhood. Further, the chapter also discussed the development of community-based macro-level collision prediction models, the application of CPMs for neighborhood level, and the assessment tools used for evaluating the quality of life and health of residents in a neighborhood. From previous researches no evidence of development and application of the SG neighborhood design was found. The information from this chapter is used to develop and apply CPMs for neighborhoods and develop the retrofit design for neighborhoods based on the principle of SG.

Chapter 3: Development and Application of Collision Prediction Models

3.1 Overview

This chapter is composed of five main sections. Section 3.2 describes the data type, sources, data collection and preparation process used in this study. Section 3.3 describes the development process of community-based macro-level collision prediction models. Section 3.4 describes the application of CPMs and the traffic assessment process in the study area and Section 3.5 presents the discussion and conclusions.

3.2 Data Collection and Processing

A reliable and well-fit statistical model depends on the quality of the data. To develop reliable collision prediction models, the required data should be sufficient and of sound quality. Based on the recommendations found in the literature in Chapter 2, this section describes the data collection and processing method for this research.

3.2.1 Geographic Scope

The data collection and processing for the model development are related to two geographic areas and the two geographic areas are Kelowna, British Columbia, Canada, and Dhaka, Bangladesh showed in Figure 3-1 and Figure 3-2.

There are significant differences between these two geographic areas. Whereas Kelowna, British Columbia, Canada is in North America and Dhaka, Bangladesh is located in the South of Asia. Both cities have their own challenges. The study areas were selected to compare whether the SG design could be applied to a neighborhood that had differences between population density and income. Kelowna city has a low rural-residential population density with neighborhood dispersed along highways and mountainsides, with valley bottom farms throughout, however, Dhaka is highly populated, and developments are mostly in the core.

Kelowna became a city in 1905 with a population of 600. The population growth increased radically after World War II and reached 13000 in 1961. Until the provincial recession in the mid-1980s, the population growth increased consistently. Over a century later, the population of Kelowna reached 127,380 in 2016. In 2016, Kelowna had a land area of 211.85 square kilometers and the population density was 601.3 people per square kilometer. Kelowna was considered to be one of the fastest-growing cities in Canada, with a growth rate of 8.6% from 2011 to 2016. In 1990, Kelowna was connected to Coquihalla highway to link directly with lower mainland. Since then Kelowna had experienced suburbanization and urban sprawl, resulting in low-density private vehicle dependent developments. Approximately 83% people in Kelowna used cars for the work trip and only 4% were dependent on transit and only 10% on active transportation (walk or bike) (Statistics Canada, 2016). Kelowna is considered to be the most private vehicle dependent city in Canada and the second-largest contributor to greenhouse gas emission as a city. Considering the future growth of Kelowna, the Kelowna City Council has proposed 2030 Official community plan to promote mixed land use across neighborhoods and make them denser. The 2030 official community plan focused to fight urban sprawl and promote active transportation to reduce the GHG gas emission in Kelowna (Official Community Plan Year 2030).

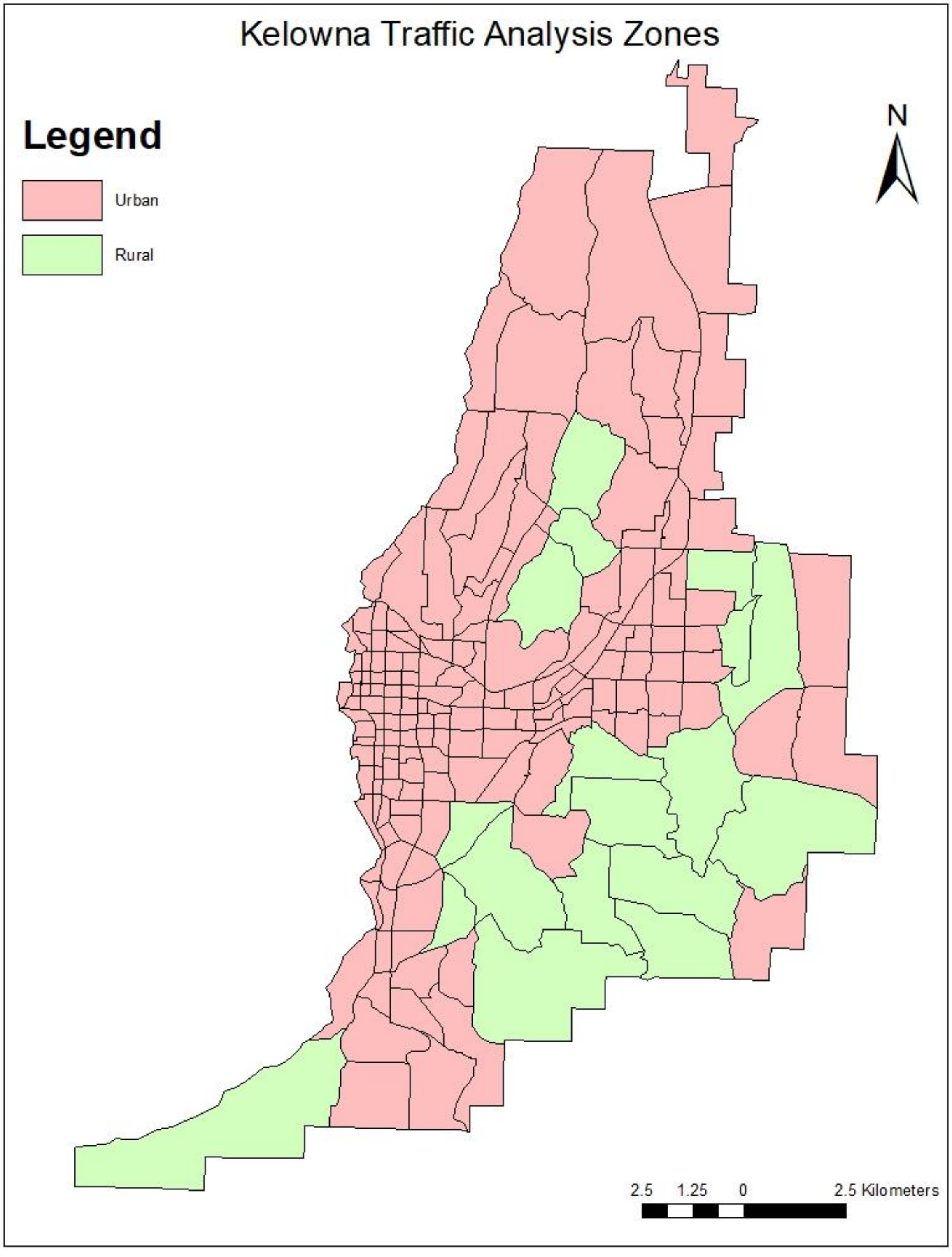


Figure 3-1: Traffic Analysis Zones of Kelowna (Population 601 people/ square kilometers)

On the other extreme, Dhaka, the bustling megacity and capital of Bangladesh, is one of the most densely populated cities in the world. It is expected to be one of the five largest cities in the world by 2025 for its growing population. The city is located in Southeast Asia and bounded by 4 major rivers. Dhaka city is approximately 400 years old. Before 1950, the urban growth rate was slow in Dhaka. However, after the independence of Bangladesh in 1971, Dhaka experienced rapid urban growth, resulted in unplanned and uncontrolled urban sprawl. Compared to other megacities, Dhaka is by far the most densely populated megacities in the world. Mumbai is approximately 1/3 less dense than Dhaka. Other megacities such as Jakarta, Seoul, Shanghai, and Paris is way behind compared to Dhaka in terms of density.

Dhaka has a population of 18.89 million (may rise to 20 million by 2020) and a land area of 300 square kilometers. The population density is 23,234 per square kilometer and the population growth rate is 4.5% annually (BBS, 2011). Due to the rapid urbanization and urban sprawl, the plots and green spaces in Dhaka have been converted into built-up areas. Moreover, the low land, water bodies, playgrounds, and agricultural lands were occupied and filled in to create more built-up areas and playgrounds. The increasing population and urban sprawl are increasing urban poverty, waterlogging, environment pollution and o socio-economic problems (World Bank, 2007).

The road networks in Dhaka are poor and only 7% of the total space is dedicated to the roads. There’s no infrastructure constructed till now to accommodate bikes on the road. Approximately 19% of the people depend on walking, either for economic or efficiency reasons and a significant number of trips are made through motorcycles, bicycles, and three-wheeled rickshaws. 30% of people rely on public transit and only 4.3% of people have access to a private automobile (Hoque, Barua, Ahsan, & Alam, 2012). Mobility is a major issue for this huge population. The main problem is unplanned road network and lack of effective transit systems (Gallagher, 2016). Moreover, the heterogeneity of modes and associated speeds makes the roads and intersections more complex for operation with many safety problems (Anowar, Alam, & Raihan, 2008).

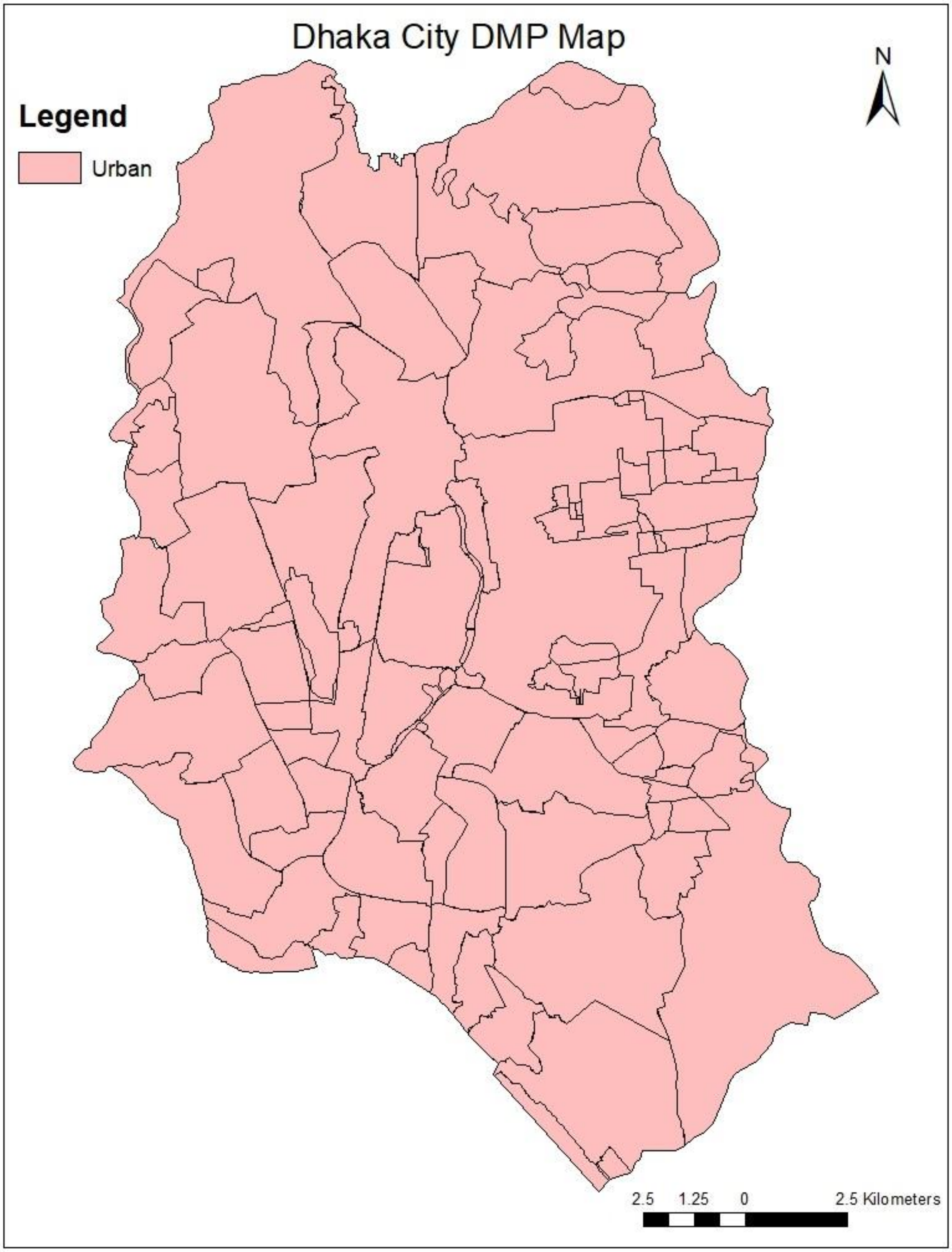


Figure 3-2: Dhaka Metropolitan Police Map (Population 23,234 people/ square kilometers)

3.2.2 Data Sources and Data Preparation

Given the geographic scopes of the two cities, the first step of this research was to collect the data for both the cities. The urban TAZs were analyzed for both the cities as Dhaka city doesn't have any rural areas in between the city. Moreover, the same variables were analyzed for both the cities to make models consistent.

The data for Kelowna, BC, Canada is primarily collected from the City of Kelowna. Geo-referenced collision data is one of the most important information to identify the total number of collisions in a zone. The geo-referenced from 2013 to 2015 is collected from the ICBC collision database and was selected to develop the CPMs. To develop the macro-level CPMs for Kelowna the total number of collisions for 3 years (2013-2015) in traffic analysis zones (TAZ) are considered as a dependent variable. The independent variables that are used to develop the macro-level CPMs were identified by Lovegrove (2007) and Garg (2019). The independent variables are grouped into four variable groups, those are exposure (EXP), sociodemographic (SD), transportation demand management (TDM), and the road network (NET). The socio-demographic dataset for Kelowna was collected from the City of Kelowna and the network variable shapefiles which contains road networks, number of lanes, road lengths, road class, roundabouts, intersections, and other data related to the road network is collected from the open database of City of Kelowna. The data for Capri-Landmark neighborhood of Kelowna is collected from the City of Kelowna and 2040 Capri-Landmark preferred proposed urbanization design by City of Kelowna. The EXP variables were collected by using analysis toolbox in ArcGIS and TDM variables were calculated manually following methodology by Lovegrove (2007).The data sources and statistical summary are given in Table 3.1.

Table 3-1: Variables Sources and Data Summary for Kelowna (n=131) (Garg (2019))

Variables	Symbol	Source	Years	Zonal Min	Zonal Max	Zonal Avg.
Collisions						
Total collisions	T3	ICBC[1]	13-15	1	1338	107
Exposure						
Total lane km	TLKM	CoK[2]	2014	1.16	59.68	12.93
Arterial lane km	ALKM	CoK	2014	0	53.61	6.65
Collector lane km	CLKM	CoK	2014	0	23.37	2.98
Local lane km	LLKM	CoK	2014	0	27.88	3.26
Zonal area (hectares)	AREA	CoK	2014	4.36	1083.41	117.85
Socio-demographic						
Population	POP	CoK	2014	0	5045	663
Population density (=POP/AREA)	POPD	CoK	2014	0	61.29	14.92
Employed residents	EMP	CoK	2014	0	4437	367
Employed density (=EMP/AREA)	EMPD	CoK	2014	0	323.14	16.92
Unemployed residents	UNEMP	CoK	2014	0	2340	204.21
Unemployed rate (=UNEMP/ (UNEMP + EMP)) (%)	UNEMPP	CoK	2014	0	100	50.78
Transport Demand Management						
Core area (Hectares)	CORE	CoK	2014	4.4	1083.4	113.12
CORE/AREA	CRP	CoK	2014	50	100	98

Network						
No. of intersections	INT	CoK	2014	0	97	11.86
Intersection density (INT/AREA)	INTD	CoK	2014	0	1.3	0.24
No. of intersections/TLKM	INTKD	CoK	2014	0	10.98	0.99
No. of signalized intersections	SIG	CoK	2014	0	5	0.63
Signalized intersection density	SIGD	CoK	2014	0	0.59	0.02
No. of 3-way intersections/INT (%)	I3WP	CoK	2014	0	100	70.23
No. of arterial-local intersections/INT (%)	IALP	CoK	2014	0	100	18.9
No. of roundabouts/INT (%)	IRBP	CoK	2014	0	33.33	0.97
ALKM/TLKM (%)	ALKP	CoK	2014	0	100	50.47
CLKM/TLKM (%)	CLKP	CoK	2014	0	89.85	22.93
LLKM/TLKM (%)	LLKP	CoK	2014	0	100	26.36

Note:
1 ICBC: Insurance Corporation of British Columbia
2 CoK: City of Kelowna

Dhaka City Corporation (DCC) area was selected to conduct the research. The collision data for 2013 to 2015 for Dhaka, Bangladesh is collected from Accident Research Institute (ARI), Bangladesh University of Engineering and Technology (BUET). The socio-demographic dataset for Dhaka was collected from the Bangladesh Bureau of Statistics (2011) and the network variable shapefiles which contain road networks, and road lengths are collected from the Open Street Map. The accident data for Dhaka is collected by the Police department of Bangladesh and the police station concerning the accident fill-up the Accident Reporting Form (ARF) for each accident.

These ARFs are sent to Dhaka Metropolitan Police (DMP) headquarters and from there the data is collected and uploaded into Microcomputer Accident Analysis Package (MAAP5) software by ARI (I. Ahmed, Ahmed, & Hainin, 2013). This software is an outdated software that doesn't support geo-referencing of collisions' location. This is why the collision data of Dhaka doesn't have any precise location of where the collision actually happened. Therefore, to collect the collision data for Dhaka city the DMP has its own map, each area of the map assigned to specific police stations. The DMP map was used in this research to develop the digitized GIS map of Dhaka, with police station area to aggregate data as a TAZ. According to the Dhaka Metropolitan Police, DCC area has 41 police stations (DMP, 2018). The aggregated collision data for each TAZ was then used for the development of community-based macro-level CPMs for Dhaka. The road class and the number of lanes for each road were calculated manually from Google Earth Pro and the network variables are measured manually and also using geo-processing tools in ArcGIS. The EXP variables were collected by using the analysis toolbox in ArcGIS, TDM variables were calculated manually following methodology by Lovegrove (2007). The data sources and statistical summary are given in Table 3-2.

Table 3-2: Variables Sources and Data Summary for Dhaka (n=46)

Variables	Symbol	Source	Years	Zonal Min	Zonal Max	Zonal Avg.
Collisions						
Total collisions	T3	ARI[1]	11-13	1	140	24.20
Exposure						
Total lane km	TLKM	OSM[2]	2016	28.44	486.59	132.84
Arterial lane km	ALKM	OSM	2016	0	115.35	35.31
Collector lane km	CLKM	OSM	2016	2.90	58.49	26.95
Local lane km	LLKM	OSM	2016	8.41	341.33	70.58
Zonal area (hectares)	AREA	Manual[3]	2016	55.03	2163.80	544.66
Socio-demographic						
Population	POP	BBS	2016	10626	596835	190923.96
Population density (=POP/AREA)	POPD	BBS	2016	37.68	1560.25	497.41
Employed residents	EMP	BBS	2016	4859	274150	86943.17
Employed density (=EMP/AREA)	EMPD	BBS	2016	19.32	2142.50	284.22
Unemployed residents	UNEMP	BBS	2016	4977	251799	85845.11
Unemployed rate (=UNEMP/ (UNEMP + EMP)) (%)	UNEMPP	BBS	2016	32	58	50

Transport Demand Management						
Core area (Hectares)	CORE	Manual	2016	0.08	2007.08	375.75
CORE/AREA	CRP	Manual	2016	0	100	64
Network						
No. of intersections	INT	OSM	2016	8	414	101.413
Intersection density (INT/AREA)	INTD	OSM	2016	0.032	1.349	0.274
No. of intersections/TLKM	INTKD	OSM	2016	0.144	2.28	0.765
No. of signalized intersections	SIG	OSM	2016	0	23	11.22
Signalized intersection density	SIGD	OSM	2016	0	0.143	0.039
No. of 3-way intersections/INT (%)	I3WP	OSM	2016	81	100	94
No. of arterial-local intersections/INT (%)	IALP	OSM	2016	0	57	17
No. of roundabouts/INT (%)	IRBP	OSM	2016	0	13	1
ALKM/TLKM (%)	ALKP	OSM	2016	0	71	29
CLKM/TLKM (%)	CLKP	OSM	2016	6	64	24
LLKM/TLKM (%)	LLKP	OSM	2016	12	91	48

Note:
1 ARI: Accident Research Institute, BUET
2 OSM: Open Street Map
3 BBS: Bangladesh Bureau of Statistics
4 Manual: the zonal area was developed and calculated manually in ArcGIS

3.3 Model Development

To evaluate the safety of existing neighborhoods and to compare the safety of retrofitted neighborhood designs, NB generalized linear regression (GLM) community-based macro-level CPMs were developed for both Kelowna and Dhaka.

3.3.1 Negative Binomial Models Development

Several regression techniques were employed to develop CPMs. The choice of regression models determines the accuracy of the model (El-Basyouny & Sayed, 2007). The earlier CPMs were developed using ordinary regression techniques. However, several researchers criticized the accuracy of the ordinary regression model as these models were not able to model the collision as they are discrete, not negative and rare events (Hauer, Ng, & Lovell, 1988; Jovanis & Chang, 1986; Miaou & Lum, 1993). The limitations of the ordinary regression techniques led to Poisson regression and consequently to Negative Binomial regression is considered to be the most popular regression model to develop accident prediction models. NB itself is a variant of Poisson regression. It is evident that most collision data is usually over-dispersed data (Kulmala & Roine, 1988). NB is considered to be more accurate in developing CPMs than Poisson regression as it introduces an over-dispersion parameter which deals with over-dispersed count data (Coxe et al. 2009; Hilbe, 2011). The models are evaluated using the log-likelihood and deviance. The larger value of log-likelihood indicates poor fitting of the model, whereas the larger value of deviance is considered to be a good statistical model (Gigliotti, 2007). The statistical significance for each model is tested to check independent variables over dependent variables.

The model form used for the development of NB models is as follows:

$$\mathrm{E}\ (\Lambda) = a_0 (Z)^{a_1} e^{\sum b_j X_j}$$

Where E (Λ) = the predicted collision frequency (3-year); a_0, a_1, b_j = model parameters; Z = leading exposure variables (e.g. vehicle kilometer traveled (VKT) or total lane kilometers (TLKM)); and, X_j = other explanatory variables (e.g. socio-demographic, economic, and network variables).

The effect on leading exposure variables (Z) and other explanatory variables (X_j) can be differentiated in this model form and it also considers zero-risk logic (Sawalha & Sayed, 2006). For each model, the addition of each explanatory variables were followed by a stepwise process. Firstly, the explanatory variables added in each model in such a way that it starts with no variables. Secondly, each variables were added in the model based on their model comparison criteria (i.e. *SD*). Thirdly, explanatory variables were added from same variable groups (i.e. EXP, SD, TDM or NET) to increase the accuracy of the CPMs. Fourthly, iterations were done until significant improvement was observed in the models (Garg, 2019). In each model the TLKM was the leading exposure variable. In the models each independent variable was discarded or kept based on the criteria's discussed by Sawalha & Sayed (2006) as follows:

To keep an independent variable the logic (+/-) of that parameter should be logically related to collisions. At 95% confidence the t statistics value of each parameter should be higher or lower than 1.96. There should be little or no correlation between the independent variables in a model. The estimate of scaled deviance at 95% confidence level should reduce with the addition of each independent variable.

To measure the goodness fit of the models scaled deviance (*SD*) and the Pearson χ^2 statistic were used. To compare and select models AIC and BIC's were used. The formulation of SD and Pearson χ 2 measures were shown in equation 2.2 and 2.3 (Enderlein, 1987).

The models were developed in the statistical programming language R (Team, 2013) using the Mass package (Venables, Ripley, & Isbn, 2002) and Stargazer (Hlavac, 2018) in R Studio v1.1.463. The CPMs for urban TAZs in Kelowna were derived from Garg (2019) and applied at Capri-Landmark neighborhood to assess the traffic safety of the existing, proposed and retrofitted designs. The models were developed for measured exposure variables (i.e. TLKM) and for 4 variable groups (i.e. EXP, SD, TDM, and NET). Total collision for 3 years (2011 to 2013) was the dependent variable in developing the CPMs. The CPMs for urban TAZs of Dhaka are listed in table 3-3.

Table 3-3 Negative Binomial URBAN CPMs for Dhaka City– Total Collisions

Model Group #	Model form	κ	DOF	Pearson χ^2	SD	$\chi^2_{0.05,\ dof}$	AIC	BIC	t-Statistics
1	Urban, Measured, Exposure	1.30	44	50.56	88.05	61	383	389	Constant = 2.8 TLKM = 3.30
	Total Collisions/3yr = $1.196*TLKM^{0.698}$								
2	Urban, Measured, Socio-demographics	1.42	42	48.16	52.64	59	383	392	Constant = 2.57 TLKM = 2.78 EMPD =2.09 POPD = 2.82
	Total Collisions/3yr = $1.863*TLKM^{0.601}e^{0.0004POPD + 0.001EMPD}$								
3	Urban, Measured, TDM	1.46	43	49.05	53.68	60	380	387	Constant = 3.21 TLKM = 4.02 CORE = -2.63
	Total Collisions/3yr = $3.865*TLKM^{1.01}e^{-0.001CORE}$								
4	Urban, Measured, Network	1.54	41	55.07	66.94	57	381	392	Constant = 1.96 TLKM = 2.66 RB = -3.35 INTD = 2.14 IALP = 2.25
	Total Collisions/3yr = $1.067*TLKM^{0.551}e^{-0.308RB + 0.456INTD + 1.117IALP}$								

3.4 Application of CPMs and Traffic Safety assessment of the Study Area

3.4.1 Capri-Landmark neighborhood, Kelowna, BC, Canada

3.4.1.1 Existing Condition

The Capri-Landmark neighborhood is one of the study areas of this research. The neighborhood is situated between Gordon and Spall, and Highway 97 and Springfield. The neighborhood is one of Kelowna's major employment hubs and attracting more people for housing. More than 2600 people live in the neighborhood (i.e. 1.9% of the total population of Kelowna) and the population density is 28 people/hectare, higher than Kelowna's average population density.

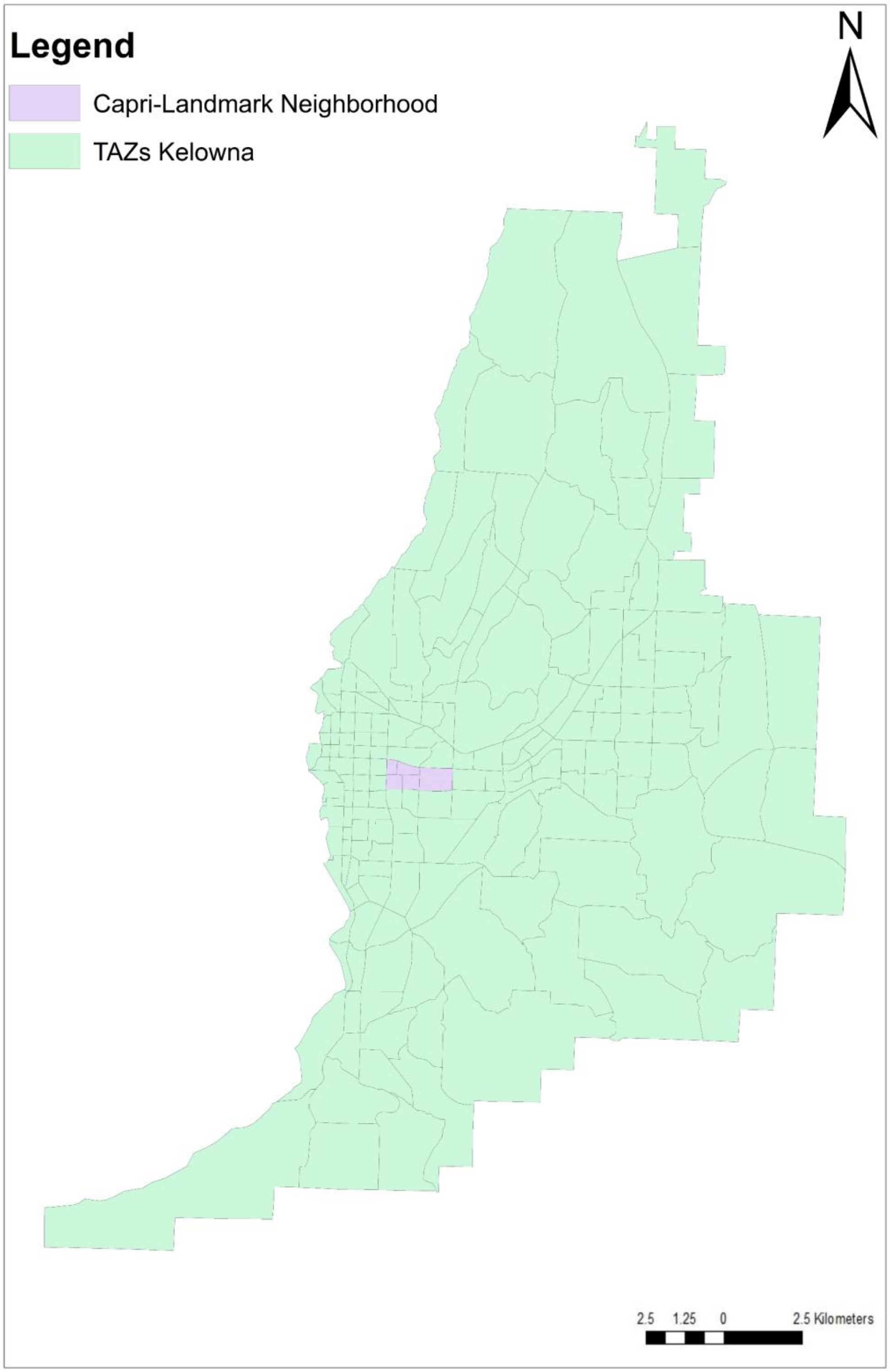


Figure 3-3: Location of Capri-Landmark in Kelowna

Figure 3-4: Capri-Landmark Neighborhood Kelowna (Existing Condition)

Approximately 450 businesses are located in the Capri-Landmark area which supports 5200 jobs making Capri-Landmark the second largest employment hub in Kelowna. The area is mainly employment-oriented and there are some apartments and single detached houses for dwelling. The transportation network in the Capri-Landmark was not designed to accommodate large number of traffics which is resulting in congestion during peak hours. The area is also one of the most collision prone areas in Kelowna (Garg, 2019). The neighborhood is surrounded by major arterial roads and the internal road network has poor connectivity and has many cul-de-sacs and private driveways. Only one type of land use, limited access to major roads, poor internal road network connectivity and traffic congestion at peak hours makes the condition worse. Moreover, Capri-Landmark also lacks green spaces compared to the population.

3.4.1.2 Capri-Landmark Neighborhood Proposed Urbanization Design

To overcome the existing problems in managing the future growth of the Capri-Landmark neighborhood the Kelowna City Council proposed the 2040 Capri-Landmark neighborhood proposed urbanization design. The proposed 2040 Capri-Landmark neighborhood proposed urbanization design was developed with the help of community feedback and considering the future growth, accessibility, housing options and availability of open spaces. The main aim of the approved plan for the Capri-Landmark is to increase population density and mix land use while maintaining growth and making the neighborhood more livable and vibrant. Several amenities such as green spaces, shops, and services will be provided to the neighborhood dwellers and some of the major streets will be realigned to construct protected cycling lanes, wider sidewalks, and more transit stop to promote walking and biking across the neighborhood or to other neighboring neighborhoods (Real Estate Foundation, 2019). The Capri-Landmark neighborhood proposed urbanization design focused more on improving visitors' experience and residents' quality of life, less emphasis on improving the traffic safety of the neighborhood.

3.4.1.3 Application of Community-based Macro-Level Collision Prediction Models to Capri-Landmark

For this research, the Capri-Landmark neighborhood was divided into six TAZs (Figure 3-4). Each of these zones has its own urban form, street network, greenspaces, population, and employment. The different variable groups (i.e. EXP, NET, and TDM) for each of these zones were measured using ArcGIS and manually and the socio-demographic variables were collected from City of Kelowna. The urban measured models for Kelowna developed by Garg(2019) were applied to each zone for both existing conditions, proposed urbanization design plan, and retrofit design.

The data for the 2040 Capri-Landmark neighborhood proposed urbanization design were collected from the 2040 Capri-Landmark neighborhood proposed urbanization design published by Real Estate Foundation (2019) and the EXP, NET, and TDM variables were calculated by ArcGIS and manually, based on the new road network and new land-use plan and the SD variables were calculated based on the projection of population and employment on the 2040 proposed urbanization design for Capri-Landmark.

The variables from the retrofit design were measured on ArcGIS based on the new road network and new land-use plan and the SD variables were calculated based on the study conducted by Grammenos & Lovegrove (2015). The amount of green space in the retrofit design was assumed 9 m^2 per person based on the recommendation of Urban Green Space (UGS) goal for compact and sustainable cities (Russo & Cirella, 2018). The new calculated variable values for the retrofit design are applied to the model to predict the total number of collisions for the retrofit design and comparison between the existing design and the retrofit design were done. The comparison between the designs shows the percentage of collision reduction in the newly improved design based on the principle of SG.

3.4.2 Gulshan, Dhaka, Bangladesh

3.4.2.1 Exiting Neighborhood Condition

Gulshan was the neighborhoods in Dhaka, Bangladesh used for this research. It is one of the largest employment hubs, situated in the middle of Dhaka. The total administrative area is approximately 1030 hectares and the land-use area is 800 hectares (B Ahmed, Raj, & Ahmad, 2008). The area is surrounded by Tejgaon and Khilgaon to the South, Dhaka Cantonment to the North, Badda is at East and Kafrul is at West. The population density in Gulshan is approximately 300 people/hectare. Gulshan's total administrative area and density were approximately 11 times higher compared to Capri Landmark neighborhood. The area was planned as a residential area in 1961 for higher-income people (B Ahmed et al., 2008). However, the area is currently used for both residential, commercial, and diplomatic purposes, turning it into a mixed land-use area. The grid pattern was implemented in Gulshan area and three types of road networks (i.e. arterial, secondary and access roads) were constructed to provide connectivity (B Ahmed et al., 2008; Hashem, 2001). However, the traffic system is failing due to rapid growth of traffic and outdated traffic management systems (Habib, 2002; Rahman, Okura, & Nakamura, 2004; Shakil, Asif, Begum, Akter, & Hasan, 2016).

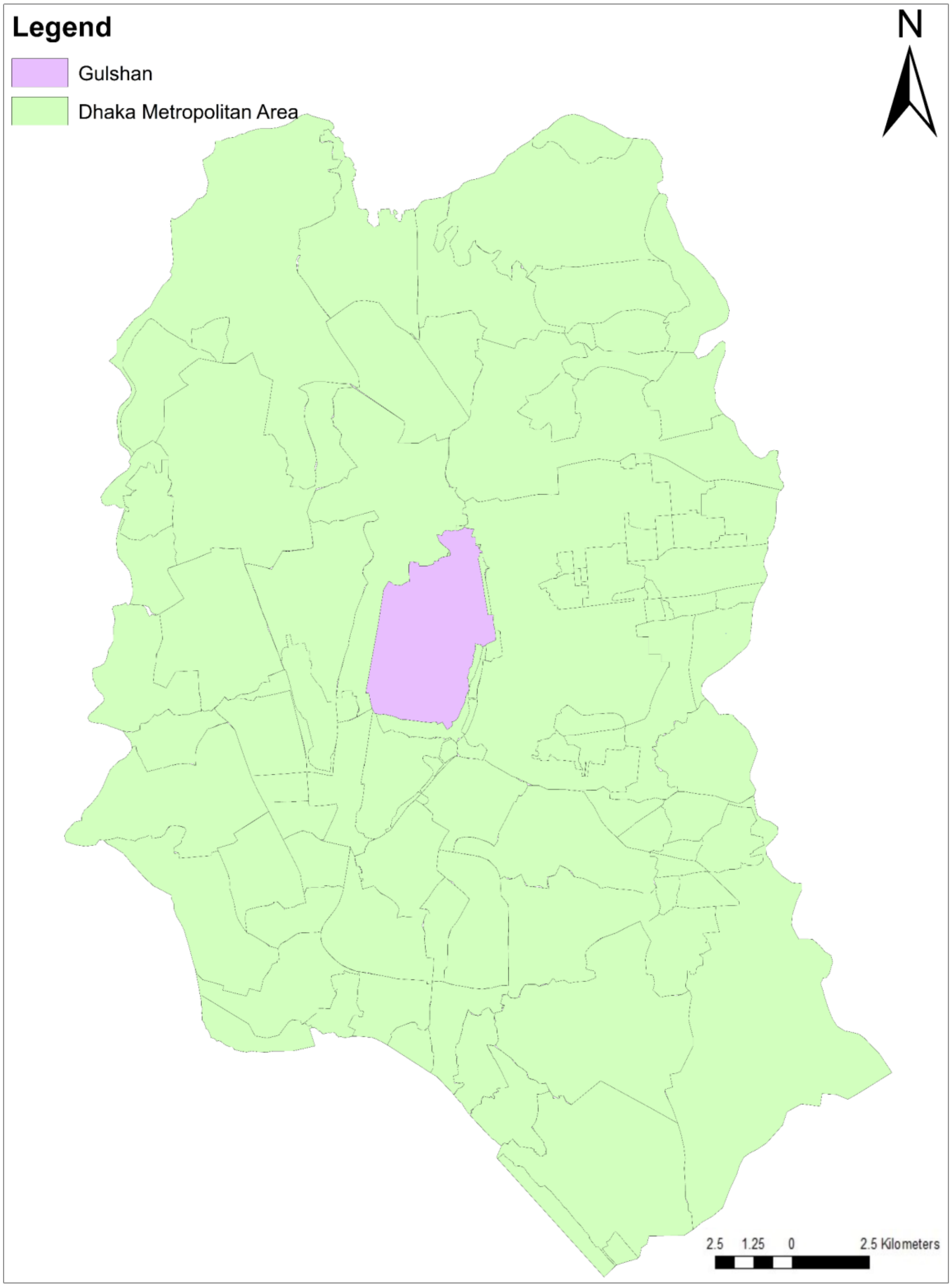


Figure 3-5: Location of Gulshan in Dhaka

Figure 3-6 Gulshan, Dhaka, Bangladesh (Existing Neighborhood Condition)

The existing condition is worsened due to the heterogeneous traffic sharing the same road. The public transit is inefficient and least desirable in terms of safety, comfort, and reliability. Rapid urbanization and increased dependency on motorcycles and private automobiles are making the situation worse (Bayes Ahmed, Hasan, & Maniruzzaman, 2014). The inefficient transit system, inferior transportation management system and facilities and increased dependency on private automobiles further congest the roads and increase safety issues and greenhouse gas (GHG) emission (Begum, Biswas, & Hopke, 2011; Karim, 1999). Several streets in Gulshan missing sidewalks which makes it challenging for the pedestrian to walk and also there are no bicycle lanes or bike paths. Parks and open spaces are located in Gulshan area to provide the dwellers a sense of green. However, the presence of parks and open space are reducing due to rapid urbanization and population growth (Byomkesh, Nakagoshi, & Dewan, 2012).

3.4.2.2 Application of CPMs to Gulshan, Dhaka, Bangladesh

The total Gulshan area was divided into nine zones, six of these zones represented the waterbody and lakes and the remaining zones represented the land use area. The remaining three zones were used as TAZ for this study. Each of these zones had their own urban form, street network, population, and employment. The different variable groups (i.e. EXP, NET, and TDM) for each of these zones were measured using ArcGIS and manually and the socio-demographic variables were collected from the Bangladesh Bureau of Statistics (2011). The developed CPMs for Dhaka were applied to each TAZs data to predict collision for both existing and retrofit designs. The retrofit design is shown in Chapter 5. The variables from the retrofit design were calculated on ArcGIS based on the new road network and new land-use plan and the SD variables were calculated based on the study conducted by Grammenos & Lovegrove (2015). The new calculated variable values for the retrofit design are applied to the model to predict the total number of collisions for the retrofit design and comparison between the existing design and the retrofit design were done. The comparison between the designs shows the percentage of collision reduction in the newly improved design based on the principle of SG.

3.5 Summary

Four urban measured community based macro-level collision prediction models were developed for Dhaka, Bangladesh to predict the total collision frequency. The CPMs developed for both the cities were applied to assess the traffic safety at the existing conditions. The parameter estimates for CPMs showed a positive association between the total number of collision with vehicle kilometers traveled, population and employment density, intersection density, and proportion of arterial-local intersections. However, the number of roundabouts and core size showed a negative association with the total number of collisions. Furthermore, the developed CPMs were applied to the study areas and the results have been discussed in the next chapter.

Chapter 4: Application of SMARTer Growth Design Manual to Design to Develop Retrofit Neighborhood Design for Capri-Landmark

4.1 Overview

Designing a SMARTer Growth (SG) neighborhood design requires consideration of different components of the built environment. The built environment components are inter-related and the impacts or outcomes depend on two or more components working together. Previous researchers had developed a suite of tools to assess the outcomes and different prospects of life of residents in a neighborhood. The tools have been discussed in the literature review (Section 2.4) and summarized below in Table 4-1. The system based analysis and application of these tools for a neighborhood in Kelowna and their outcomes has been presented in this chapter. Moreover, the development of the retrofitted neighborhood design for Capri-Landmark, Kelowna has been discussed in this chapter.

This chapter is composed of fourteen main sections. Section 4.2 describes the development of the retrofit design for Capri-Landmark neighborhood, Kelowna and the design of each component of the design is described in detail. Section 4.3 presents the application and evaluation of iThrive. Section 4.4 and 4.5 illustrate the application and evaluation using Healthy Built Environment Linkages Toolkit and Envision respectively. Section 4.6 to 4.13 discusses the walkability, bikeability, playability, ecological footprint, transport equity, universal accessibility, air quality, and noise respectively. Section 4.14 presents a discussion of this chapter.

Table 4-1: Suite of Tools Towards SMARTer Growth

Name of the tools	Developer(s)	Design Criteria	Data Required
iThrive	UBC STS researchers (Masoud et al., 2015)	• Density • Service Proximity • Land Use Mix • Street Connectivity • Road Network and Sidewalk Characteristics • Parking • Aesthetics and Human Scale • Functionality • Predictability • Homogeneity • Forgivingness • State Awareness	• Population density • Employment density • Street Network • Land use plan • Parking Plan • Active Transportation Infrastructure • Traffic Calming Infrastructure
Healthy Built Environment Linkages Toolkit	Population & Public Health team at the BC Centre for Disease Control (BCCDC)	• Neighborhood Design, • Transportation Networks,	• Population density • Employment density • Street Network • Land use plan • Destination Density

Name of the tools	Developer(s)	Design Criteria	Data Required
		• Natural Environments,	• Location of Natural Habitat • Location of wetland • Location of Farmland
		• Housing, and	• Population density • Employment density • Land use plan • Destination Density
		• Food Systems.	
Envision	Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design and the Institute for Sustainable Infrastructure.	• Quality of Life • Leadership • Resource Allocation	• Population density • Employment density • Land use plan • Destination Density • Connectivity • Greenspaces

Name of the tools	Developer(s)	Design Criteria	Data Required
		• Natural World	• Location of Natural Habitat • Location of wetland • Location of Farmland
		• Climate and Risk	• Air Quality • Noise
Walkability			• Connectivity • Housing Density • Destination Density • Land use mix • Retail density

Name of the tools	Developer(s)	Design Criteria	Data Required
Bikeability			• Active Transportation Network • Connectivity • Bike lane or Bike path availability • Topography • Destination Density
Playability			• Street Connectivity • Land use plan • Walkabilty • Housing Density • Destination Density • Greenspaces • Active Transportation Infrastructure

Name of the tools	Developer(s)	Design Criteria	Data Required
Ecological Footprint			• Energy Consumption • Transport Modes • Population density • Employment density • Street Network • Land use plan • Active Transportation Infrastructure • Destination Density

Name of the tools	Developer(s)	Design Criteria	Data Required
Transport Equity			• Population and Employment density • Street Connectivity • Land use plan • Destination Density • Income • Traffic Calming Infrastructure • Population with Disability

Name of the tools	Developer(s)	Design Criteria	Data Required
Universal Accessibility			• Population with Disability • Street Network Characteristics • Land use plan • Active Transportation Infrastructure • Availabilty of parking spot for people with disability • Availabilty of Universal accessible buildings • Availabilty of Universal accessible transit services

Name of the tools	Developer(s)	Design Criteria	Data Required
Air Quality			• Traffic Volume • Transport Modes • Traffic Speed • Street Network • Land use plan • Active Transportation Infrastructure • Destination Density
Noise			• Traffic Volume • Transport Modes • Traffic Speed • Street Network • Land use plan • Destination Density

4.2 Development of Retrofit Design for Capri-Landmark Neighborhood

A safe and sustainable neighborhood design requires careful planning and implementation of the design that provides a sustainable quality of life. A well-designed neighborhood contributes to the economy of the city and acts as a foundation of the city by attracting more people and businesses. Designing a new neighborhood system or improving the existing condition of a neighborhood depends on several components and on understanding how these components interact. Neighborhood planning is very crucial as the neighborhood pattern remains the same for several decades after it's constructed once. It's critical to select the appropriate plan for the neighborhood as it's to a certain extent impossible to reconstruct or modify the plan after it's constructed, even if it's feasible it would be troublesome and costly. Retrofitting the existing neighborhood can be suggested as one of the solutions to solve the problems of today.

In this research, the retrofit design of the study area was developed by using SMARTer Growth Neighborhood Design Manual to evaluate each system component and how it interacts with others. The newly formed retrofit designs were expected to result in the following outcomes or metrices after the retrofitted neighborhoods were built.

1. Reduced traffic collisions and traffic conflicts,
2. Reduced automobile dependency,
3. increased use of public transportation and active transportation,
4. Improved active transportation facilities and plentifulful of greenspaces,
5. Increased accessibility to amenities and services and,
6. A proper blend of land use which ensures connectivity across the neighborhood.

The Capri-Landmark area in Kelowna was selected for this study to apply the SG principles and to retrofit the existing neighborhood. The City of Kelowna had prioritized redevelopment of Capri-Landmark and proposed a detailed urban center plan for Capri-Landmark and it is one of the major employment hubs and housing locations in Kelowna. The Capri-landmark was chosen to be the study location based on these considerations, which ensured adequate relevant data was available.

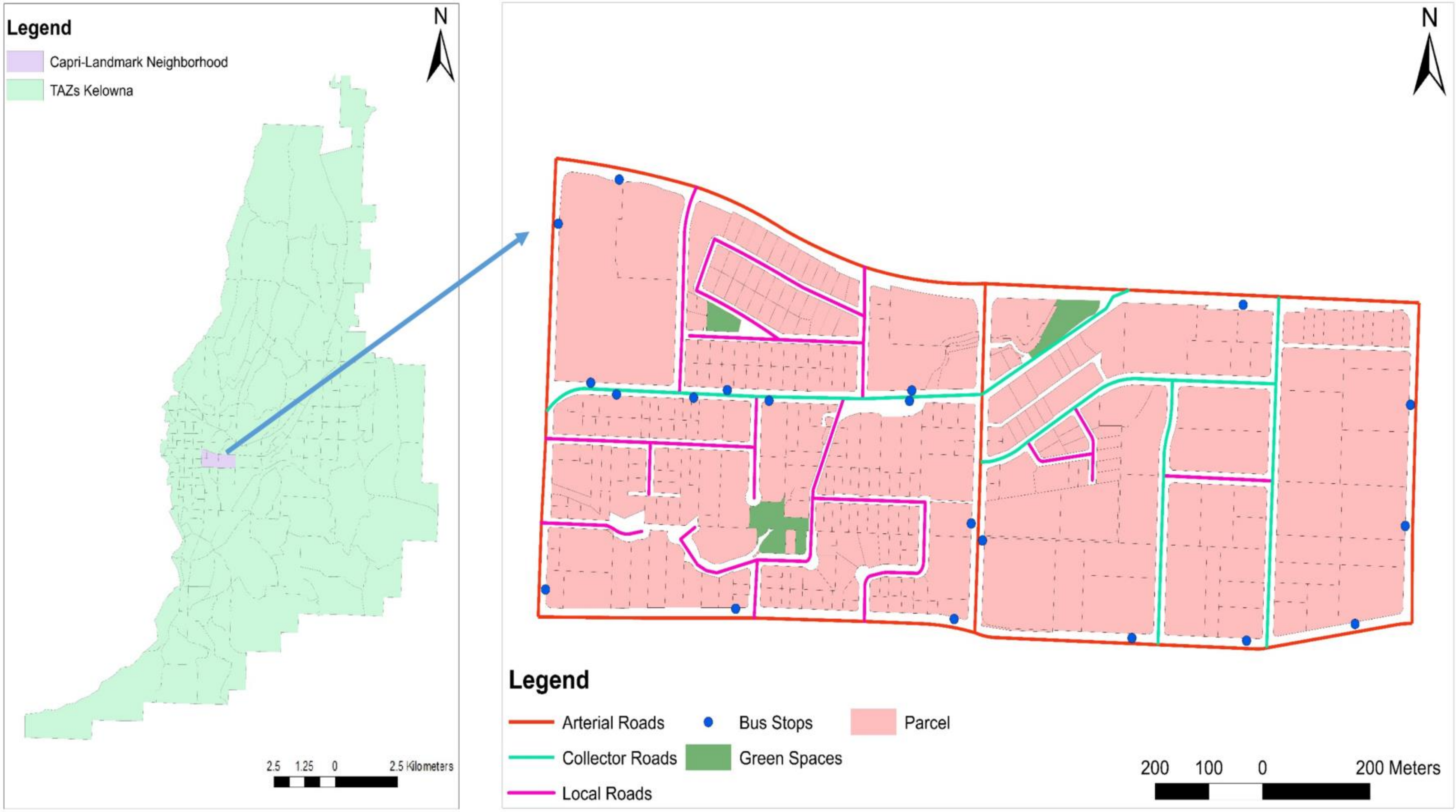


Figure 4-1: Location of Capri-Landmark

There were six TAZs in the existing neighborhood plan. The retrofit design for each TAZs were developed according to SG design manual and the best features of the existing and the city were retained in our SG design. The SG design components and consideration for the area are discussed below.

4.2.1 Street Network

Street network is considered as one of the major components of SMARTer Growth (SG) neighborhood design. In the retrofitted Capri-Landmark neighborhood, the major arterial was converted to one way perimeter arterial couplet to decrease conflicts between traffics(i.e. left turn maneuver) (Figure 4-3). Medians were converted to a new block and local roads were made discontinuous to reduce shortcutting of high-speed traffic in the neighborhood.

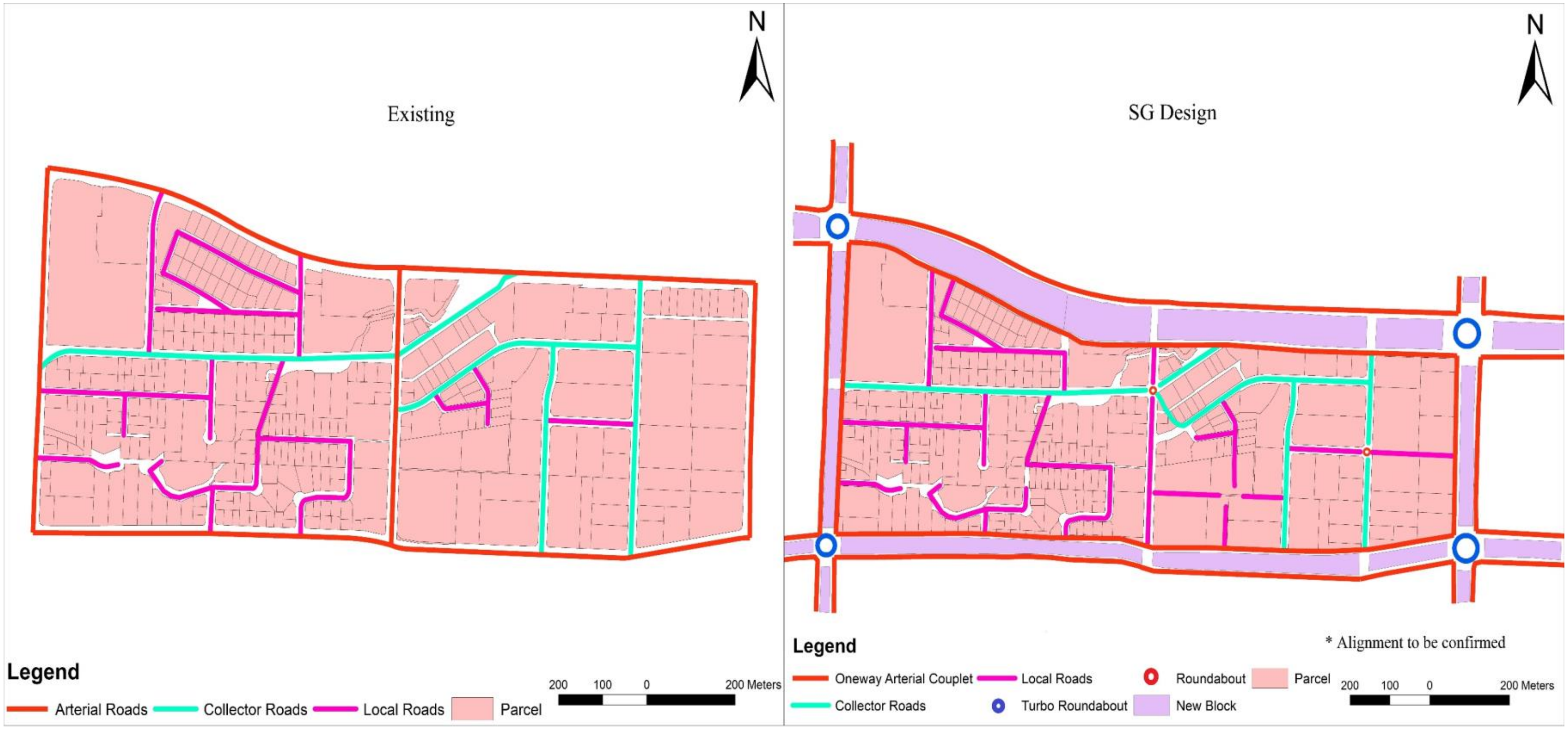


Figure 4-2: Comparison Between Existing and SG Design Road Network

Rodegerdts et al. (2007) suggest roundabout reduces approximately 78% traffic conflicts and improves the overall traffic safety at the intersection in contrast to signalized roundabouts. The major signalized intersections were replaced with turbo roundabouts to increase capacity, decrease traffic conflicts, and to reduce traffic collision.

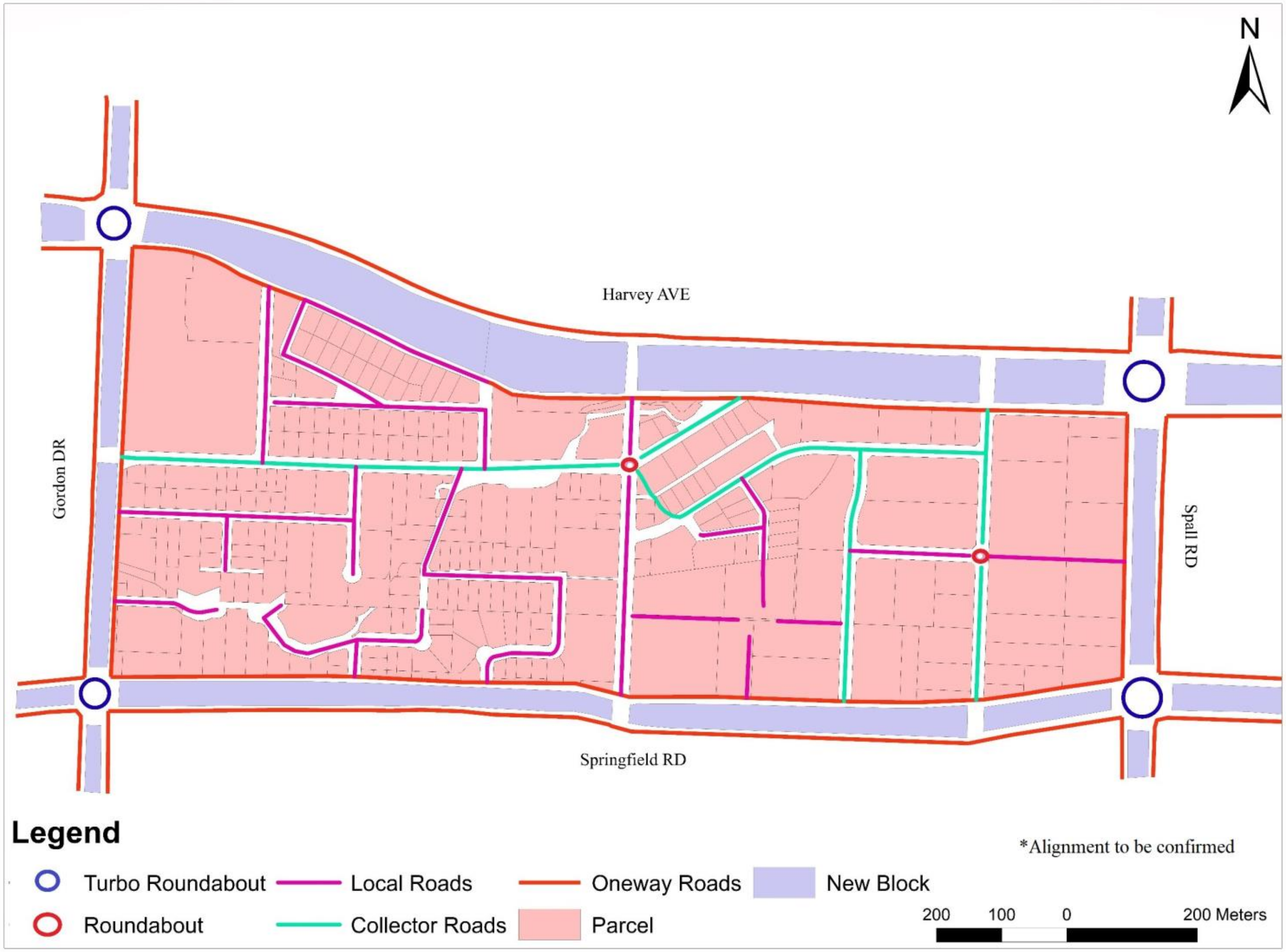


Figure 4-3: SG Road Network (Capri-Landmark)

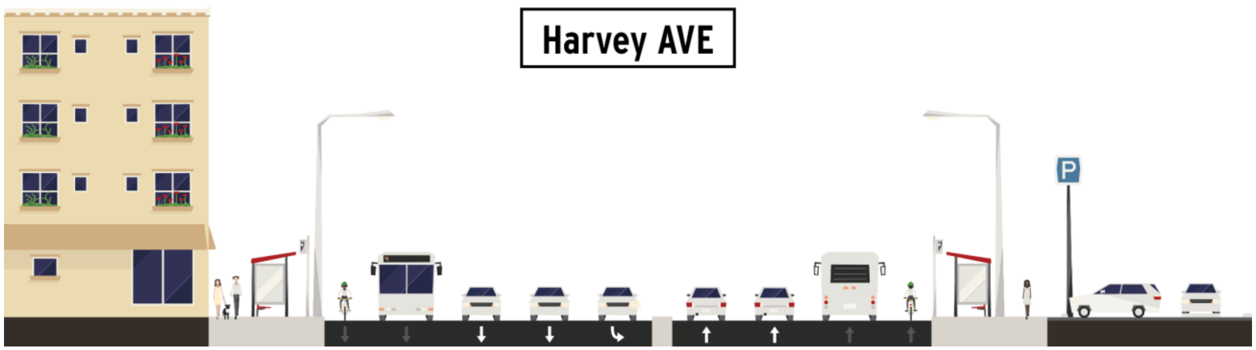


Figure 4-4: Existing Road Network Cross-section

Figure 4-5: SG Design One-way Arterial Couplet

4.2.2 Active Transportation Network

The active transportation infrastructure depends on the availability of sidewalks and cycling infrastructure (i.e. cycle paths, bike racks). To separate the fast-moving traffic from bikers and pedestrians, bike lanes and pedestrian sidewalks will be constructed in all arterial and collector roads in Capri-Landmark. The speed limit for local roads was limited to 30 km/h and the off-road biking and walkway was constructed in the neighborhood to reduce trip distance by walking and biking across the neighborhood. Bike parking facilities and benches will be installed in front of mixed-use zones to promote biking and walking to those areas. The underpass would be constructed in the active transportation crossing to facilitate pedestrian and bicycle movement.

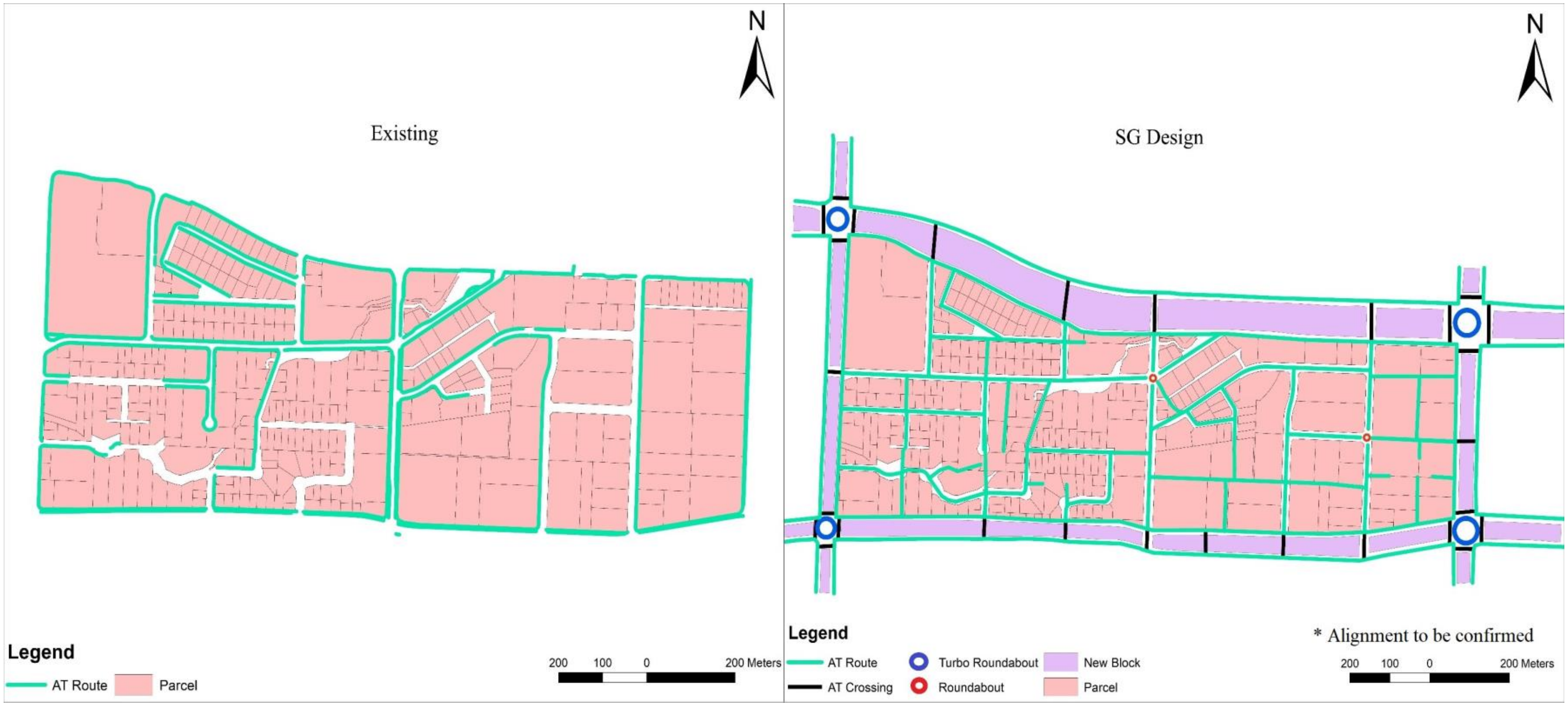


Figure 4-6: Comparison Between Existing and SG Active Transportation Network

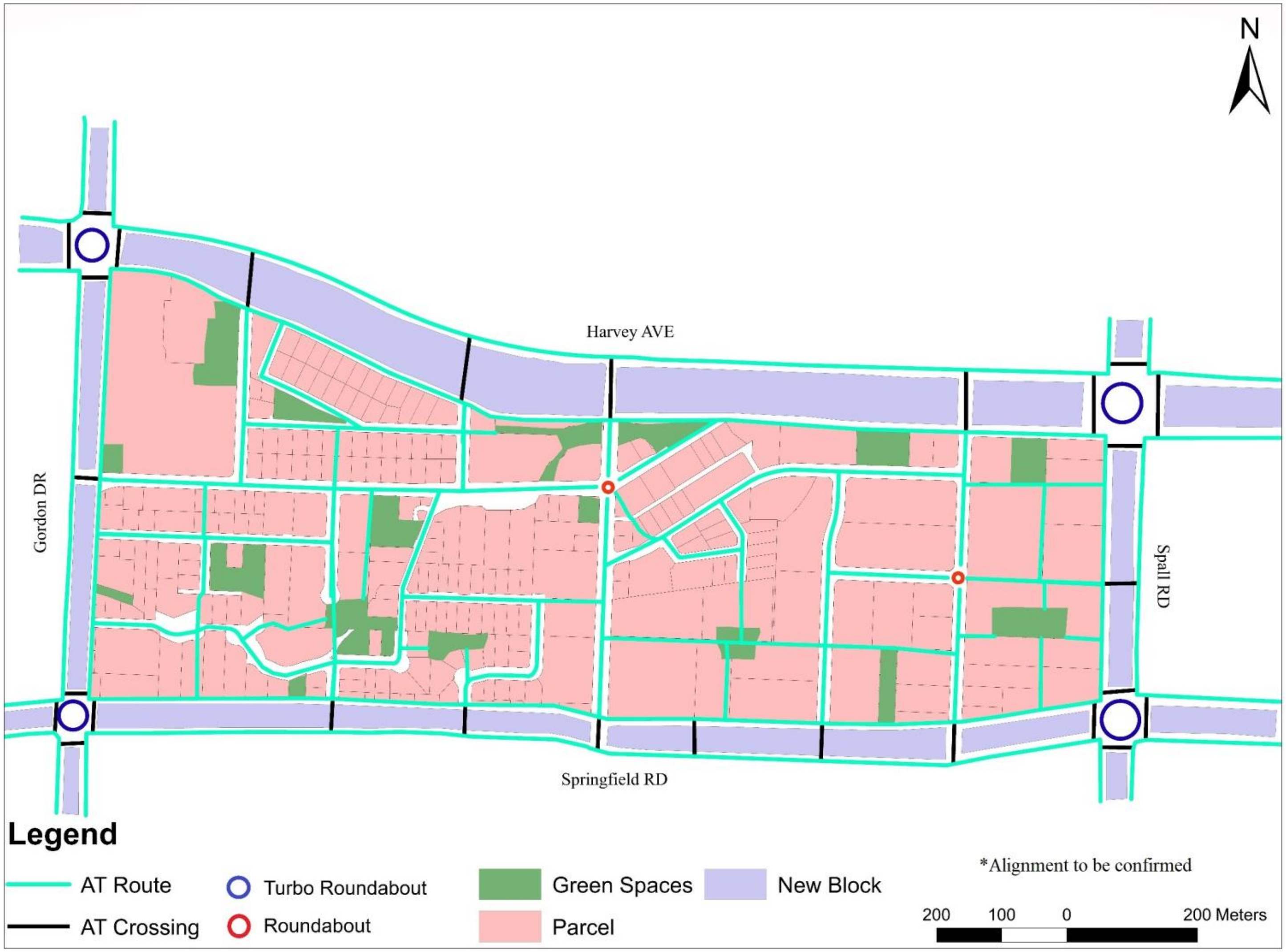


Figure 4-7: SG Active Transportation Network (Capri-Landmark)

The off-road and on-road cycle paths and walkway will facilitate movement and reduce travel time for walking and biking (Masoud, Idris, & Lovegrove, 2019a). The increased AT mobility is also expected to reduce traffic collision between cars and vulnerable road users (i.e. pedestrian and bicyclist) (V. F. Wei & Lovegrove, 2012)

4.2.3 Greenspace

Greenspace is another key component of the SG design. Green spaces do not contribute directly to the traffic safety of residents. However, it was found to be beneficial to the health of the resident living in the neighborhood (Croucher, Myers, & Bretherton, 2008). The green spaces allow people of all age groups and people with a disability to access it and give them a chance to socialize. The green space increases the aesthetic of the area and also provides people a sense of green. The amont of green space in the retrofit drawing was assumed 9 m^2 per person as recommended by the Urban Green Space (UGS) goal for compact and sustainable cities (Russo & Cirella, 2018). The unused lands and brownfields and some of the parking lots were converted to green space to provide the residents with a sense of green. The green spaces were placed in the neighborhood in a way that it was within a minute walking distance (i.e 80-100 meters) from all doors of the neighborhood.

Figure 4-8: Comparison Between Existing and SG Greenspaces

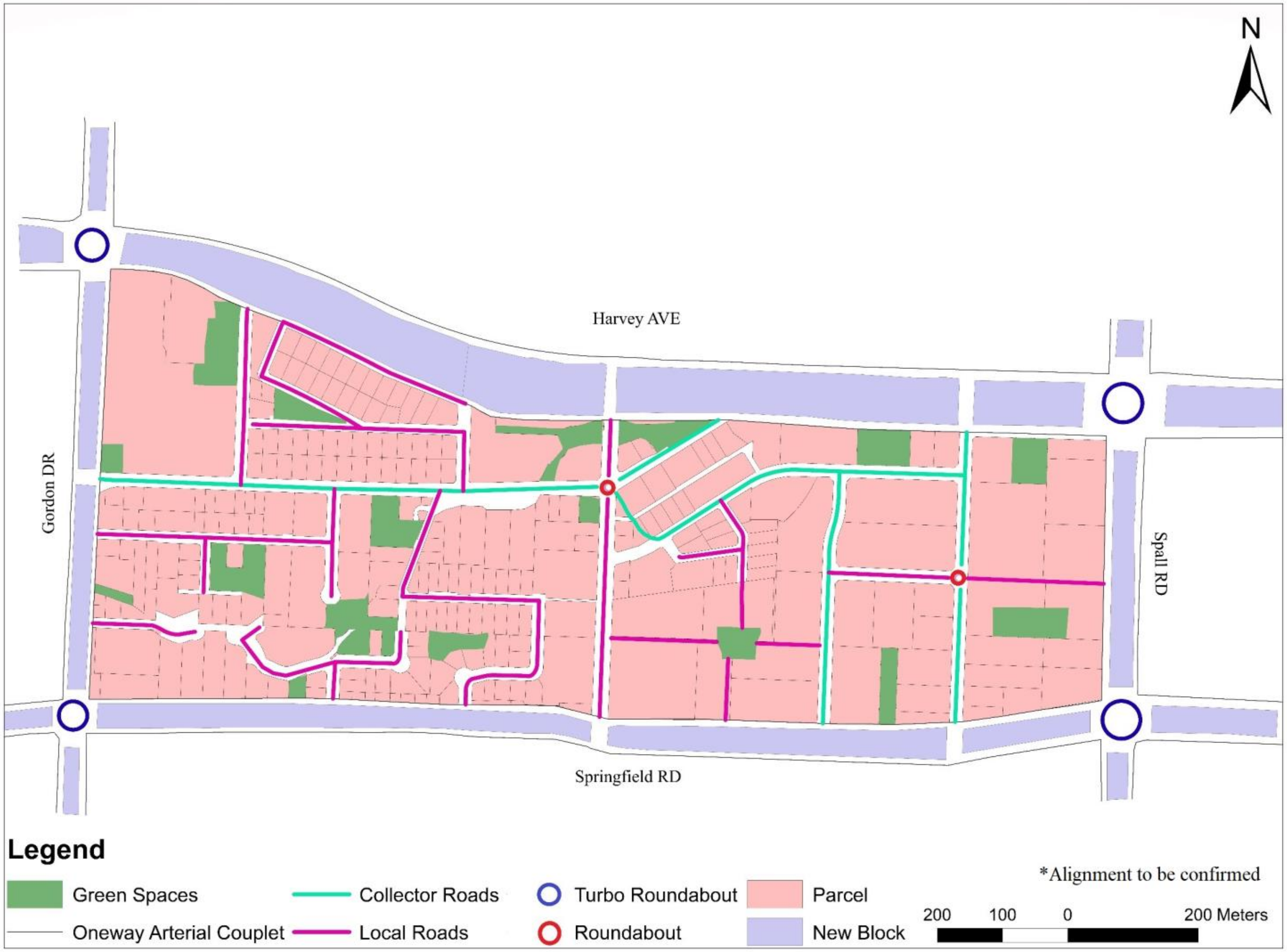


Figure 4-9: SG Greenspaces (Capri-Landmark)

The arterial perimeter couplets were equipped with new block and these new blocks would accommodate more people.

4.2.4 Transit and Parking Policies

Parking in the retrofitted neighborhoods was made to be limited to reduce auto-ownership. Unbundled parking was made mandatory for residential buildings and apartments. Shared parking was also made compulsory for the attraction points and mixed-use buildings so one parking lot can be used by different buildings. On-street parking has been made limited on local and neighborhood roads and a maximum two-hour on-street parking on all roads within 200m of a mixed-use center. The existing bus routes run on the arterial and collector roads only. To maximize coverage of bus routes and bus timing optimization is recommended for future research.

Figure 4-10: Existing Bus routes (Capri-Landmark)

4.2.5 Traffic Safety Evaluation Between Existing and Retrofit Designs

The CPMs developed by Garg (2019), were employed in Capri-Landmark area to assess traffic safety. The data were collected for existing and proposed road networks based on the street network. The CPM showed a significant reduction of traffic collision when roundabouts were constructed at the intersections. The major signalized intersections were replaced with turbo roundabouts to increase capacity, decrease traffic conflicts, and to reduce traffic collision. Based on the street network data the CPM forecasted the number of collisions for each zone. The CPMs showed a positive correlation with population density and employment with the total number of collisions. Increased population density and employment density increased the number of traffic collisions in the new retrofitted neighborhood. The SG principle recommends higher density and employment. The City of Kelowna proposed a detailed urban center plan for Capri-Landmark and the proposed population density is 100 residents/hectare and employment density is 51 jobs /hectare in the neighborhood. Therefore, the population and employment density was projected to be 100 people/ hectare and employment density to be 51 jobs /hectare in the neighborhood to achieve the goal of SG. The construction of a one-way perimeter arterial couplet and replacing four-way signalized intersection with roundabouts showed a greater reduction in a traffic collision. Moreover, by making local roads discontinuous shortcutting of high-speed traffic was discouraged which also improved traffic safety. By comparing the predicted values between the existing and proposed street networks, the CPMs showed an approximately 62% reduction in the total number of collisions for the retrofitted Capri-Landmark neighborhood.

Table 4-2: Collision Prediction for Existing Capri Landmark Neighborhood

Zone Number	Area	TLKM	POPD	EMPD	Core	LLKP	ALKP	SIGD	IRBP
1550	9.08	5.616855	11.67	50.99	9.08	6.026967	93.97303	0.44	0
1560	13.96	6.258289	32.74	44.34	13.96	24.44429	65.78945	0.28	0
1570	45.68	16.78269	11.89	43.34	45.68	2.795654	74.40899	0.13	0
1620	14.45	4.33593	52.32	44.35	14.45	31.57221	49.8249	0.13	0
1630	15.06	4.810343	50	44.35	15.06	27.75318	41.27955	0.06	0

Model 1 (Exposure)	Model 2 (S-D)	Model 3 (TDM)	Model 4 (Network)
Collision Frequency			
9.619608055	35.90679424	0.027521717	72.06056828
10.15842615	21.74799628	0.001014653	29.30828849
16.70102284	128.0260727	6.13431E-13	44.60177515
8.443106323	18.05742594	0.00053883	13.31132802
8.89671185	16.75530119	0.000383338	10.93280111

Table 4-3: Collision Prediction for SG Neighborhood Design for Capri-Landmark

Zone Number	Area	TLKM	POPD	EMPD	Core	LLKP	ALKP	SIGD	IRBP
1550	9.08	5.616855	100	51	9.08	6.026967	93.97303	0	25
1560	13.96	6.258289	100	51	13.96	24.44429	65.78945	0	12.5
1570	45.68	19.60245	100	51	25	7.820156	72.66354	0	21
1620	14.45	4.43933	100	51	14.45	33.16602	48.66439	0	11.11111
1630	15.06	4.708743	100	51	15.06	26.19432	42.17024	0	12.5

Model 1 (Exposure)	Model 2 (S-D)	Model 3 (TDM)	Model 4 (Network)
Collision Frequency			
9.619608055	65.05543471	0.027521717	11.11431441
10.15842615	55.67086119	0.001014653	9.911200574
18.06080925	126.3564289	6.94369E-13	15.43097589
8.54399101	43.06965286	0.000549059	6.445534177
8.80150443	45.00809498	0.000376863	6.203511699

4.3 Application and Evaluation using iThrive

This section evaluates the retrofit designs by applying the iThrive. The components of iThrive are composed of Healthy Development Index (HDI) and Dutch sustainable road safety principles. iThrive is the improved version of HDI. Therefore, in this study, the iThrive tool was applied to evaluate the retrofitted neighborhoods. The iThrive evaluation of the retrofit designs is presented and discussed below:

4.3.1 Density

The population and employment density for the existing Capri-landmark neighborhood were approximately 28 residents/hectare and 41 jobs/hectare in 2013. The SMARTer growth (SG) principle and iThrive support and prescribe higher density in the neighborhood. For the retrofitted designs, the population and employment density of the Capri-Landmark area was assumed to be 100 people/hectare and 51 jobs/hectare respectively for this research. These assumptions were taken from the City of Kelowna 2040 proposed Capri-Landmark's future plan. Based on the population and employment density the Capri-Landmark scored 10 out of 10 in iThrive for the retrofitted neighborhood. For the existing neighborhood, Capri-Landmark scored 1 out of 10 for population and employment density. The evaluation criteria are illustrated in Table 4-4.

Table 4-4 Application of iThrive for Density (Masoud et al., 2015)

Criteria	Credits	Total Credits		Maximum Achievable Credit
		Existing Neighborhood	Retrofitted Neighborhood	
Population Density	35-44 residential people per hectares (1 credit)	1		10
	45-64 residential people per hectares (4 credits)			
	65-84 residential people per hectares (7 credits)			
	85+ residential people per hectares (10 credits)		10	
Floor Area Ratio	FAR = 0.70-0.80 (1 credit)			10
	FAR = 0.81-0.95 (2 credits)			
	FAR = 0.96-1.25 (4 credits)			
	FAR = 1.26-1.75 (6 credits)			
	FAR = 1.76-2.5 (8 credits)	8		
	FAR > 2.5 (10 credits)		10	

For the retrofitted neighborhood, density was assumed to be higher close to the arterial roads to provide proximity to amenities and improved transit services. The existing FAR for the Capri-

Landmark area was 2 and it scored 8 out of 10 in iThrive. The floor area ratio (FAR) in the retrofitted designs were maintained 2.5, as recommended by HDI. Based on the floor area ratio the retrofitted Capri-Landmark scored 10 out of 10 in iThrive. The higher population density in the retrofitted area would decrease trip distance, reduce automobile dependency and support active transportation, transit, and land use diversity (Masoud et al., 2015).

4.3.2 Mixed Land Use and Street Connectivity

Mixed land use and Street connectivity are some of the key elements of SG neighborhood design. The inclusion of mixed land use in the built environment is very crucial in sustainable neighborhood design and included in the design of retrofitted neighborhoods. The mix of different land uses (i.e. residential, commercial, industrial, green spaces) eventually reduces trip distance and makes daily amenities (convenient shops, green spaces, offices, schools, etc.) more accessible to the residents in those areas (Dempsey & Jenks, 2010). In the exiting neighborhood, approximately 1% of the total neighborhood was dedicated to greenspaces and outdoor public spaces. However, in the retrofitted neighborhood the total area dedicated to greenspaces was approximately 9% of the total land area of the Capri-Landmark area. The existing neighborhood was close to the commercial areas and had access to different services (government services, auto shops, restaurants, churches, etc.). The mix of different land uses is considered in the retrofitted neighborhood and most of the daily amenities (convenient shops, bus stop, green spaces, offices, schools, etc.) were placed in such a manner that it would reduce the trip distance and people would be encouraged to walk or bike. The ground floor of the mixed-use buildings and commercial buildings were prescribed to have retail shops and workspaces so people would have more access to these buildings. In the retrofitted neighborhoods, the heterogeneity of land use mix was considered and land use mix is expected to improve active transportation by reducing trip distance.

Table 4-5 Application of iThrive and HDI for Land Use Mix (Masoud et al., 2015)

Criteria	Credits	Total credits		Maximum Achievable Credit
		Existing Neighborhood	Retrofitted Neighborhood	
Heterogeneity of land use mix	≥ 5 % of total community land is outdoor public space (3 points)	0	3	3
	The community provides ≥ 4 new services to an existing neighborhood (within a 1 km radius of the community center) (3 points)	3	3	3
	There is a mix of 3 housing types, 6 different services, a public school, and a park ≥ 0.4/ha within 800m of the community center (5 points)	0	5	5

Criteria	Credits	Total credits		Maximum Achievable Credit
		Existing Neighborhood	Retrofitted Neighborhood	
Heterogeneity of Building mix	≥ 60 % of commercial buildings include a ground floor pedestrian use along ≥ 60 % of their street façades (4 points)	0	4	4
	100 % of mixed-use buildings include ground-floor retail, live/workspaces, or residential dwellings along ≥ 60 % of their street façade (4 points)	0	0	4
	≥ 50 % of multifamily residential buildings have a pedestrian use on the ground floor (4 points)	0	4	4
Mixed housing types	≤ 30 % of housing is large lot detached homes (3 points)	3	3	3
	As above and the community includes ≥ 3 housing types, with none making up less than 20 % of the total residential units (5 points)	0	5	5

Street network in the retrofitted neighborhoods was designed (Figure 4-3) in such a manner to support active transportation and improve residents' proximity to daily amenities and transit services. The street network and active transportation infrastructure in the neighborhoods were constructed to enhance walking and biking and discourage drivers to ride automobiles. Moreover, perimeter one-way arterial couplets were constructed around the retrofitted neighborhoods to decrease traffic conflicts (i.e. left turn maneuver) and improve the aesthetics of the neighborhood. To measure the effectiveness of the on-road and off-road bike route, the route directness was measured. It was calculated by comparing the active transportation route with the vehicular route. The route directness should be lower than one and the lower the value the higher it supports active transportation (Masoud et al., 2015).

$$\text{Route Directness} = \frac{\text{AT Route}}{\text{Vechicle Route}}$$

Table 4-6 Application of iThrive and HDI for Street Connectivity (Masoud et al., 2015)

Criteria	Credits	Total credits		Maximum Achievable Credit
		Existing Neighborhood	Retrofitted Neighborhood	
Active Transportation Route Directness	1-0.95 AT to vehicle Route directness ratio (1 point)	1		10
	0.95-0.90 AT to vehicle Route directness ratio (3 points)			
	0.90-0.85 AT to vehicle Route directness ratio (7 points)		7	
	< 0.85 AT to vehicle Route directness ratio (10 points)			

The route directness for the existing neighborhood was 0.98. The active transportation crossing and on and off-road bike lane increased biking facility and reduced trip distance, resulting in route directness of 0.846 on average in the retrofitted Capri-Landmark area. Based on the street connectivity the retrofitted Capri-Landmark scored 7 out of 10 in iThrive.

4.3.3 Greenspace and Sidewalk Characteristics

In a SMARTer Growth (SG) neighborhood, the green spaces and natural elements are protected to promote the health and quality of life of the residents. In the retrofitted neighborhood, unused lands and brownfields were converted to green space to provide the residents with a sense of green. The green spaces were constructed within 1-minute walking distance (i.e 80-100 meters) radius from houses and can be accessible by people of all age groups. The arterial perimeter couplets were equipped with medians and these medians would be converted as new blocks for the residents and would not allow crossing of vehicles except bikes and emergency vehicles. The green spaces will be equipped with playground equipment and places for individuals or groups to talk and socialize.

Fast-moving traffic, bikes, and pedestrians sharing the same road have some safety concerns and to make the road safer the bike and pedestrians have their separate paths in the retrofitted neighborhoods (Figure 4-7). In the retrofitted neighborhoods the bike paths and sidewalks were constructed in all arterial and collector roads, speed limits for local roads were posted 30 km/h. Self-enforcing traffic calming measures (i.e. roundabouts, speed limit signage, speed humps, buffer strips) were implemented on all roads to discourage shortcutting of fast-moving traffic in the neighborhoods while promoting active transportation in the neighborhoods.

Bike racks, street lamps, side benches, and two-way bike lanes were constructed in the one way arterial couplets and collectors to facilitate biking and walking.

The on-street parking is discouraged on the street and unbundled parking was introduced to reduce auto ownership and infrastructure cost to build more parking lots. On-street parking was only available close to the mixed-use zones and for 2 hours only. The scores for each criteria for the retrofitted neighborhoods have been illustrated in table 4-7.

Table 4-7 Application of iThrive and HDI for Sidewalk Characteristics (Masoud et al., 2015)

Criteria	Credits	Total credits		Maximum Achievable Credit
		Existing Neighborhood	Retrofitted Neighborhood	
Traffic Calming	4-6 traffic calming measures*/hectare (1 credit)			7
	7-10 traffic calming measures*/hectare (3 credits)	3		
	11-13 traffic calming measures*/hectare (5 credits)			
	14+ traffic calming measures*/hectare (7 credits)		7	
Speed Control / Pedestrian Priority	10-19 % of local roads are ≤ 15km/h with ped-priority (1)	0		10
	20-29 % of local roads are ≤ 15km/h with ped-priority (3 credits)		3	
	30-39 % of local roads are ≤ 15km/h with ped-priority (6 credits)			
	≥ 40 % of local roads are ≤ 15km/h with ped-priority(10 credits)			
Sidewalks and buffer strips	Buffer strips with physical barriers all roads ≥ 50km/h (5)	0	5	5

Criteria	Credits	Total credits		Maximum Achievable Credit
		Existing Neighborhood	Retrofitted Neighborhood	
Cycle friendly design	bicycle-priority streets (cars must yield to cyclists; speed ≤ 30km/h) (5 credits)	0	5	5
	streets that are one-way for cars; two-way for cyclists; speed ≤ 30km/h (2 credits)	0	2	2
	cul-de-sacs with bicycle cut-throughs (2 credits)	0	2	2
	advance green lights for cyclists (1 credit)	0	0	1
	off-street pedestrian and cyclist shortcuts (2 credits)	0	2	2
	right-hand turn short cuts for cycles (1 credit)	0	1	1
	1 bicycle rack per ten car parking spots (includes on- and off-street spots) (3 credits)	0	3	3

Criteria	Credits	Total credits		Maximum Achievable Credit
		Existing Neighborhood	Retrofitted Neighborhood	
Lighting	All mixed-use streets have an average luminance of 10 lux, with a minimum of 5 lux(3 credits)	3	3	3
	Provide ≤ 4.6m tall street lamps spaced no more than 30m apart on both sides of 80 % of mixed-use streets (3 credits)	3	3	3
	Provide ≤ 4.6m tall aesthetically-pleasing (artistically-designed) lamp posts on both sides of 100 % of mixed-use 'core' streets (2 credits).	2	2	2
Unbundled & Shared parking	Provide unbundled parking for 50 % of multifamily dwellings (1 credit)	0		7
	Provide unbundled parking for 75 % (5 credits)		5	
	Provide unbundled parking for 100 % (7 credits)			
	Allow shared parking so that parking spaces can count towards the requirements of two separate uses, such as a civic building and a restaurant, or a place of worship and an office building (3 credits).	0	3	3

Criteria	Credits	Total credits		Maximum Achievable Credit
		Existing Neighborhood	Retrofitted Neighborhood	
Parking price and restrictions	Charge the market rate* for off- and on-street parking for all mixed-use and retail streets (4 credits)	0	4	4
	Designated 'Parking Meter Zones' - parking revenues go back to the zone for ped-friendly and aesthetic imp's, such as public art, paving, street furniture, lighting, trees, cleaning, and painting/maintenance (3 credits)	0	3	3
	Variable parking pricing, so that costs increase with the length of stay, or limit the length of stay to ≤ 2 hrs (2 credits)			2
	Max 2-hour on-street parking, or resident-only parking on all streets within 200m of a mixed-use center (2 credits)	0	2	

4.3.4 Transportation Safety Evaluation

The transportation safety evaluation section of iThrive was derived from the Dutch Sustainable Transport Safety Principles. The section is divided into five components and those are functionality, predictability, homogeneity, forgiveness and state awareness.

4.3.4.1 Functionality

The Functionality criteria focuses on classifying the roads according to their traffic function and the cataloging aids in defining road characteristics and layout of the roads. In the retrofitted neighborhoods, the roads are classified as one-way arterial couplet, collector and local roads (Figure 4-3)

4.3.4.2 Predictability

The Predictability criteria focuses on creating foreseeable road environment (i.e. speed, maneuver, etc.) for the road users. This criteria is achieved by providing continuous and consistent unique features of street layout and for each street class in the retrofitted neighborhood (Figure 4-3).

4.3.4.3 Homogeneity

The Homogeneity criteria focuses on achieving homogenous roads by minimizing road users' differences in speed and direction. This criteria is achieved in the retrofitted neighborhood by separating high-speed traffic from low-speed traffic (i.e. bike path) so the severity of collision can be minimized (Figure 4-5).

4.3.4.4 Forgiveness

The Forgiveness criteria focuses on reducing collision on roads. This criteria can be achieved by providing a forgiving road environment which allows for driver error and limits collision probability. The traffic calming measures improved the traffic safety of the neighborhoods and active transportation infrastructure and AT routes improved biking and walking across the neighborhood. By providing traffic calming measure (i.e. roundabouts) and managing speed limits in the retrofitted neighborhood (Figure 4-7) the consequences of driver's error can be avoided.

4.3.4.5 State Awareness

State Awareness focuses on reducing conflict points to reduce the task demand of road users. This criteria focuses on creating improved bicycle facilities that will reduce conflicts between vulnerable road users (i.e. pedestrian and biker) and motorists. In the retrofitted neighborhood the bike paths were separated from high-speed traffic and the arterial roads were converted to one way couplet to reduce conflicts (i.e. left turn maneuver) between vulnerable road users and motorists. The scores for each criteria for the retrofitted neighborhoods were illustrated in table 4-8.

Table 4-8 Application of iThrive and HDI for Transportation Safety Evaluation (Masoud et al., 2015)

Criteria	Credits	Total credits		Maximum Achievable Credit
		Existing Neighborhood	Retrofitted Neighborhood	
Functional Classification	≥ 60% of the roads are categorized based on one function they fulfill (1 credit)			7
	≥ 75% of the roads are categorized based on one function they fulfill (3 credit)	3		
	≥ 90% of the roads are categorized based on one function they fulfill (5 credit)			
	100% of the roads are categorized based on one function they fulfill (7 credit)		7	
Access Management on collector roads	≥ 30-35 access points per km road (1 credit)			5
	≥ 25-30 access points per km road (3 credit)	3		
	≥ 0-20 access points per km road (5 credit)		5	

Criteria	Credits	Total credits		Maximum Achievable Credit
		Existing Neighborhood	Retrofitted Neighborhood	
Distinguishable design characteristics	Road design has at least 1 distinguishable characteristics for differentiating road categories (2 credit)			12
	Road design has at least 2 distinguishable characteristics for differentiating road categories (4 credit)			
	Road design has at least 3 distinguishable characteristics for differentiating road categories (8 credit)	8		
	As above and two of the distinguishable characteristics are either driving direction separation, centerline marking, or intersection design (12 credit)		12	
Homogeneity	0-30 km/h & < 3000 vpd Bike: shared land or bicycle boulevard. Sidewalk: 0-2 (2 credit)	2		4

	30-50 km/h & > 3000 vpd Bike: bike lane in both directions. Sidewalk: 2 (3 credit)			
	≥ 50 km/h & > 3000 vpd Bike: cycle track or buffered bike lane. Sidewalk: 2 (4 credit)		4	
	One-way couplets system on arterial/collector roads. (4 credits)	0	4	4
Forgiving road design measures on collector and arterial roads	≥ 60% of collector and arterial roads have at least one forgiving environment measure (2 credit)	2		12
	≥ 75% of collector and arterial roads have at least one forgiving environment measure (4 credit)			
	≥ 90% of collector and arterial roads have at least one forgiving environment measure (8 credit)			
	≥ 100% of collector and arterial roads have at least one forgiving environment measure (12 credit)		12	
Reducing motorists task demand	≥ 20% of intersections are either 3-way or roundabout (1 credit)	1		7

	≥ 30% of intersections are either 3-way or roundabout (3 credit)			
	≥ 40% of intersections are either 3-way or roundabout (7 credit)		7	

In the existing neighborhood, approximately 80% of the roads were categorized based on their functions and the collector and arterial roads had 28 access points on an average. The arterial roads and collector roads had road centerlines or medians, parking, edge marking and the arterials were equipped with bike lanes. These distinguishable traits were present in the roads to differentiate road class and the bike lane was shared with the bus lane on the main arterial roads (Figure 4-5). However, for the retrofitted neighborhood all the roads were classified based on their function and one-way arterial couplets and roundabouts were introduced to reduce access points on roads to make it safer to cross and access. Green colored two way separate from traffic bike paths were introduced in the arterial and collector roads to improve mobility by active transportation (Figure 4-5). Based on the design criteria the retrofitted neighborhood scored higher in all the categories of transport safety evaluation.

4.4 Application and Evaluation using Healthy Built Environment Linkages Toolkit

The Healthy Built Environment Linkages Toolkit doesn't have an application interface. However, the developer of this toolkit has discussed several outcomes of improving the built environment components and the impact of the built environment on health and well-being to create more liveable communities (BC Centre for Disease Control, 2018). The aim of the toolkit is to link community design, planning, and health together. The toolkit is composed of five physical components of the built environment. Based on the evidence and data, impacts on the built environment and health outcomes were discussed. The toolkit was applied to evaluate the SMARTer Growth neighborhood design and based on the similarity of principles, the possible outcomes were discussed in this chapter. Evidence is still emerging in these areas, and future reviews could consider looking more systematically at all of these concepts. The built environment components of the toolkit were evaluated and given below:

4.4.1 Healthy Neighborhood Design

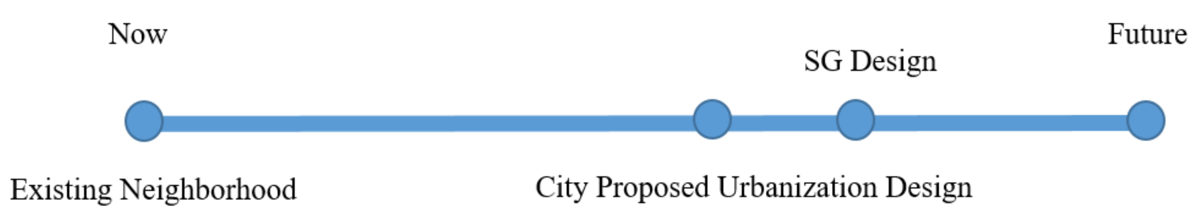
The toolkit discusses the planning principle of building healthy neighborhoods. The SMARTer growth (SG) retrofitted neighborhoods would improve neighborhood walkability, mixed land use and improve connectivity in between neighborhoods. The toolkit discussed the outcomes of improving mixed land use development and the street connectivity for building Healthy Neighborhood. The outcome showed, the inclusion of mixed land use and improvement of street connectivity improves the accessibility of the residents to parks, green spaces, and daily amenities and improves walkability, outdoor air quality, general health, respiratory health, walkability, cycling, economic co-benefits, healthy weights, physical activity, and social well-being. Moreover, it reduces collision, stress and noise exposure (BC Centre for Disease Control, 2018).

In the retrofit SG design the mixed land use and human-scale design with improved active transportation network and oneway streets would improve street connectivity and accessibility of the residents. The SG design would have the similar outcomes of healthy neighborhood design.

4.4.2 Healthy Transportation Networks

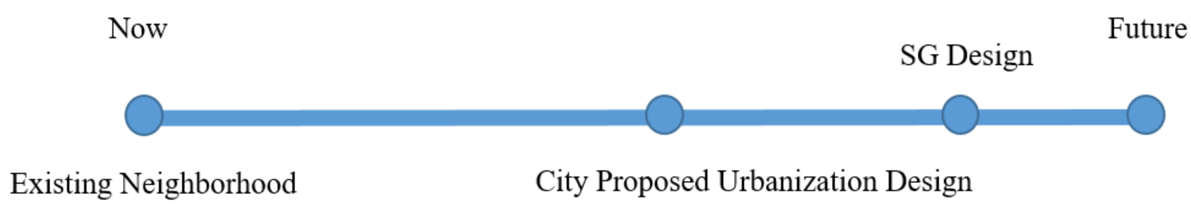
The aim of the toolkit is to help planners and engineers create a safe and accessible transportation system. The system will combine different modes of transportation to create diversity and focuses on promoting active transportation while reducing automobile dependency. The principle of SMARTer growth (SG) neighborhood design and the principle of building healthy transportation networks align together. The toolkit suggested promoting active transport and improving mobility in the neighborhood, improves outdoor air quality, traffic safety, transit use, and walkability. Moreover, it reduces noise exposure, premature mortality, unintentional injury, and stress (BC Centre for Disease Control, 2018).

In the retrofit SG design the improved active transportation network, bicycle paths and oneway streets would improve street connectivity and accessibility of the residents. Moreover, it would make the street network more safer in terms of traffic safety. The SG design transportation network would also allow different modes of transportation and would reduce VKT in the neighborhood. The SG design would have the similar outcomes of Healthy Transportation Networks.



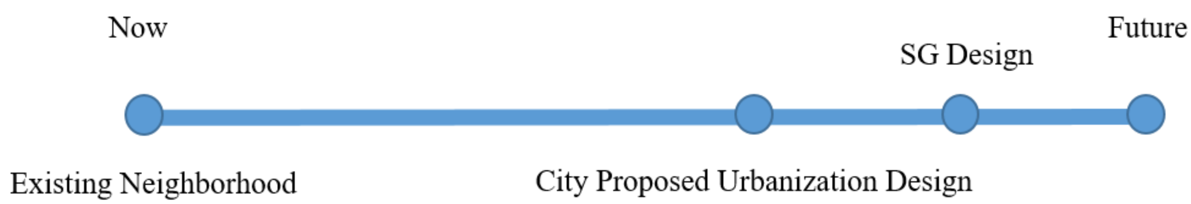
4.4.3 Healthy Natural Environments

The toolkit focuses on preserving green space and environmentally sensitive areas. The toolkit suggests preserving greenspaces in the retrofitted neighborhood, improves air quality, urban greening, mental health, depression regulation, and social well being. Moreover, it reduces noise exposure and stress (BC Centre for Disease Control, 2018). The SG design provide green spaces in the neighborhoods and allow all ages of people to access green spaces. It maximizes the opportunity to involve nature and mitigate the urban heat island effect. These greenspaces in the SG design would reduce noise pollution, improve air quality and mental health.



4.4.4 Healthy Housing

The toolkit discusses on housing affordability. SG design recommended higher population and employment density in the community and mixed land use. It would reduce the land required for building roads and would allocate those lands by building more and diverse houses. This would make housing more affordable and would help the neighborhoods achieving housing affordability goals. The housing affordability in the SG design would increase access to good quality housing, improve indoor air quality, sense of safety and reduce crime (BC Centre for Disease Control, 2018).



4.5 Application and Evaluation using Envision

The Envision sustainability rating system (Envision, 2016) was applied to the retrofitted neighborhood designs to examine if they met the United Nations Sustainable Development Goals (UN SDG) set up by Envision. Envision supports sustainable choices in infrastructure and has different sustainability matrices to evaluate a project. Envision rating system interface has several questions on different sustainability criteria and based on the question-answer it gives the score to each criteria. Based on the total score different projects can be compared whether these will meet the sustainability goals in the future. However, Envision doesn't prescribe how these criteria will be met by the project. Envision has 60 sustainability criteria and these are categorized into 5 groups, results of Envision application are following:

4.5.1 Quality of Life

Quality of life in the retrofitted neighborhoods was evaluated using the Envision rating system. Quality of life addressed the impacts of the retrofitted neighborhoods on the communities and individuals. Moreover, it evaluated whether retrofitted neighborhoods meet community goals (i.e. sustainability, growth, public health and safety, accessibility, and mobility) and benefit communities. The retrofitted Capri-Landmark will improve quality of life by reducing negative impacts on the host and nearby communities), promoting sustainable growth (i.e. improving local employment, making the neighborhood more attractive to people and businesses), improving public health and safety, improving accessibility and mobility, and developing alternative modes of transportation. The criteria were applied at the retrofitted neighborhoods and the retrofitted Capri-Landmark neighborhood scored 25. The maximum achievable score was 26 in Envision for Quality of Life. The assessment results have been illustrated in Appendix A.1.

4.5.2 Leadership

Building sustainable neighborhoods require a new way of thinking. To build a sustainable neighborhood, planners, engineers, clients, and stakeholders need to collaborate together to create ideas and understand the long term initiatives which need to be implemented to achieve the goals. The Leadership criteria aim at reducing energy consumption and usage of water by providing effective and collaborative leadership and building a new sustainable community. Moreover, these criteria ask for collaboration, management, and planning in the projects and include decisions and opinions of different stakeholders for future innovation. The retrofitted Capri-Landmark will form a sustainability management system and eliminate conflicting design elements to promote sustainability across the neighborhood to reach sustainability goals. The maximum achievable score was 19 in Envision for Leadership. The retrofitted neighborhoods scored 19 for Leadership. The assessment results have been illustrated in Appendix A.2.

4.5.3 Resource Allocation

Resources are required to build a community. This criteria discusses three types of resources, including materials, energy, and water. This criteria is concerned with the resources and their impact on the sustainability of building the project. The resources are limited and minimizing the total amount of materials used in a project , is a major concern for building retrofitted neighborhoods. To build the retrofitted neighborhoods, the building materials would be used in a balanced manner considering safety, stability, and durability. The energy sources are limited and for the project, the use of renewable energy would be encouraged. The improved active transportation infrastructure and discontinuous streets would reduce the number of automobiles on the street and eventually would reduce the consumption of fossil fuel. To build the retrofitted neighborhoods recycled materials would be used where possible. The maximum achievable score was 14 in Envision for Resource Allocation. The retrofitted neighborhoods scored 10 for Resource Allocation. The assessment results have been illustrated in Appendix A.3.

4.5.4 Natural World

Building a community has an impact on the natural world they surround. Unwanted impacts may be caused if the community is located close to natural habitat and it might unbalance the natural system around them. This criteria asks for minimizing the unwanted adverse impacts on the natural system caused by a new infrastructure or a community. The retrofitted neighborhoods were shaped in such a manner that it didn’t affect the ecological site where there are diversity of habitats and had water bodies or wetlands. This criteria also asks for minimizing adverse effects on existing hydrologic, nutrient cycles and preserving floodplain functions, preserving Greenspaces and preventing surface and groundwater flow. The maximum achievable score was 26 in Envision for Natural World. The retrofitted neighborhoods scored 25. The assessment results have been illustrated in Appendix A.4.

4.5.5 Climate and Risk

Climate and risk aim to minimize GHG emissions and to ensure resiliency in the infrastructure. This criteria focuses on the reduction of harmful gases and GHG emissions during the project life cycle. Moreover, it focuses on improving the infrastructure's ability to endure sudden flooding or fire and minimizing the weakness of the structure. The improved adaptability of the infrastructure contributes to improving the useful life of the infrastructure to meet the future goals of the community. The retrofitted neighborhoods will reduce automobile dependency and also introduce clean energy in different transportation modes that would reduce GHG emissions. The maximum achievable score was 10 in Envision for Natural World. The retrofitted neighborhoods scored 7 for Climate and Risk. The assessment results have been illustrated in Appendix A.5.

4.6 Walkability

After calculating the values of each variables the walkability was measured. The existing neighborhood scored 3.48 and the SMARTer growth (SG) neighborhood scored 4.20. The SMARTer growth (SG) neighborhood was 21% more walkable in comparison to the existing neighborhood.

4.7 Bikeability

Winters et al. (2013) introduced the scoring criteria and method. The maximum score for each components was 10 and the minimum was 0. Based on the distance of bicycle routes the score was given to each zone. The bicycle route separation score was measures based on the availability of bike paths. The connectivity of bicycle-friendly streets was calculated based on the number of intersections and topography was measured based on the digital elevation model. The destination density was measured based on the number of bicycle-friendly destination. The scores for each of the variable was placed in the equation to measure the total score for the zone. The existing Capri-Landmark scored 25 and the retrofitted SMARTer Growth (SG) neighborhood scored 41 on Bikeability index. The SMARTer growth (SG) neighborhood was 64% more bikeable in comparison to the existing neighborhood.

4.8 Playability

In the retrofitted SMARTer Growth (SG) neighborhood the residential density would be higher than the existing neighborhood and the mix of land use would reduce the proximity to school or any other amenities. The improved street connectivity and pedestrian and biker friendly roads across the SG neighborhood would improve Playability of the neighborhood.

4.9 Ecological Footprint

In the retrofitted Capri-Landmark neighborhood the land use mix would reduce the trip distance between different amenities and services and reduce VKT. The increased employment and population density would make it more effective to invest in infrastructure and in transit services and would reduce per capita ecological footprint.

4.10 Transport Equity

In the retrofit SG neighborhood for Capri-Landmark, the trip distances were reduced by increasing mixed land use and increasing population density. The decreased trip distance reduces VKT and improves overall pedestrian and biker mobility, accessibility, and ridership of public transit.

Moreover, the retrofitted neighborhood is expected to improve housing affordability by providing more and different housing options. The neighborhood would accommodate people with disabilities and other special needs by providing universally accessible sidewalks, road crossings, and improve the economic opportunities and development of the area.

4.11 Universal Accessibility

In the retrofit SG design universally accessible sidewalks and road crossings would be provided at the oneway perimeter couple and at collector roads. Moreover, benches and bike racks would be provided at all the sidewalks and disabled parking would be available in front of all the amenities so people with disability could access those places.

4.12 Air Quality

In the retrofitted Capri-Landmark area the density is higher and the area is traffic-calmed. The traffic-calmed neighborhood might increase the idling time of the vehicle but as the land use mix will be increased and more amenities will be available within a short distance, which will eventually reduce the trip distance and number of cars on the roads. The increased density will also make transit more effective resulting in less emission per capita. Moreover, the one-way arterial couplet is parallel to each other which is also supposed to decrease GHG emission by reducing number of automobiles from roads.

4.13 Noise

In the retrofitted Capri-Landmark area the higher density and the mix of land use would reduce the noise exposure in the neighborhood. The retrofitted neighborhood would accommodate and offer multi-transport modes which would reduce automobile use and make transit more popular and user-friendly. The greenspaces in the neighborhood would be located not more than 400 m from any location of the neighborhood. The retrofitted neighborhood would be less exposed to noise pollution as greenspaces reduce the susceptibility of noise (Dzhambov & Dimitrova, 2015; Margaritis & Kang, 2017) and improve the quality of life of the residents.

4.14 Summary

This chapter summarizes the development of the retrofit SG design and the application of different SMARTer growth (SG) design tools for Capri-Landmark neighborhood in Kelowna, BC, Canada. The development of the retrofit design and the traffic safety evaluation was presented in section 4.2. The retrofitted neighborhood was found to be 62% safer than the existing neighborhood in the traffic safety evaluation. The traffic safety was assessed using the CPM model. The CPM model evaluated the exposure, socio-demographic, network and transportation demand management aspects of the neighborhood to evaluate safety. The results suggest changing different components of the street network, replacing the signalized intersection with turbo roundabout and four-way intersections with roundabout reduced collision the most. The tools were applied to the retrofitted neighborhood to assess the different aspects offered in a SMARTer growth (SG) neighborhood design. The health aspects were evaluated in iThrive, and Healthy Built Environment Linkages Toolkit and the probable health outcomes were also discussed. The iThrive scored the existing and retrofit neighborhood whereas Healthy Built Environment Linkages Toolkit discussed the possible outcomes of the retrofit design based on the literature. The Envision sustainable infrastructure rating system was applied to the retrofit SG design to measure different sustainability criteria in the project. The five criteria for Envision were discussed and the total score for each criteria was measured for the retrofit SG design and was presented in Section 4.3, 4.4 and 4.5. The walkability and bikeability were measured in Section 4.6 and 4.7. Walkability was measured based on the land use mix, destination density and road network facilities available and bikeability was measured based on the topography and active transportation infrastructure. Playability, Ecological footprint, Transport Equity, Universal Accessibility, Air Quality, and Noise were evaluated based on the literature available. The tools could not be quantified due to insufficient data and unavailability of application interface or model to evaluate. The literature looked for the possible ways to improve the criteria based on the SMARTer growth (SG) Neighborhood principle and how the design would improve the criteria was shown.

Chapter 5: Application of SMARTer Growth Design Manual to Design to Develop Retrofit Neighborhood Design for Gulshan, Bangladesh

5.1 Overview

Designing a SMARTer Growth (SG) neighborhood design requires consideration of different components of the built environment. The built environment components are inter-related and the impacts or outcomes depend on two or more components working together. Previous researchers had developed a suite of tools to assess the outcomes and different prospects of life of residents in a neighborhood. The tools have been discussed in the literature review (Section 2.4) and summarized in Table 4-1. The system based analysis and application of these tools for a neighborhood in Kelowna and their outcomes has been presented in this chapter. Moreover, the development of the retrofitted neighborhood design for Gulshan, Dhaka has been discussed in this chapter.

This chapter is composed of fourteen main sections. Section 5.2 describes the development of the retrofit design for Gulshan neighborhood, Dhaka and the design of each component of the design is described in detail. Section 5.3 presents the application and evaluation of iThrive. Section 5.4 and 5.5 illustrate the application and evaluation using Healthy Built Environment Linkages Toolkit and Envision respectively. Section 5.6 to 5.13 respectively discuss the walkability, bikeability, playability, ecological footprint, transport equity, universal accessibility, air quality, and noise. Section 5.14 presents a discussion of this chapter.

5.2 Development of Retrofit Design for Gulshan Neighborhood

The Gulshan area in Dhaka was selected for this study to apply the SG principles and to retrofit the existing neighborhood. Gulshan is one of the central business districts of Dhaka and one of the major employment hubs and housing locations in Dhaka. The Gulshan was chosen to be the study location based on the considerations. The NB models were employed to evaluate the traffic safety of the existing neighborhood which is discussed in Chapter 3.

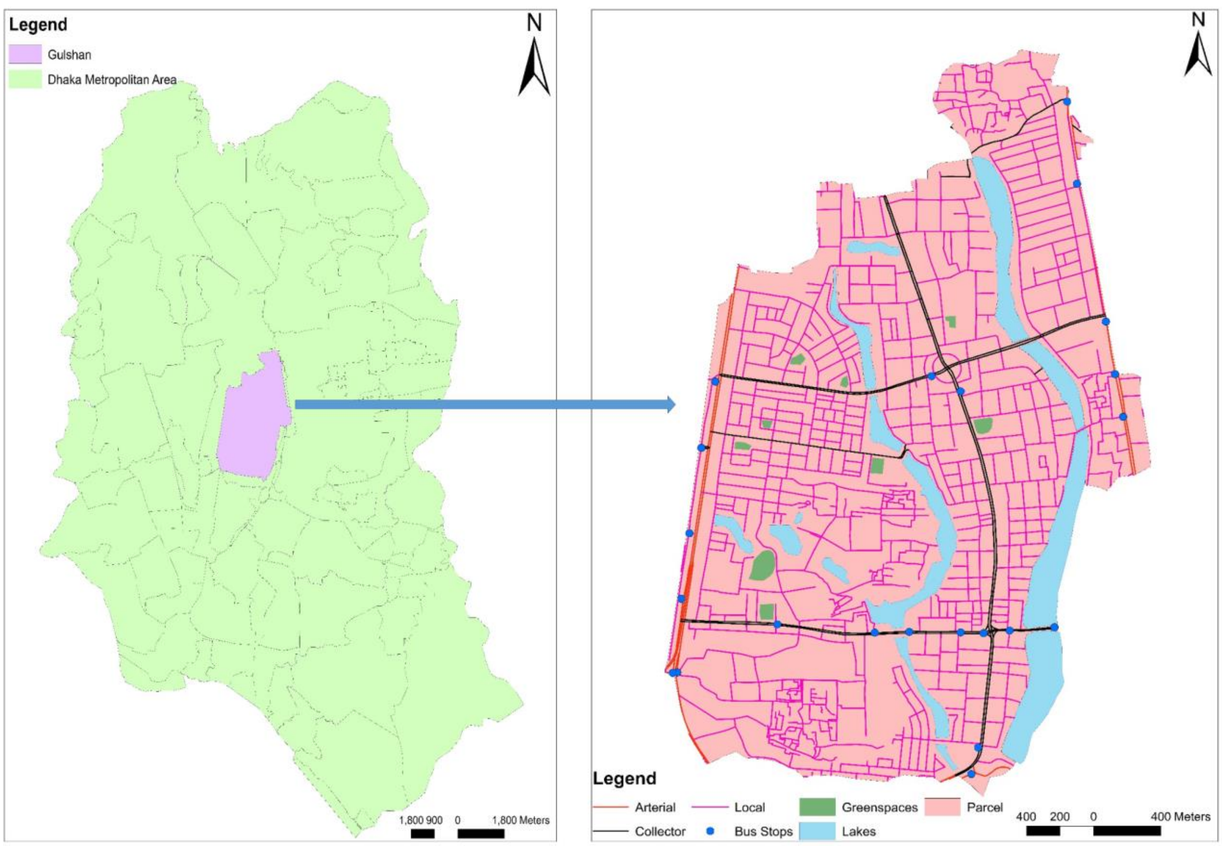


Figure 5-1: Location of Gulshan

There were three TAZs in the existing neighborhood plan. Each TAZs were retrofitted according to the principle of SG and the best features of the existing and the proposed plan were retained in the new design which helps in achieving goals of SG. The design components and consideration for the area are discussed below.

5.2.1 Street Network

Street network is considered as one of the major components of SMARTer Growth (SG) neighborhood design. In the retrofitted Gulshan neighborhood, based on the SG principle the major arterial was converted to one way perimeter arterial couplet to decrease conflicts between traffics (Figure 5-3). Medians were converted to new blocks and neighborhood roads were made discontinuous to reduce shortcutting and high speed across neighborhoods.

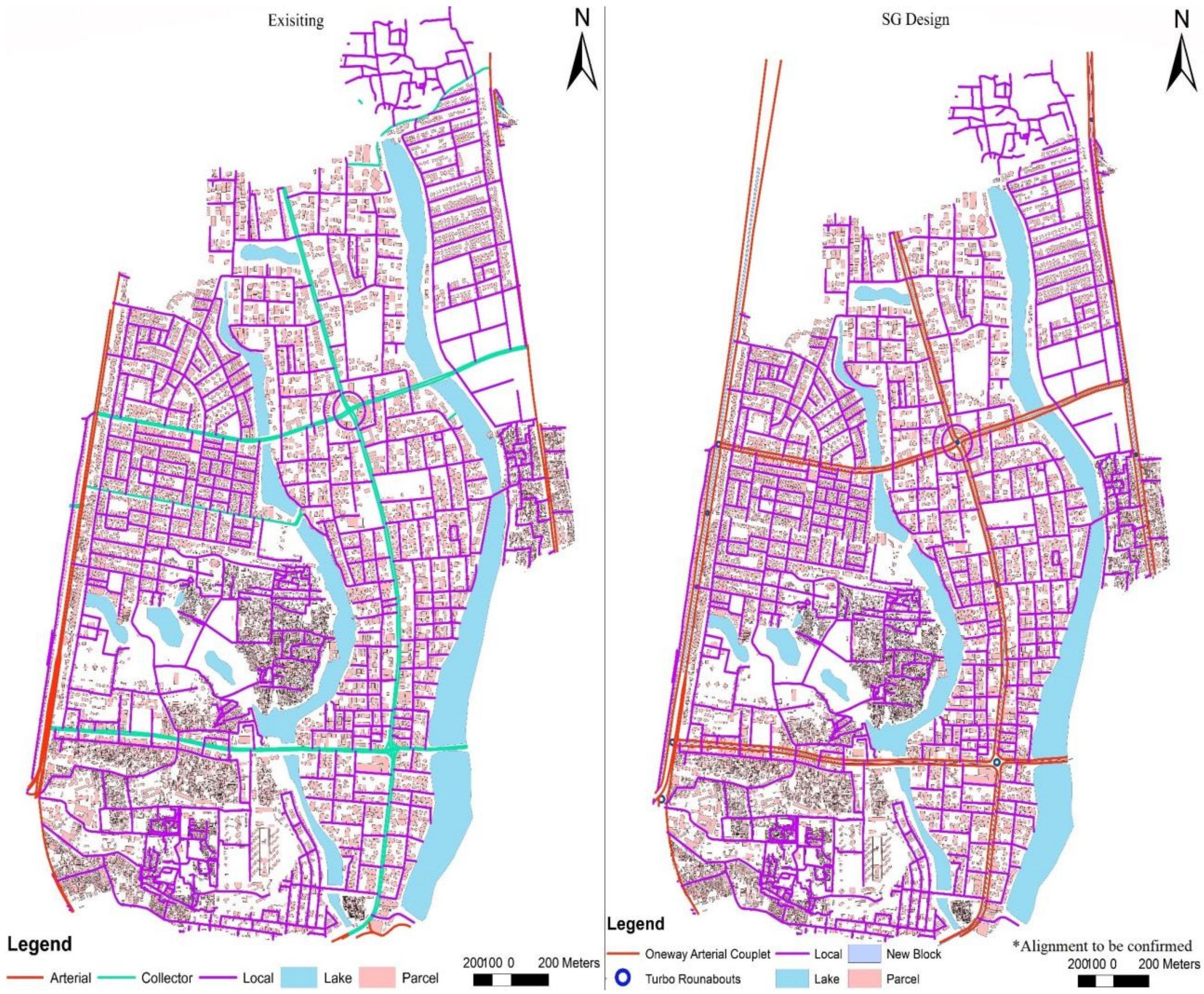


Figure 5-2: Comparison Between Existing and Proposed Road Network

Rodegerdts et al. (2007) suggest roundabout reduces approximately 78% traffic conflicts and improves the overall traffic safety at the intersection in contrast to signalized roundabouts. The major signalized intersections were replaced with turbo roundabouts to increase capacity, decrease traffic conflicts, and to reduce traffic collision.

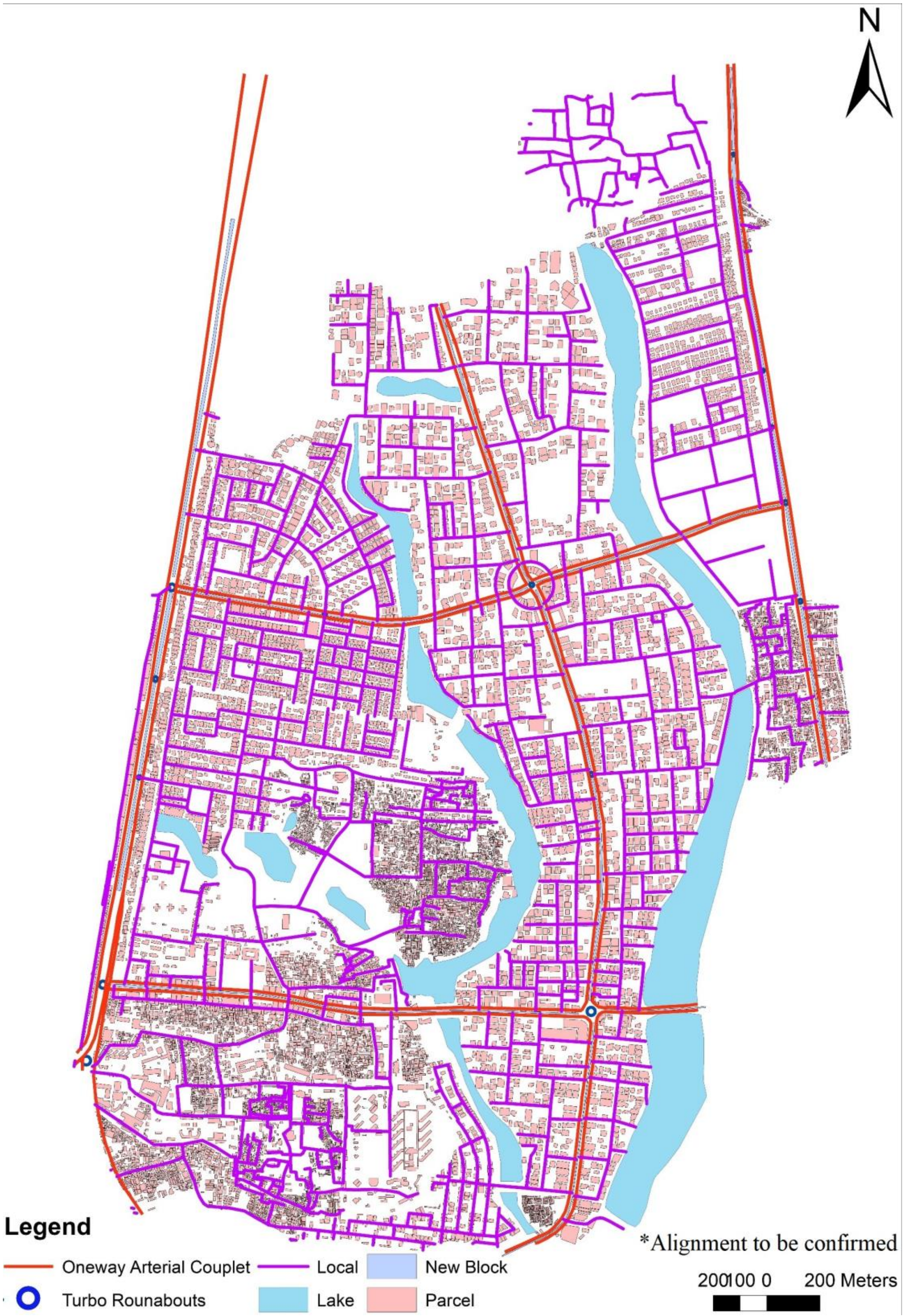


Figure 5-3: SG Road Network (Gulshan)

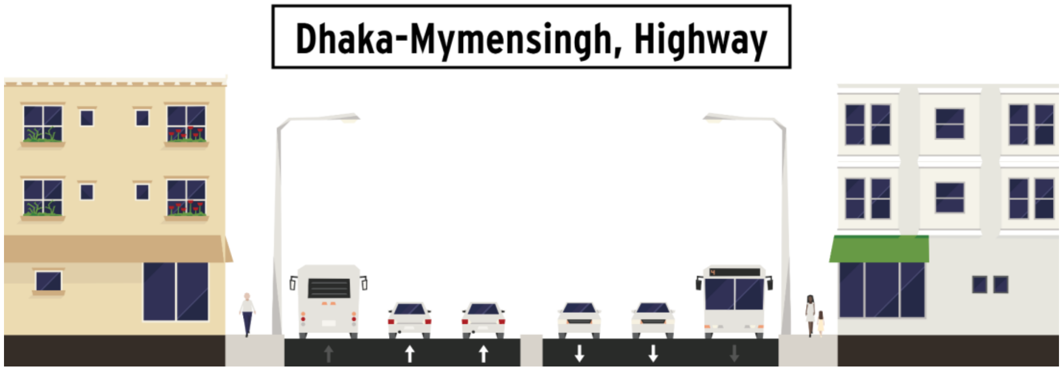


Figure 5-4: Existing Road Network Cross-Section

Figure 5-5: SG One-way Arterial Couplet

5.2.2 Active Transportation Network

The active transportation infrastructure depends on the availability of sidewalks and cycling infrastructure (i.e. cycle paths, bike racks). There is no exisiting active transportation infrastructure in Dhaka, Bangladesh. To separate the fast-moving traffic from bikers and pedestrians, bike lanes and pedestrian sidewalk will be constructed in all arterial and collector roads in Gulshan. The speed limit for local roads were limited to 30 km/h and the off-road biking and walkway was constructed in the neighborhood to reduce trip distance by walking and biking across the neighborhood. Bike parking facilities and benches will be installed in front of mixed-use zones to promote biking and walking to those areas. Underpass would be installed in the active transportation crossing to facilitate pedestrian and bicycle movement.

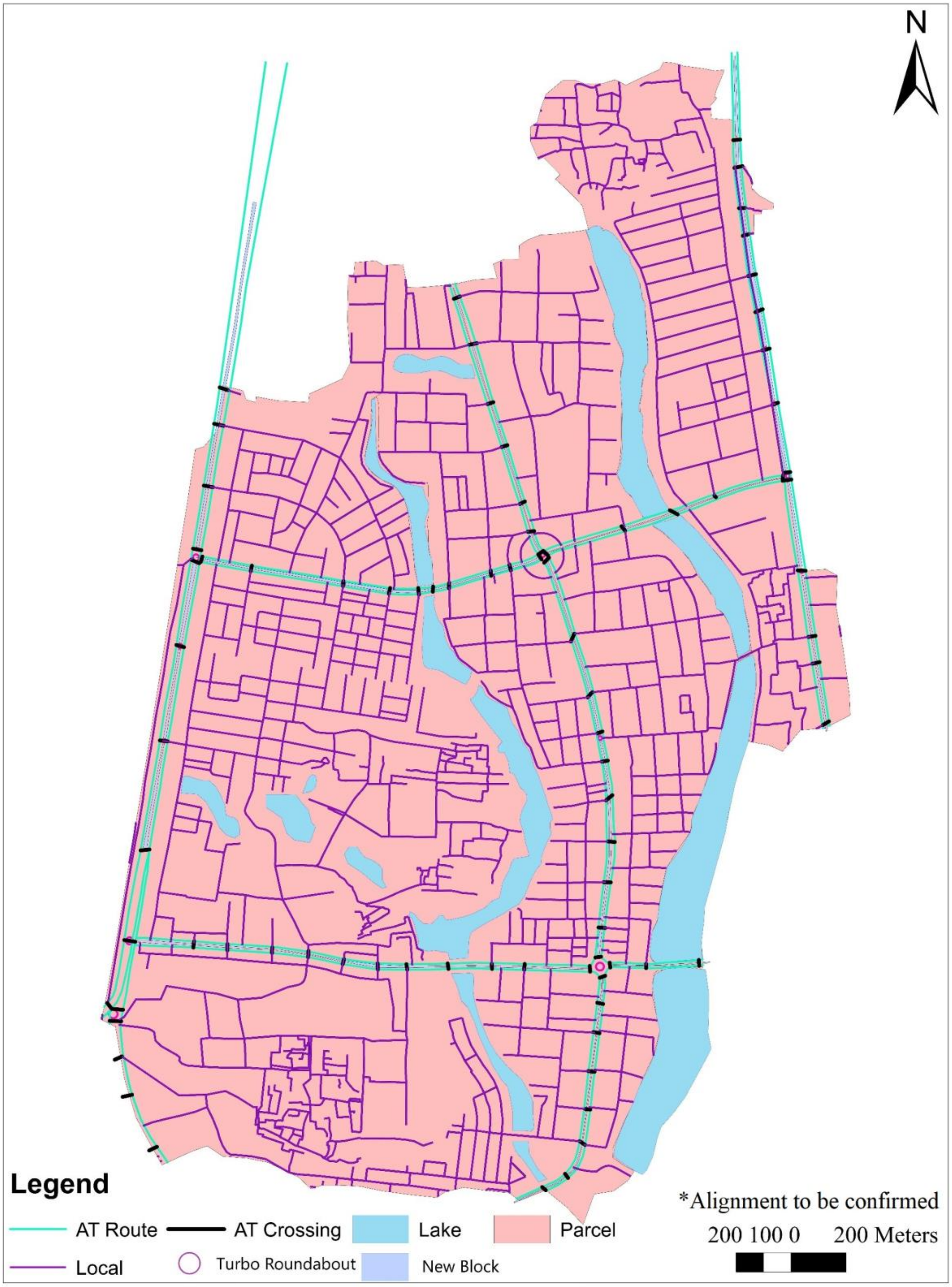


Figure 5-6: SG Active Transportation Network (Gulshan)

The off-road and on-road cycle paths and walkway will facilitate movement and reduce travel time for walking and biking (Masoud et al., 2019a). The increased AT mobility is also expected to reduce traffic collision between cars and vulnerable road users (i.e. pedestrian and bicyclist) (V. F. Wei & Lovegrove, 2012)

5.2.3 Greenspace

Greenspace is another key component of the SG design. Green spaces do not contribute directly to the traffic safety of residents. However, it was found to be beneficial to the health of the resident living close to the area (Croucher, Myers, & Bretherton, 2008). The green spaces allow people of all age groups and people with a disability to access it and give them a chance to socialize. The green space increases the aesthetic of the area and also provides people a sense of green. The percentage of green space in the retrofit drawing was assumed 9 m^2 per person based on the urban green space (UGS) goal for compact and sustainable cities (Russo & Cirella, 2018). The unused lands and brownfields and some of the parking lots were converted to green space to provide the residents with a sense of green. The lakesides would be also considered as greenspaces for Gulshan. There was insufficient space to build new greenspaces in Gulshan, Dhaka. However, the rooftop of the mixed-used buildings and residents could be developed as a greenspace. To improve the greenspaces on the rooftop, the Dhaka City Corporation also introduced a tax rebate that'll encourage people to develop greenspaces on the rooftop (Jahan, 2016).The green spaces were located in the middle of the quadrants (400m * 400m grid) of the neighborhoods to make the greenspaces more accessible by within 1-minute walking distance (i.e 80-100 meters).

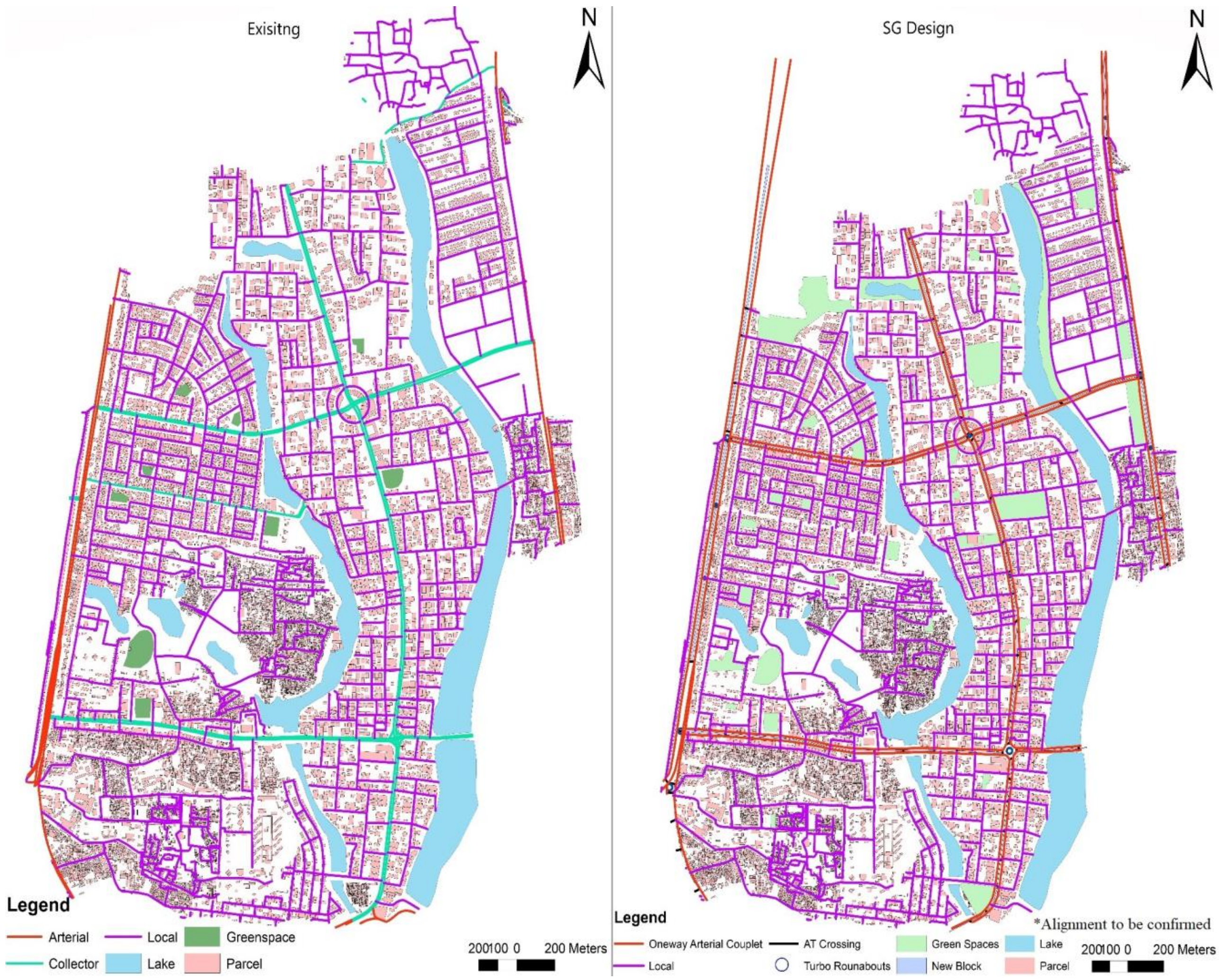


Figure 5-7: Comparison Between Existing and SG Greenspaces

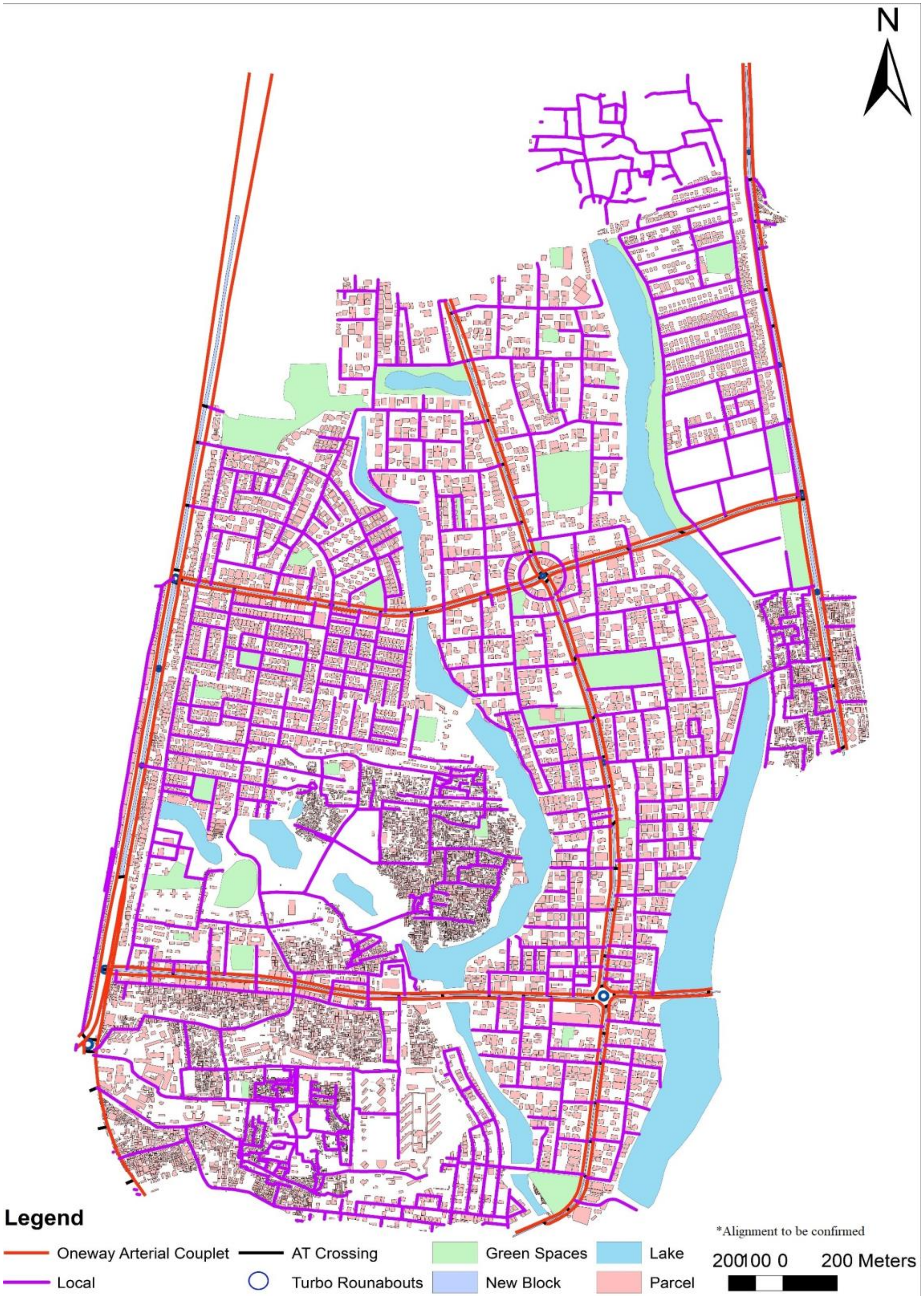


Figure 5-8: SG Greenspaces (Gulshan)

The arterial perimeter couplets were equipped with medians and these medians were converted to work as a new block for the residents.

5.2.4 Transit and Parking Policies

Parking in the retrofitted neighborhoods was made to be limited to reduce auto-ownership. Unbundled parking was made mandatory for residential buildings and apartments. Shared parking was also made compulsory for the attraction points and mixed-use buildings so one parking lot can be used by different buildings. On-street parking has been made limited on local and neighborhood roads and a maximum two-hour on-street parking on all roads within 200m of a mixed-use center. The existing bus routes run on the arterial and collector roads only. To maximize coverage of bus routes and bus timing optimization is recommended for future research.

5.2.5 Traffic Safety Evaluation Between Existing and Retrofitted Neighborhoods

The CPMs were employed in Gulshan area to assess traffic safety. The data were collected for existing and proposed road networks based on the street network. The CPM showed a significant reduction of traffic collision when roundabouts were constructed at the intersections. The major signalized intersections were replaced with turbo roundabouts to increase capacity, decrease traffic conflicts, and to reduce traffic collision. Based on the street network data the CPM forecasted the number of collisions for each zone. The CPMs showed a positive correlation with population density and employment with the total number of collisions. Increased population density and employment density increased the number of traffic collisions in the new retrofitted neighborhood. The SG principle demands higher density and employment. Gulshan had a very high population and employment density. Therefore, the population and employment density was unchanged in this research. The construction of one-way perimeter arterial couplet and replacing four-way signalized intersection with roundabouts showed a greater reduction in a traffic collision. In Gulshan most of the local roads are narrow and do not allow shortcutting of the car. By comparing the predicted values between the existing and proposed street networks, the CPMs showed an approximately 56% reduction in the total number of collisions for the retrofitted Gulshan neighborhood.

Table 5-1: Collision Prediction for Existing Gulshan Neighborhood

Zone Number	Area	TLKM	POPD	EMPD	Core	INTD	RB
1	613.76	173.33	298.43	154.35	600.80854374900	0.30142116	1
84	129.14	50.17	298.43	154.35	120.15069963800	0.301998342	1
88	55.03	28.44	298.44	154.34	51.54759109040	0.290768987	1

Model 1 (Exposure)	Model 2 (S-D)	Model 3 (TDM)	Model 4 (Network)
Collision Frequency			
43.69820578	54.19403524	386.7960674	15.40681751
18.39344201	25.72617903	178.8334951	7.783427721
12.37508113	18.28845085	107.9428694	5.663433517

Table 5-2: Collision Prediction for SG Neighborhood Design for Gulshan, Dhaka

Zone Number	Area	TLKM	POPD	EMPD	Core	INTD	RB
1	613.76	173.33	298.43	154.35	600.80854374900	0.30142116	1
84	129.14	50.17	298.43	154.35	120.15069963800	0.301998342	1
88	55.03	28.44	298.44	154.34	51.54759109040	0.290768987	1

Model 1 (Exposure)	Model 2 (S-D)	Model 3 (TDM)	Model 4 (Network)
Collision Frequency			
43.69820578	54.19403524	386.7960674	1.712487811
18.39344201	25.72617903	178.8334951	3.931050641
12.37508113	18.28845085	107.9428694	3.960256674

5.3 Application and Evaluation using iThrive

This section evaluates the retrofit designs by applying the iThrive. The components of iThrive are composed of Healthy Development Index (HDI) and Dutch sustainable road safety principles. iThrive is the improved version of HDI. Therefore, in this study, the iThrive tool was applied to evaluate the retrofitted neighborhoods. The iThrive evaluation of the retrofit designs is presented and discussed below:

5.3.1 Density

The population and employment density for Gulshan neighborhood were approximately 300 residents/hectare and 155 jobs/hectare in 2011. The SMARTer growth (SG) principle and iThrive support and prescribe higher density in the neighborhood. as the population and employment density is 11 times higher compared to Capri-Landmark, for the retrofitted designs, the population and employment density of the Gulshan area was assumed to be unchanged (i.e. population density = 300 residents/hectare and employment density = 155 jobs/hectare) for this research. Based on the population and employment density the Gulshan scored 10 out of 10 in iThrive for both the existing and the retrofitted neighborhood. The evaluation criteria are illustrated in Table 5-3

.

Table 5-3 Application of iThrive for Density (Masoud et al., 2015)

Criteria	Credits	Total Credits		Maximum Achievable Credit
		Existing Neighborhood	Retrofitted Neighborhood	
Population Density	35-44 residential people per hectares (1 credit)			10
	45-64 residential people per hectares (4 credits)			
	65-84 residential people per hectares (7 credits)			
	85+ residential people per hectares (10 credits)	10	10	
Floor Area Ratio	FAR = 0.70-0.80 (1 credit)			10
	FAR = 0.81-0.95 (2 credits)			
	FAR = 0.96-1.25 (4 credits)			
	FAR = 1.26-1.75 (6 credits)			
	FAR = 1.76-2.5 (8 credits)			
	FAR > 2.5 (10 credits)	10	10	

For the retrofitted neighborhood, density was redistributed close to the arterial roads to provide proximity to amenities and improved transit services. The existing FAR for the Gulshan area was

4 and it scored 10 out of 10 in iThrive. Based on the floor area ratio both the existing and the retrofitted Gulshan neighborhood scored 10 out of 10 in iThrive. The higher population density in the retrofitted area will decrease trip distance, reduce automobile dependency and support active transportation, transit, and land use diversity (Masoud et al., 2015).

5.3.2 Mixed Land Use and Street Connectivity

Mixed land use and Street connectivity are some of the key elements of SG neighborhood design. The inclusion of mixed land use in the built environment is very crucial in sustainable neighborhood design and included in the design of retrofitted neighborhoods. The mix of different land uses (i.e. residential, commercial, industrial, green spaces) eventually reduces trip distance and makes daily amenities (convenient shops, green spaces, offices, schools, etc.) more accessible to the residents in those areas (Dempsey & Jenks, 2010). In the exiting neighborhood, approximately 1% of the total neighborhood was dedicated to greenspaces and outdoor public spaces. However, in the retrofitted neighborhood the total area dedicated to greenspaces was approximately 9% of the total land area of the Gulshan area. The existing neighborhood was close to the commercial areas and had access to different services (government services, auto shops, restaurants, churches, etc.). The mix of different land uses is considered in the retrofitted neighborhood and most of the daily amenities (convenient shops, bus stop, green spaces, offices, schools, etc.) were placed in such a manner that it would reduce the trip distance and people would be encouraged to walk or bike. The ground floor of the mixed-use buildings and commercial buildings were prescribed to have retail shops and workspaces so people would have more access to these buildings. In the retrofitted neighborhoods, the heterogeneity of land use mix was considered and land use mix is expected to improve active transportation by reducing trip distance.

Table 5-4 Application of iThrive and HDI for Land Use Mix (Masoud et al., 2015)

Criteria	Credits	Total credits		Maximum Achievable Credit
		Existing Neighborhood	Retrofitted Neighborhood	
Heterogeneity of land use mix	≥ 5 % of total community land is outdoor public space (3 points)	0	3	3
	The community provides ≥ 4 new services to an existing neighborhood (within a 1 km radius of the community center) (3 points)	3	3	3
	There is a mix of 3 housing types, 6 different services, a public school, and a park ≥ 0.4/ha within 800m of the community center (5 points)	5	5	5

Heterogeneity of Building mix	≥ 60 % of commercial buildings include a ground floor pedestrian use along ≥ 60 % of their street façades (4 points)	4	4	4
	100 % of mixed-use buildings include ground-floor retail, live/workspaces, or residential dwellings along ≥ 60 % of their street façade (4 points)	0	0	4
	≥ 50 % of multifamily residential buildings have a pedestrian use on the ground floor (4 points)	4	4	4
Mixed housing types	≤ 30 % of housing is large lot detached homes (3 points)	3	3	3
	As above and the community includes ≥ 3 housing types, with none making up less than 20 % of the total residential units (5 points)	5	5	5

Street network in the retrofitted neighborhoods was designed in such a manner to support active transportation and improve residents' proximity to daily amenities and transit services. The street network and active transportation infrastructure in the neighborhoods were constructed to enhance walking and biking and discourage drivers to ride automobiles. Moreover, perimeter one-way arterial couplets were constructed around the retrofitted neighborhoods to decrease traffic conflicts (i.e. left turn maneuver) and improve the aesthetics of the neighborhood. To measure the effectiveness of the on-road and off-road bike route, the route directness was measured. It was calculated by comparing the active transportation route with the vehicular route. The route directness should be lower than one and the lower the value the higher it supports active transportation (Masoud et al., 2015).

Table 5-5 Application of iThrive and HDI for Street Connectivity (Masoud et al., 2015)

Criteria	Credits	Total credits		Maximum Achievable Credit
		Existing Neighborhood	Retrofitted Neighborhood	
Active Transportation Route Directness	1-0.95 AT to vehicle Route directness ratio (1 point)			10
	0.95-0.90 AT to vehicle Route directness ratio (3 points)			
	0.90-0.85 AT to vehicle Route directness ratio (7 points)		7	
	< 0.85 AT to vehicle Route directness ratio (10 points)			

As there was no existing active transportation facilities the route directness for the existing active transportation facility was 0. The active transportation crossing and on and off-road bike lane increased biking facility and reduced trip distance, resulting in route directness of 0.86 on average in the retrofitted Gulshan area. Based on the street connectivity the retrofitted Gulshan scored 7 out of 10 in iThrive.

5.3.3 Greenspace and Sidewalk Characteristics

In a SMARTer Growth (SG) neighborhood, the green spaces and natural elements are protected to promote the health and quality of life of the residents. In the retrofitted neighborhood, unused lands and brownfields were converted to green space to provide the residents with a sense of green. The green spaces were constructed within 1-minute walking distance (i.e 80-100 meters) radius from houses and can be accessible by people of all age groups. The arterial perimeter couplets were equipped with medians and these medians would be converted to new block for the residents and would not allow crossing of vehicles except bikes and emergency vehicles. The lakesides will be considered as greenspaces for Gulshan. The green spaces will be equipped with playground equipment and places for individuals or groups to talk and socialize.

Fast-moving traffic, bikes, and pedestrians sharing the same road have some safety concerns and to make the road safer the bike and pedestrians have their separate paths in the retrofitted neighborhoods (Figure 5-6). In the retrofitted neighborhoods the bike paths and sidewalks were constructed in all arterial and collector roads, speed limits for local roads were posted 30 km/h. Self-enforcing traffic calming measures (i.e. roundabouts, speed limit signage, speed humps, buffer strips) were implemented on all roads to discourage shortcutting of fast-moving traffic in the neighborhoods while promoting active transportation in the neighborhoods.

Bike racks, street lamps, side benches, and two-way bike lanes were constructed in the one way arterial couplets and collectors to facilitate biking and walking. The typical cross-section of the roads has been illustrated in Figure 5-4.

The on-street parking is discouraged on the street and unbundled parking was introduced to reduce auto ownership and infrastructure cost to build more parking lots. On-street parking was only available close to the mixed-use zones and for 2 hours only. The scores for each criteria for the retrofitted neighborhoods are illustrated in Table 5-6.

Table 5-6 Application of iThrive and HDI for Sidewalk Characteristics (Masoud et al., 2015)

Criteria	Credits	Total credits		Maximum Achievable Credit
		Existing Neighborhood	Retrofitted Neighborhood	
Traffic Calming	4-6 traffic calming measures*/hectare (1 credit)			7
	7-10 traffic calming measures*/hectare (3 credits)			
	11-13 traffic calming measures*/hectare (5 credits)			
	14+ traffic calming measures*/hectare (7 credits)	7	7	
Speed Control / Pedestrian Priority	10-19 % of local roads are ≤ 15km/h with ped-priority (1)			10
	20-29 % of local roads are ≤ 15km/h with ped-priority (3 credits)			
	30-39 % of local roads are ≤ 15km/h with ped-priority (6 credits)			
	≥ 40 % of local roads are ≤ 15km/h with ped-priority(10 credits)			
Sidewalks and buffer strips	Buffer strips with physical barriers all roads ≥ 50km/h (5)	5	5	5

Cycle friendly design	bicycle-priority streets (cars must yield to cyclists; speed ≤ 30km/h) (5 credits)	0	6	6
	streets that are one-way for cars; two-way for cyclists; speed ≤ 30km/h (2 credits)	0	2	2
	cul-de-sacs with bicycle cut-throughs (2 credits)	0	2	2
	advance green lights for cyclists (1 credit)	0	1	1
	off-street pedestrian and cyclist shortcuts (2 credits)	0	2	2
	left-hand turn short cuts for cycles (1 credit)	0	1	1
	1 bicycle rack per ten car parking spots (includes on- and off-street spots) (3 credits)	0	3	3

Lighting	All mixed-use streets have an average luminance of 10 lux, with a minimum of 5 lux(3 credits)	3	3	3
	Provide ≤ 4.6m tall street lamps spaced no more than 30m apart on both sides of 80 % of mixed-use streets (3 credits)	3	3	3
	Provide ≤ 4.6m tall aesthetically-pleasing (artistically-designed) lamp posts on both sides of 100 % of mixed-use 'core' streets (2 credits).	2	2	2
Unbundled & Shared parking	Provide unbundled parking for 50 % of multifamily dwellings (1 credit)	0		7
	Provide unbundled parking for 75 % (5 credits)		5	
	Provide unbundled parking for 100 % (7 credits)			
	Allow shared parking so that parking spaces can count towards the requirements of two separate uses, such as a civic building and a restaurant, or a place of worship and an office building (3 credits).	0	3	3

Parking price and restrictions	Charge the market rate* for off- and on-street parking for all mixed-use and retail streets (4 credits)	0	4	4
	Designated 'Parking Meter Zones' - parking revenues go back to the zone for ped-friendly and aesthetic imp's, such as public art, paving, street furniture, lighting, trees, cleaning, and painting/maintenance (3 credits)	0	0	3
	Variable parking pricing, so that costs increase with the length of stay, or limit the length of stay to ≤ 2 hrs (2 credits)			2
	Max 2-hour on-street parking, or resident-only parking on all streets within 200m of a mixed-use center (2 credits)	0	2	

5.3.4 Transportation Safety Evaluation

The transportation safety evaluation section of iThrive was derived from the Dutch Sustainable Transport Safety Principles. The section is divided into five components and those are functionality, predictability, homogeneity, forgiveness and state awareness.

5.3.4.1 Functionality

The Functionality criteria focuses on classifying the roads according to their traffic function and the cataloging aids in defining road characteristics and layout of the roads. In the retrofitted neighborhoods, the roads are classified as one-way arterial couplet, collector and local roads (Figure 5-3)

5.3.4.2 Predictability

The Predictability criteria focuses on creating foreseeable road environment (i.e. speed, maneuver, etc.) for the road users. This criteria is achieved by providing continuous and consistent unique features of street layout and for each street class in the retrofitted neighborhood (Figure 5-3).

5.3.4.3 Homogeneity

The Homogeneity criteria focuses on achieving homogenous roads by minimizing road users' differences in speed and direction. This criteria is achieved in the retrofitted neighborhood by separating high-speed traffic from low-speed traffic (i.e. bike path) so the severity of collision can be minimized (Figure 5-5).

5.3.4.4 Forgiveness

The Forgiveness criteria focuses on reducing collision on roads. This criteria can be achieved by providing a forgiving road environment which allows for driver error and limits collision probability. The traffic calming measures improved the traffic safety of the neighborhoods and active transportation infrastructure and AT routes improved biking and walking across the neighborhood. By providing traffic calming measure (i.e. roundabouts) and managing speed limits in the retrofitted neighborhood (Figure 5-5) the consequences of driver's error can be avoided.

5.3.4.5 State Awareness

State Awareness focuses on reducing conflict points to reduce the task demand of road users. This criteria also focuses on creating improved bicycle facilities that will reduce conflicts between vulnerable road users (i.e. pedestrian and biker) and motorists. In the retrofitted neighborhood the bike paths were separated from high-speed traffic and the arterial roads were converted to one way couplet to reduce conflicts (i.e. left turn maneuver) between vulnerable road users and motorists. The scores for each criteria for the retrofitted neighborhoods were illustrated in Table 5-7.

Table 5-7 Application of iThrive and HDI for Transportation Safety Evaluation

Criteria	Credits	Total credits		Maximum Achievable Credit
		Existing Neighborhood	Retrofitted Neighborhood	
Functional Classification	≥ 60% of the roads are categorized based on one function they fulfill (1 credit)			7
	≥ 75% of the roads are categorized based on one function they fulfill (3 credit)	3		
	≥ 90% of the roads are categorized based on one function they fulfill (5 credit)			
	100% of the roads are categorized based on one function they fulfill (7 credit)		7	
Access Management on collector roads	≥ 30-35 access points per km road (1 credit)	1		5
	≥ 25-30 access points per km road (3 credit)			
	≥ 0-20 access points per km road (5 credit)		5	

Distinguishable design characteristics	Road design has at least 1 distinguishable characteristics for differentiating road categories (2 credit)			12
	Road design has at least 2 distinguishable characteristics for differentiating road categories (4 credit)			
	Road design has at least 3 distinguishable characteristics for differentiating road categories (8 credit)			
	As above and two of the distinguishable characteristics are either driving direction separation, centerline marking, or intersection design (12 credit)	12	12	
Homogeneity	0-30 km/h & < 3000 vpd Bike: shared land or bicycle boulevard. Sidewalk: 0-2 (2 credit)	0		4
	30-50 km/h & > 3000 vpd Bike: bike lane in both directions. Sidewalk: 2 (3 credit)			
	≥ 50 km/h & > 3000 vpd Bike: cycle track or buffered bike lane. Sidewalk: 2 (4 credit)		4	

	One-way couplets system on arterial/collector roads. (4 credits)	0	4	4
Forgiving road design measures on collector and arterial roads	≥ 60% of collector and arterial roads have at least one forgiving environment measure (2 credit)			12
	≥ 75% of collector and arterial roads have at least one forgiving environment measure (4 credit)	4		
	≥ 90% of collector and arterial roads have at least one forgiving environment measure (8 credit)			
	≥ 100% of collector and arterial roads have at least one forgiving environment measure (12 credit)		12	
Reducing motorists task demand	≥ 20% of intersections are either 3-way or roundabout (1 credit)			7
	≥ 30% of intersections are either 3-way or roundabout (3 credit)			
	≥ 40% of intersections are either 3-way or roundabout (7 credit)	7	7	

In the existing neighborhood, approximately 80% of the roads were categorized based on their functions and the collector and arterial roads had 42 access points on average. The arterial roads and collector roads had road centerlines or medians, parking, edge marking. These distinguishable characters were present in the roads to differentiate road class and the bike lane was not available (Figure 5-4). However, for the retrofitted neighborhood all the roads were classified based on their function and one-way arterial couplets and roundabouts were introduced to reduce access points on roads to make it safer to cross and to access. Green colored two way separate from traffic bike paths were introduced in the arterial and collector roads to improve mobility by active transportation (Figure 5-5). These bike paths can be used by both bikes and rickshaws. Based on the design criteria the retrofitted neighborhood scored higher in all the categories of transport safety evaluation.

5.4 Application and Evaluation using Healthy Built Environment Linkages Toolkit

The Healthy Built Environment Linkages Toolkit doesn't have an application interface. However, the developer of this toolkit has discussed several outcomes of improving the built environment components and the impact of the built environment on health and well-being to create more livable communities (BC Centre for Disease Control, 2018). The aim of the toolkit is to link community design, planning, and health together. The toolkit is composed of five physical components of the built environment. Based on the evidence and data, impacts on the built environment and health outcomes were discussed. The toolkit was applied to evaluate the SMARTer Growth (SG) neighborhood design and based on the similarity of principles, the possible outcomes were discussed in this chapter. Evidence is still emerging in these areas, and future reviews could consider looking more systematically at all of these concepts. The built environment components of the toolkit were evaluated and given below:

5.4.1 Healthy Neighborhood Design

The toolkit discusses the planning principle of building healthy neighborhoods. The SMARTer growth (SG) retrofitted neighborhoods would improve neighborhood walkability, mixed land use and improve connectivity in between neighborhoods. The toolkit discussed the outcomes of improving mixed land use development and the street connectivity for building Healthy Neighborhood. The outcome showed, the inclusion of mixed land use and improvement of street connectivity improves the accessibility of the residents to parks, green spaces, and daily amenities and improves walkability, outdoor air quality, general health, respiratory health, walkability, cycling, economic co-benefits, healthy weights, physical activity, and social well-being. Moreover, it reduces collision, stress and noise exposure (BC Centre for Disease Control, 2018).

In the retrofit SG design the mixed land use and human-scale design with improved active transportation network and oneway streets would improve street connectivity and accessibility of the residents. The SG design would have the similar outcomes of healthy neighborhood design.

5.4.2 Healthy Transportation Networks

The aim of the toolkit is to help planners and engineers create a safe and accessible transportation system. The system will combine different modes of transportation to create diversity and focuses on promoting active transportation while reducing automobile dependency. The principle of SMARTer growth (SG) neighborhood design and the principle of building healthy transportation networks align together. The toolkit suggested promoting active transport and improving mobility in the neighborhood, improves outdoor air quality, traffic safety, transit use, and walkability. Moreover, it reduces noise exposure, premature mortality, unintentional injury, and stress (BC Centre for Disease Control, 2018).

In the retrofit SG design the improved active transportation network, bicycle paths and oneway streets would improve street connectivity and accessibility of the residents. Moreover, it would make the street network more safer in terms of traffic safety. The SG design transportation network would also allow different modes of transportation and would reduce VKT in the neighborhood. The SG design would have the similar outcomes of Healthy Transportation Networks.

5.4.3 Healthy Natural Environments

The toolkit focuses on preserving green space and environmentally sensitive areas. The toolkit suggests preserving greenspaces in the retrofitted neighborhood, improves air quality, urban greening, mental health, depression regulation, and social well being. Moreover, it reduces noise exposure and stress (BC Centre for Disease Control, 2018). The SG design provide green spaces in the neighborhoods and allow all ages of people to access green spaces. It maximizes the opportunity to involve nature and mitigate the urban heat island effect. These greenspaces in the SG design would reduce noise pollution, improve air quality and mental health.

5.4.4 Healthy Housing

The toolkit discusses on housing affordability. SG design recommended higher population and employment density in the community and mixed land use. It would reduce the land required for building roads and would allocate those lands by building more and diverse houses. This would make housing more affordable and would help the neighborhoods achieving housing affordability goals. The housing affordability in the SG design would increase access to good quality housing, improve indoor air quality, sense of safety and reduce crime (BC Centre for Disease Control, 2018).

5.5 Application and Evaluation using Envision

The Envision sustainability rating system (Envision, 2016) was applied to the retrofitted neighborhood designs to examine if they met the United Nations Sustainable Development Goals (UN SDG) set up by Envision. Envision supports sustainable choices in infrastructure and has different sustainability matrices to evaluate a project. Envision rating system interface has several questions on different sustainability criteria and based on the question-answer it gives the score to each criteria. Based on the total score different projects can be compared whether these will meet the sustainability goals in the future. However, Envision doesn’t prescribe how these criteria will be met by the project. Envision has 60 sustainability criteria and these are categorized into 5 groups, results of Envision application are following:

5.5.1 Quality of Life

Quality of life in the retrofitted neighborhoods was evaluated using the Envision rating system. Quality of life addressed the impacts of the retrofitted neighborhoods on the communities and individuals. Moreover, it evaluated whether retrofitted neighborhoods meet community goals (i.e. sustainability, growth, public health and safety, accessibility, and mobility) and benefit communities. The retrofitted Gulshan will improve quality of life by reducing negative impacts on the host and nearby communities), promoting sustainable growth (i.e. improving local employment, making the neighborhood more attractive to people and businesses), improving public health and safety, improving accessibility and mobility, and developing alternative modes of transportation. The criteria were applied at the retrofitted neighborhoods and the retrofitted Gulshan neighborhood scored 22. The maximum achievable score was 26 in Envision for Quality of Life. The assessment results have been illustrated in Appendix B.1.

5.5.2 Leadership

Building sustainable neighborhoods require a new way of thinking. To build a sustainable neighborhood, planners, engineers, clients, and stakeholders need to collaborate together to create ideas and understand the long term initiatives which need to be implemented to achieve the goals. The Leadership criteria aim at reducing energy consumption and usage of water by providing effective and collaborative leadership and building a new sustainable community. Moreover, these criteria ask for collaboration, management, and planning in the projects and include decisions and opinions of different stakeholders for future innovation. The retrofitted Gulshan will form a sustainability management system and eliminate conflicting design elements to promote sustainability across the neighborhood to reach sustainability goals. The maximum achievable score was 19 in Envision for Leadership. The retrofitted neighborhoods scored the maximum for Leadership. The assessment results have been illustrated in Appendix B.2.

5.5.3 Resource Allocation

Resources are required to build a community. This criteria discusses three types of resources, including materials, energy, and water. This criteria is concerned with the resources and their impact on the sustainability of building the project. The resources are limited and minimizing the total amount of materials used in a project, is a major concern for building retrofitted neighborhoods. To build the retrofitted neighborhoods, the building materials would be used in a balanced manner considering safety, stability, and durability. The energy sources are limited and for the project, the use of renewable energy would be encouraged. The improved active transportation infrastructure and discontinuous streets would reduce the number of automobiles on the street and eventually would reduce the consumption of fossil fuel. To build the retrofitted neighborhoods recycled materials would be used where possible. The maximum achievable score was 14 in Envision for Resource Allocation. The retrofitted neighborhoods scored 8 for Resource Allocation. The assessment results have been illustrated in Appendix B.3.

5.5.4 Natural World

Building a community has an impact on the natural world they surround. Unwanted impacts may be caused if the community is located close to natural habitat and it might unbalance the natural system around them. This criteria asks for minimizing the unwanted adverse impacts on the natural system caused by a new infrastructure or a community. In the retrofitted neighborhoods, the new infrastructures were not constructed close to the natural habitat. The retrofitted neighborhoods were shaped in such a manner that it didn’t affect the ecological site where there are diversity of habitats and had water bodies or wetlands. This criteria also asks for minimizing adverse effects on existing hydrologic, nutrient cycles and preserving floodplain functions, preserving Greenspaces and preventing surface and groundwater flow. The maximum achievable score was 26 in Envision for Natural World. The retrofitted neighborhoods scored 25. The assessment results have been illustrated in Appendix B.4.

5.5.5 Climate and Risk

Climate and risk aim to minimize GHG emissions and to ensure resiliency in the infrastructure. This criteria focuses on the reduction of harmful gases and GHG emissions during the project life cycle. Moreover, it focuses on improving the infrastructure’s ability to endure sudden flooding or fire and minimizing the weakness of the structure. The improved adaptability of the infrastructure contributes to improving the useful life of the infrastructure to meet the future goals of the community. The retrofitted neighborhoods will reduce automobile dependency and also introduce clean energy in different transportation modes that would reduce GHG emissions. The criteria were applied at the retrofitted neighborhoods and the assessment results are given below.

The maximum achievable score was 10 in Envision for Natural World. The retrofitted neighborhoods scored 7 for Climate and Risk. The assessment results have been illustrated in Appendix B.5.

5.6 Walkability

After measuring the values of each variables the walkability was measured. The existing neighborhood scored 6.47 and the SMARTer growth (SG) neighborhood scored 6.94. The

SMARTer growth (SG) neighborhood was 7.26% more walkable in comparison to the existing neighborhood.

5.7 Bikeability

Winters et al. (2013) introduced the scoring criteria and method. The maximum score for each components was 10 and the minimum was 0. Based on the distance of bicycle routes the score was given to each zone. The bicycle route separation score was measures based on the availability of bike paths. The connectivity of bicycle-friendly streets was calculated based on the number of intersections and topography was measured based on the digital elevation model. The destination density was measured based on the number of bicycle-friendly destination. The scores for each of the variable was placed in the equation to measure the total score for the zone. The scores for each of the variable was placed in the equation to measure the total score for the zone. The existing Gulshan neighborhood scored 24 and the retrofitted SMARTer Growth (SG) neighborhood scored 56 on Bikeability index. The SMARTer growth (SG) neighborhood was 133% more bikeable in comparison to the existing neighborhood.

5.8 Playability

In the retrofitted SMARTer Growth (SG) neighborhood the residential density would be higher than the existing neighborhood and the mix of land use would reduce the proximity to school or any other amenities. The improved street connectivity and pedestrian and biker friendly roads across the SG neighborhood would improve Playability of the neighborhood.

5.9 Ecological Footprint

In the retrofit SG design for Gulshan, Dhaka, the land use mix would reduce the trip distance between different amenities and services and reduce VKT. The increased employment and population density would make it more effective to invest in infrastructure and in transit services and would reduce per capita ecological footprint.

5.10 Transport Equity

In the retrofit SG neighborhood for Gulshan, Dhaka, the trip distances were reduced by increasing mixed land use and increasing population density. The decreased trip distance reduces VKT and improves overall pedestrian and biker mobility, accessibility, and ridership of public transit. Moreover, the retrofitted neighborhood is expected to improve housing affordability by providing more and different housing options. The neighborhood would accommodate people with disabilities and other special needs by providing universally accessible sidewalks, road crossings, and improve the economic opportunities and development of the area.

5.11 Universal Accessibility

In the retrofit SG design universally accessible sidewalks and road crossings would be provided at the oneway perimeter couple and at collector roads. Moreover, benches and bike racks would be provided at all the sidewalks and disabled parking would be available in front of all the amenities so people with disability could access those places.

5.12 Air Quality

In the retrofitted Gulshan area the density is higher and the area is traffic-calmed. The traffic-calmed neighborhood might increase the idling time of the vehicle but as the land use mix will be increased and more amenities will be available within a short distance, which will eventually reduce the trip distance and number of cars on the roads. The increased density will also make transit more effective resulting in less emission per capita. Moreover, the one-way arterial couplet is parallel to each other which is also supposed to decrease GHG emission by reducing number of automobiles from roads.

5.13 Noise

In the retrofit SG design for Gulshan, Dhaka area the higher density and the mix of land use would reduce the noise exposure in the neighborhood. The retrofitted neighborhood would accommodate and offer multi-transport modes which would reduce automobile use and make transit more popular and user-friendly. The greenspaces in the neighborhood would be located not more than 400 m from any location of the neighborhood. The retrofitted neighborhood would be less exposed to noise pollution as greenspaces reduces the susceptibility of noise (Dzhambov & Dimitrova, 2015; Margaritis & Kang, 2017) and improve quality of life of the residents.

5.14 Discussion of Similarities & Differences between Capri-Landmark, Kelowna & Gulshan, Dhaka Results: Lessons Learned

The comparison of results between the Capri-Landmark neighborhood and the Gulshan neighborhood showed in both cases by changing different components of street networks reduced the future total number of collisions the most. The addition of roundabout played a vital role in reducing the total number of collisions. The on and off-road active transportation routes in the retrofitted neighborhoods improved AT connectivity (i.e. route directness), walkability and bikeability. The walkability in the retrofitted neighborhoods for Gulshan, Dhaka showed less improvement than the retrofitted neighborhood of Capri-Landmark. The result is logical as the existing Gulshan, Dhaka neighborhood already has mixed land use, discontinuous local roads, and proximity to amenities. The bikeability in the retrofitted Gulshan neighborhood improved more than 100% as the existing neighborhood did not have biking facilities.

From this research, we learned the existing Gulshan neighborhood is better than the existing Capri-Landmark in terms of connectivity and walkability and most of the trips can be made without private automobiles. To meet the goals of SG design Gulshan needs to invest lesser than the Capri-Landmark. However, the main challenges for Dhaka would be constructing green paces, whereas for Capri-Landmark the challenge would be to gain optimum population and employment density.

5.15 Summary

This chapter summarizes the development of the retrofit SG design and the application of different SMARTer growth (SG) design tools for Gulshan neighborhood in Dhaka, Bangladesh. The development of the retrofit design and the traffic safety evaluation was presented in section 5.2. The retrofitted neighborhood was found to be 56% safer than the existing neighborhood in the traffic safety evaluation. The traffic safety was assessed using the CPM model. The CPM model evaluated the exposure, socio-demographic, network and transportation demand management aspects of the neighborhood to evaluate safety. The results suggest changing different components of the street network, replacing the signalized intersection with turbo roundabout and four-way intersections with roundabout reduced collision the most. The tools were applied to the retrofitted neighborhood to assess the different aspects offered in a SMARTer growth (SG) neighborhood design. The health aspects were evaluated in iThrive, and Healthy Built Environment Linkages Toolkit and the probable health outcomes were also discussed. The iThrive scored the existing and retrofit neighborhood whereas Healthy Built Environment Linkages Toolkit discussed the possible outcomes of the retrofit design based on the literature. The Envision sustainable infrastructure rating system was applied to the retrofit SG design to measure different sustainability criteria in the project. The five criteria for Envision were discussed and the total score for each criteria was measured for the retrofit SG design and was presented in Section 5.3, 5.4 and 5.5. The walkability and bikeability were measured in Section 5.6 and 5.7. Walkability was measured based on the land use mix, destination density and road network facilities available and bikeability was measured based on the topography and active transportation infrastructure. Playability, Ecological footprint, Transport Equity, Universal Accessibility, Air Quality, and Noise were evaluated based on the literature available. The tools could not be quantified due to insufficient data and unavailability of application interface or model to evaluate. The literature looked for the possible ways to improve the criteria based on the SMARTer growth (SG) neighborhood principle and how the design would improve the criteria was shown.

Chapter 6: Conclusions & Future Research

6.1 Overview

This chapter is divided into four main sections. Section 6.2 summarizes the research and concludes the thesis. Section 6.3 presents the research contributions and Section 6.4 discusses limitations and recommendations for future research.

6.2 Summary & Conclusions

Urban Sprawl has been the least desirable form of urban development. It has been considered as one of the main threats to the sustainable economic, environmental, social and cultural well-being of businesses and visitors living in a sprawling city. This research focuses on presenting the new form of urban planning, SMARTer Growth (SG) neighborhood design to mitigate the impacts of Urban Sprawl. The research focused on linking the relationship between urban form, SG neighborhood design, and quality of life using a suite of tools, including traffic safety among others. Macro-level collision prediction models were developed to assess the traffic safety of the two neighborhoods. The models predicted the total collision frequency based on the urban form between the existing and retrofitted SMARTer Growth (SG) neighborhood designs. Additionally, SMARTer Growth (SG) neighborhood design tools were applied to evaluate the quality of life in the existing and retrofitted neighborhoods, including iThrive, Envision, Healthy Built Environment Linkages Toolkit, Walkability, Bikeability, Playability, Ecological Footprint, Transport Equity, Universal Accessibility, Air Quality, and Noise.

The application and construction of the SG neighborhoods might take 30 to 40 years. However, developing building lines for the cities would help to build the design neighborhood without hampering the life of residents. The results suggest that SMARTer growth (SG) neighborhood design tools can be used effectively and promoted active transportation, reduced traffic collision and improved public health relative to business as usual. Proposed retrofitted neighborhood designs using the SG Design Manual offered mixed land use and proximity to services, which would reduce the trip distance and lower the dependency on private automobiles. The active transportation and effective transit services would reduce the VKT of the automobile and make the residents healthier. The proximity to green spaces in the neighborhood would also create an urban environment that allows residents to socialize, linger, recover, and live.

The comparison between the existing Capri-Landmark neighborhood and existing Gulshan neighborhood showed Gulshan offered different modes of transportation and also due to higher density, land use mix, and proximity to services it supported more walking and use of public transit. Most of the trips in the existing Gulshan neighborhood could be made through walking or biking. However, people use cars in Gulshan to maintain their social status. The reduction of car dependency not only depends on the urban form but also depends on culture. To change the attitude of people, social awareness should be increased in those regions.

6.3 Research contributions

This research study makes the following contributions to SMARTer Growth (SG) neighborhood design:

1. GIS Mapping: Digitalized GIS map for Dhaka was not available for the study. In this research, the digitalized GIS map for Dhaka city was developed from scratch to analyze the area and to collect data to develop CPMs.

2. Dhaka CPM Development and Application: Road parameters (road types, lane width, lane kilometers, sidewalk characteristics, bike lane characteristics), Socio-demographic information (population, income, employment, age, gender), network design (intersection type, signal density, roundabout density) were measured manually and updated for Dhaka, Bangladesh. Moreover, the CPMs for Dhaka, Bangladesh was developed using the Negative Binomial Model.
3. This research also developed and evaluated community retrofit neighborhood designs for the Capri-Landmark Kelowna and Gulshan, Dhaka, Bangladesh, with suggestions on how to further improved in each neighborhood.

6.4 Limitations and Future Research

The limitations and recommendation for future researches are presented below:

- This research focused on developing a link between urban form and quality of life indicators. The data regarding the collision of pedestrian and bicyclist was unavailable for Dhaka, Bangladesh, so the CPMs could not model or assess the traffic safety of vulnerable road users. The future researches need to address this issue
- The TAZ level dataset, neighborhood parcel-level dataset, and geo-referenced collision data for Dhaka, Bangladesh was not available. The CPMs accuracy depends on the quality of the dataset. Future research should consider collecting geo-referenced parcel-level collision data to improve the accuracy of the CPMs.
- The effectiveness of transit services in SMARTer growth (SG) design neighborhood was not evaluated in this research. Future research should consider optimizing the transit routes and schedules to make transit more effective across the neighborhood.

- Future researches should also focus on calculating the Mode Choice Prediction, VKT shift, Energy consumption, GHG emission, Life Cycle Cost of SG neighborhood design.

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Appendices

Appendix A : Application of Envision on Retrofitted Neighborhoods at Capri-Landmark, Kelowna

A.1 Envision Rating System for Quality of Life (Envision, 2016)

QL 1.1 Improve Community Quality of Life				
Intent: Improve the net quality of life of all communities affected by the project and mitigate negative impacts to communities.				
Metric: Measures taken to assess community needs and improve quality of life while minimizing negative impacts.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Are the relevant community needs, goals and issues being addressed in the project?	●	○	○	?
Are the potentially negative impacts of the project on the host and nearby communities been reduced or eliminated?	●	○	○	?
Has the project design received broad community endorsement, including community leaders and stakeholder groups?	●	○	○	?
Total	3	of	3	

QL 1.2 Stimulate Sustainable Growth and Development				
Intent: Support and stimulate sustainable growth and development, including improvements in job growth, capacity building, productivity, business attractiveness and livability.				
Metric: Assessment of the project's impact on the community's sustainable economic growth and development.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project contribute significantly to local employment?	●	○	○	?
Will the project make a significant increase in local productivity?	●	○	○	?
Will the project make the community more attractive to people and businesses?	●	○	○	?
Total	3	of	3	

QL 1.3 Develop Local Skills and Capabilities				
Intent: Expand the knowledge, skills and capacity of the community workforce to improve their ability to grow and develop.				
Metric: The extent to which the project will improve local employment levels, skills mix and capabilities.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Does the project team intend to hire and train a substantial number of local workers?	◉	○	○	?
Does the project team intend to use a substantial number of local suppliers and specialty firms?	◉	○	○	?
Will the project, through local employment, subcontracting and education programs, make a substantial improvement in local capacity and competitiveness?	◉	○	○	?
Total	3	of	3	

QL 2.1 Enhance Public Health and Safety				
Intent: Take into account the health and safety implications of using new materials, technologies or methodologies above and beyond meeting regulatory requirements.				
Metric: Efforts to exceed normal health and safety requirements, taking into account additional risks in the application of new technologies, materials and methodologies.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Does the owner and the project team intend to identify, assess and institute new standards to address additional risks and exposures created by the application of new technologies, materials, equipment and/or methodologies?	◉	○	○	?
Total	1	of	1	

QL 2.2 Minimize Noise and Vibration				
Intent: Minimize noise and vibration generated during construction and in the operation of the completed project to maintain and improve community livability.				
Metric: The extent to which noise and vibration will be reduced during construction and operation.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project reduce noise and vibration to levels below local permissible levels during construction and operation?	◉	○	○	?
Total	1	of	1	

QL 2.3 Minimize Light Pollution				
Intent: Prevent excessive glare, light at night, and light directed skyward to conserve energy and reduce obtrusive lighting and excessive glare.				
Metric: Lighting meets minimum standards for safety but does not spill over into areas beyond site boundaries, nor does it create obtrusive and disruptive glare.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be designed to reduce excessive lighting, prevent light spillage and preserve/restore the night sky?	◉	○	○	?
Total	1	of	1	

QL 2.4 Improve Community Mobility and Access				
Intent: Locate, design and construct the project in a way that eases traffic congestion, improves mobility and access, does not promote urban sprawl, and otherwise improves community livability.				
Metric: Extent to which the project improves access and walkability, reductions in commute times, traverse times to existing facilities and transportation. Improved user safety considering all modes, e.g., personal vehicle, commercial vehicle, transit and bike/pedestrian.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project provide good, safe access to adjacent facilities, amenities and transportation hubs?	◉	○	○	?
Will the project design take into consideration the expected traffic flows and volumes in and around the project site to improve overall mobility and efficiency?	◉	○	○	?
Has the project team coordinated the design with other infrastructure assets to reduce traffic congestion, and improve walkability and livability?	◉	○	○	?
Total	3	of	3	

QL 2.5 Encourage Alternative Modes of Transportation				
Intent: Improve accessibility to non-motorized transportation and public transit. Promote alternative transportation and reduce congestion.				
Metric: The degree to which the project has increased walkability, use of public transit, non-motorized transit.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be within walking distance of accessible multi-modal transportation?	◉	○	○	?
Through its design, will the project encourage the use of transit and/or non-motorized transportation?	◉	○	○	?
Total	2	of	2	

QL 2.6 Improve Accessibility, Safety and Wayfinding				
Intent: Improve user accessibility, safety, and wayfinding of the site and surrounding areas.				
Metric: Clarity, simplicity, readability and broad-population reliability in wayfinding, user benefit and safety.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project contain the appropriate signage for safety and wayfinding in and around the constructed works?	◉	○	○	?
Will the project address safety and accessibility in and around the constructed works for users and emergency personnel?	◉	○	○	?
Will the project extend accessibility and intuitive signage to protect nearby sensitive sites or neighborhoods?	◉	○	○	?
Total	3	of	3	

QL 3.1 Preserve Historic and Cultural Resources				
Intent: Preserve or restore significant historical and cultural sites and related resources to preserve and enhance community cultural resources.				
Metric: Summary of steps taken to identify, preserve or restore cultural resources.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project minimize negative impacts on historic and cultural resources?	◉	○	○	?
Will the project be designed so that it fully preserves and/or restores historic/cultural resources on or near the project site?	◉	○	○	?
Total	2	of	2	

QL 3.2 Preserve Views and Local Character				
Intent: Design the project in a way that maintains the local character of the community and does not have negative impacts on community views.				
Metric: Thoroughness of efforts to identify important community views and aspects of local landscape, including communities, and incorporate them into the project design.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be designed in a way that preserves views and local character?	◉	○	○	?
Will the project be designed to improve local character, views or the natural landscape through preservation and/or restorative actions?	◉	○	○	?
Total	2	of	2	

QL 3.3 Enhance Public Space				
Intent: Improve existing public space including parks, plazas, recreational facilities, or wildlife refuges to enhance community livability.				
Metric: Plans and commitments to preserve, conserve, enhance and/or restore the defining elements of the public space.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project make meaningful enhancements to public space?	◉	○	○	?
Will the project result in a substantial restoration to public space?	◉	○	○	?
Total	2	of	2	

A.2 Envision Rating System for Leadership (Envision, 2016)

LD1.1 Provide Effective Leadership and Commitment				
Intent: Provide effective leadership and commitment to achieve project sustainability goals.				
Metric: Demonstration of meaningful commitment of the project owner and the project team to the principles of sustainability and sustainable performance improvement.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Has the project team issued public statements stating their commitment to sustainability?	◉	○	○	?
Is the project team's commitment to sustainability backed up by examples of actions taken or to be taken?	◉	○	○	?
Do these commitments and actions demonstrate sufficiently that sustainability is a core value of the project team?	◉	○	○	?
Total	3	of	3	

LD 1.2 Establish a Sustainability Management System				
Intent: Create a project management system that can manage the scope, scale and complexity of a project seeking to improve sustainable performance.				
Metric: The organizational policies, authorities, mechanisms and business processes that have been put in place and the judgment that they are sufficient for the scope, scale and complexity of the project.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Does the project team intend to establish a sound, workable sustainability management system that meets the requirements of the project?	◉	○	○	?
Total	1	of	1	

LD 1.3 Foster Collaboration and Teamwork				
Intent: Eliminate conflicting design elements, and optimize system by using integrated design and delivery methodologies and collaborative processes.				
Metric: The extent of collaboration within the project team and the degree to which project delivery processes incorporate whole systems design and delivery approaches.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Are the project owner and the project team intending to take a systems view of the project, considering the performance relationship of this project to other community infrastructure elements?	◉	○	○	?
Will the project owner and the project team establish a collaborative relationship on the project to achieve higher levels of sustainable performance?	◉	○	○	?
Will the project owner and the project team institute a whole systems design and delivery process with the objective of maximizing sustainable performance?	◉	○	○	?
Total	3	of	3	

LD 1.4 Provide for Stakeholder Involvement				
Intent: Establish sound and meaningful programs for stakeholder identification, engagement and involvement in project decision making.				
Metric: The extent to which project stakeholders are identified and engaged in project decision making. Satisfaction of stakeholders and decision makers in the involvement process.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will key stakeholders in the project be identified and lines of communication established?	◉	○	○	?
Does the project team plan to engage with stakeholders and solicit stakeholder feedback?	◉	○	○	?
Will the project team establish a strong stakeholder involvement process designed to involve the public meaningfully in project decision-making?	◉	○	○	?
Total	3	of	3	

LD 2.1 Pursue By-Product Synergy Opportunities				
Intent: Reduce waste, improve project performance and reduce project costs by identifying and pursuing opportunities to use unwanted by-products or discarded materials and resources from nearby operations.				
Metric: The extent to which the project team identified project materials needs, sought out nearby facilities with by-product resources that could meet those needs and capture synergy opportunities.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team establish a program to locate, assess and make use of unwanted by-products and materials on the project?	◉	○	○	?
Total	1	of	1	

LD 2.2 Improve Infrastructure Integration				
Intent: Design the project to take into account the operational relationships among other elements of community infrastructure which results in an overall improvement in infrastructure efficiency and effectiveness.				
Metric: The extent to which the design of the delivered works integrates with existing and planned community infrastructure, and results in a net improvement in efficiency and effectiveness.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team seek to optimize sustainable performance at the infrastructure component level?	◉	○	○	?
Will the project team seek to optimize sustainable performance by designing the project as an integrated system?	◉	○	○	?
Will the project be planned and designed so that its operation and functions are fully integrated with all infrastructure elements in the community?	◉	○	○	?
Total	3	of	3	

LD 3.1 Plan For Long-term Maintenance and Monitoring				
Intent: Put in place plans and sufficient resources to ensure as far as practical that ecological protection, mitigation and enhancement measures are incorporated in the project and can be carried out.				
Metric: Comprehensiveness and detail of long-term monitoring and maintenance plans, and commitment of resources to fund the activities.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project have a plan for long term monitoring and maintenance?	◉	○	○	?
Will that plan be sufficiently comprehensive, covering all aspects of long-term monitoring and maintenance?	◉	○	○	?
Total	2	of	2	

LD 3.2 Address Conflicting Regulations and Policies				
Intent: Work with officials to Identify and address laws, standards, regulations or policies that may unintentionally create barriers to implementing sustainable infrastructure.				
Metric: Efforts to identify and change laws, standards, regulations and/or policies that may unintentionally run counter to sustainability goals, objectives and practices.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will an assessment of applicable regulations, policies and standards be done, identifying those that may run counter to project sustainable performance goals, objectives and targets?	●	○	○	?
Do the owner and the project team intend to approach decision-makers to resolve conflicts?	●	○	○	?
Total	2	of	2	

LD 3.3 Extend Useful Life				
Intent: Extend a project's useful life by designing a completed project that is more durable, flexible, and resilient.				
Metric: The degree to which the project team incorporates full life-cycle thinking in improving the durability, flexibility, and resilience of the project.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be designed in ways that extend substantially the useful life of the project?	●	○	○	?
Total	1	of	1	

A.3 Envision Rating System for Resource Allocation (Envision, 2016)

RA1.1 Reduce Net Embodied Energy				
Intent: Conserve energy by reducing the net embodied energy of project materials over the project life.				
Metric: Percentage reduction in net embodied energy from a life cycle energy assessment.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Does the project team plan to conduct an assessment of the embodied energy of key materials over the project life?	◉	○	○	?
Will the project achieve at least a 10% reduction in net embodied energy over the life of the project?	◉	○	○	?
Total	2	of	2	

RA 1.2 Support Sustainable Procurement Practice				
Intent: Obtain materials and equipment from manufacturers and suppliers who implement sustainable practices.				
Metric: Percentage of materials sourced from manufacturers who meet sustainable practices requirements.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team establish a preference for using manufacturers, suppliers and service companies that have strong sustainable policies and practices?	○	◉	○	?
Will the project team establish a sound and viable sustainable procurement program?	◉	○	○	?
Does the project team intend to source at least 15% of project materials, equipment, supplies and services from these companies?	○	○	◉	?
Total	1	of	2	

RA 1.3 Use Recycled Materials				
Intent: Reduce the use of virgin materials and avoid sending useful materials to landfills by specifying reused materials, including structures, and material with recycled content.				
Metric: Percentage of project materials that are reused or recycled.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team consider the appropriate reuse of existing structures and materials and incorporated them into the project?	◉	○	○	?
Will the project team specify that at least 5% of materials with recycled content be used on the project?	○	◉	○	?
Total	1	of	2	

RA 1.4 Use Regional Materials				
Intent: Minimize transportation costs and impacts and retain regional benefits through specifying local sources.				
Metric: Percentage of project materials by type and weight or volume sourced within the required distance.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team work to identify local/regional sources of materials?	○	◉	○	?
Are at least 30% of project materials locally sourced?	○	○	◉	?
Total	0	of	1	

RA 1.5 Divert Waste from Landfills				
Intent: Reduce waste and divert waste streams away from disposal to recycling and reuse.				
Metric: Percentage of total waste diverted from disposal.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team identify potential recycling and reuse destinations for construction and demolition waste generated on site?	○	◉	○	?
Will the project team develop an operations waste management plan to decrease and divert project waste from landfills and incinerators during construction and operation?	○	○	◉	?
Will the project divert at least 25% of project waste from landfills?	○	○	◉	?
Total	0	of	1	

RA 1.6 Reduce Excavated Materials Taken Off Site				
Intent: Minimize the movement of soils and other excavated materials off site to reduce transportation and environmental impacts.				
Metric: Percentage of excavated material retained on site.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be designed to balance cut and fill to reduce the amount of excavated material taken off site?	○	○	●	?
When necessary, will the project team taken steps to identify local sources/receivers of excavated material?	○	○	●	?
Will the project reuse at least 30% of suitable excavated material onsite?	○	○	●	?
Total	0	of	0	

RA 1.7 Provide for Deconstruction and Recycling				
Intent: Encourage future recycling, up-cycling, and reuse by designing for ease and efficiency in project disassembly or deconstruction at the end of its useful life.				
Metric: Percentage of components that can be easily separated for disassembly or deconstruction.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team assess whether materials specified can be easily recycled or reused after the useful life of the project has ended?	●	○	○	?
Will the project be designed so that at least 15% of project materials can be easily separated for recycling or readily reused at the end of the project's useful life?	●	○	○	?
Will the project team incorporate methods for increasing the likelihood of materials recycling when the project is operating?	●	○	○	?
Total	3	of	3	

RA 2.1 Reduce Energy Consumption				
Intent: Conserve energy by reducing overall operation and maintenance energy consumption throughout the project life cycle.				
Metric: Percentage of reductions achieved.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team conduct reviews to identify options for reducing energy consumption during operations and maintenance of the constructed works?	◉	○	○	?
Will the project team conducted feasibility studies and cost analyses to determine the most effective methods for energy reduction and incorporated them into the design?	○	◉	○	?
Is the project expected to achieve at least a 10% reduction in energy consumption?	◉	○	○	?
Total	2	of	3	

RA 2.2 Use Renewable Energy				
Intent: Meet energy needs through renewable energy sources.				
Metric: Extent to which renewable energy resources are incorporated into the design, construction and operation.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the owner and project team identify and analyze options to meet operational energy needs through renewable energy?	○	○	◉	?
Will the project meet at least 25% of its energy needs through renewable energy?	○	○	◉	?
Total	0	of	0	

RA 2.3 Commission and Monitor Energy Systems				
Intent: Ensure efficient functioning and extend useful life by specifying the commissioning and monitoring of the performance of energy systems.				
Metric: Third party commissioning of electrical/mechanical systems and documentation of system monitoring equipment in the design.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Does the owner and project team intend to conduct an independent commissioning of the project's energy and mechanical systems?	○	○	◉	?
Will the project team assemble the necessary information needed to train operations and maintenance workers in a way that facilitates proper training and operations?	○	○	◉	?
Will the design incorporate advanced monitoring systems, such as energy sub-meters, to enable more efficient operations?	○	○	◉	?
Total	0	of	0	

RA 3.1 Protect Fresh Water Availability				
Intent: Reduce the negative net impact on fresh water availability, quantity and quality.				
Metric: The extent to which the project uses fresh water resources without replenishing those resources at their source.				
Assessment Questions:	Yes	No	N/A	
Will the project team assess project water requirements?	○	○	◉	?
Does the project team plan to conduct a comprehensive assessment of the project's long-term impacts on water availability?	○	○	◉	?
Will the project only access water that can be replenished in both quantity and quality?	○	○	◉	?
Will the project consider the impacts of fresh water withdrawal on receiving waters?	○	○	◉	?
Will the project discharge into receiving waters meet quality and quantity requirements for high value aquatic species?	○	○	◉	?
Will the project achieve a net-zero impact on water supply quantity and quality?	○	○	◉	?
Will the project restore the quantity and quality of fresh water surface and groundwater supplies to an undeveloped native ecosystem condition?	○	○	◉	?
Total	0	of	0	

RA 3.2 Reduce Potable Water Consumption				
Intent: Reduce overall potable water consumption and encourage the use of greywater, recycled water, and storm water to meet water needs.				
Metric: Percentage of water reduction.				
Assessment Questions:	Yes	No	N/A	
Will the project team conduct planning or design reviews to identify potable water reduction strategies?	○	○	◉	?
Will the project team conduct feasibility and cost analysis to determine the most effective methods for potable water reduction and incorporated them into the design?	○	○	◉	?
Will the project achieve at least a 25% reduction in potable water consumption?	○	○	◉	?
Will the project result in a net positive generation of water, and water up-cycling, as a result of on-site purification or treatment?	○	○	◉	?
Total	0	of	0	

RA 3.3 Monitor Water Systems				
Intent: Implement programs to monitor water systems performance during operations and their impacts on receiving waters.				
Metric: Documentation of system in the design				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the owner and project team conduct an independent commissioning/monitoring of the project's water systems in order to validate the design objectives?	○	○	◉	?
Will the project design incorporate the means to monitor water performance during operations?	○	○	◉	?
Will the project integrate long-term operations and impact monitoring to mitigate negative impacts and improve efficiency?	◉	○	○	?
Will specific strategies be put in place to utilize monitoring and leak detection in order for the project to be more responsive to changing operating conditions?	○	○	◉	?
Total	1	of	1	

A.4 Envision Rating System for Natural World (Envision, 2016)

NW 1.1 Preserve Prime Habitat				
Intent: Avoid placing the project – and the site compound/temporary works – on land that has been identified as of high ecological value or as having species of high value.				
Metric: Avoidance of high ecological value sites and establishment of protective buffer zones.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team take steps to identify and document areas of prime habitat near or on the site?	◉	○	○	?
Will the project avoid development on land that is judged to be prime habitat?	◉	○	○	?
Will the project establish a minimum 300 ft. natural buffer zone around all areas deemed prime habitat?	◉	○	○	?
Will the project significantly increase the area of prime habitat through habitat restoration?	◉	○	○	?
Will the project improve habitat connectivity by linking habitats?	◉	○	○	?
Total	5	of	5	

NW 1.2 Protect Wetlands and Surface Water				
Intent: Protect, buffer, enhance and restore areas designated as wetlands, shorelines, and waterbodies by providing natural buffer zones, vegetation and soil protection zones.				
Metric: Size of natural buffer zone established around all wetlands, shorelines, and waterbodies.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project avoid development on wetlands, shorelines, and waterbodies?	◉	○	○	?
Will the project maintain soil protection zones (VSPV) around all wetlands, shorelines, and waterbodies?	◉	○	○	?
Will the project restore degraded existing buffer zones to a natural state?	◉	○	○	?
Total	3	of	3	

NW 1.3 Preserve Prime Farmland				
Intent: Identify and protect soils designated as prime farmland, unique farmland, or farmland of statewide importance.				
Metric: Percentage of prime farmland avoided during development.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will this project avoid development on land designated as prime farmland?	◉	○	○	?
Total	1	of	1	

NW 1.4 Avoid Adverse Geology				
Intent: Avoid development in adverse geologic formations and safeguard aquifers to reduce natural hazards risk and preserve high quality groundwater resources.				
Metric: Degree to which natural hazards and sensitive aquifers are avoided and geologic functions maintained.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team identify and address the impacts of sensitive or adverse geology?	◉	○	○	?
Will the project be designed to reduce the risk of damage to sensitive geology?	◉	○	○	?
Will the project be designed to reduce the risk of damage from adverse geology?	◉	○	○	?
Total	3	of	3	

NW 1.5 Preserve Floodplain Functions				
Intent: Preserve floodplain functions by limiting development and development impacts to maintain water management capacities and capabilities.				
Metric: Efforts to avoid floodplains or maintain predevelopment floodplain functions.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project avoid or limit development within the design frequency floodplain?	◉	○	○	?
Will the project maintain pre-development floodplain infiltration and water quality?	◉	○	○	?
Will the project design incorporate a flood emergency operations and/or evacuation plan?	◉	○	○	?
Will the project maintain or enhance riparian and aquatic habitat, including aquatic habitat connectivity?	◉	○	○	?
Will the project maintain sediment transport?	○	◉	○	?
Does the project team intend to modify or remove infrastructure subject to frequent damage by floods?	◉	○	○	?
Total	5	of	6	

NW 1.6 Avoid Unsuitable Development on Steep Slopes				
Intent: Protect steep slopes and hillsides from inappropriate and unsuitable development in order to avoid exposures and risks from erosion and landslides, and other natural hazards.				
Metric: The degree to which development on steep slopes is avoided, or to which erosion control and other measures are used to protect the constructed works as well as other downslope structures.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team use best management practices to manage erosion and prevent landslides?	◉	○	○	?
Will the project team minimize or avoid all development on or disruption to steep slopes?	◉	○	○	?
Total	2	of	2	

NW 1.7 Preserve Greenfields				
Intent: Conserve undeveloped land by locating projects on previously developed grey field sites and/or sites classified as brownfields.				
Metric: Percentage of site that is a grey field or the use and cleanup of a site classified as a brownfield.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team consider how the project can conserve undeveloped land?	◉	○	○	?
Will at least 25% of the project development be located on previously developed sites, that is, sites classified as grey fields or brownfields?	◉	○	○	?
Total	2	of	2	

NW 2.1 Manage Storm water				
Intent: Minimize the impact of infrastructure on storm water runoff quantity and quality.				
Metric: Infiltration and evapotranspiration capacity of the site and return to pre-development capacities.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be designed to reduce storm runoff to pre-development conditions?	◉	○	○	?
Will the project be designed to significantly improve water storage capacity?	○	○	◉	?
Total	1	of	1	

NW 2.2 Reduce Pesticides and Fertilizer Impacts				
Intent: Reduce non-point source pollution by reducing the quantity, toxicity, bioavailability and persistence of pesticides and fertilizers, or by eliminating the need for the use of these materials.				
Metric: Efforts made to reduce the quantity, toxicity, bioavailability and persistence of pesticides and fertilizers used on site, including the selection of plant species and the use of integrated pest management techniques.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will operational policies be put in place to control and reduce the application of fertilizers and pesticides?	○	○	◉	?
Will the project include runoff controls to minimize contamination of ground and surface water?	○	○	◉	?
Will the project team select landscaping plants to minimize the need for fertilizer or pesticides?	○	○	◉	?
Will the project team select fertilizers and pesticides appropriate for site conditions with low-toxicity, persistence, and bioavailability?	○	○	◉	?
Will the project be designed to eliminate the need for pesticides or fertilizers?	○	○	◉	?
Total	0	of	0	

NW 2.3 Prevent Surface and Groundwater Contamination				
Intent: Preserve fresh water resources by incorporating measures to prevent pollutants from contaminating surface and groundwater and monitor impacts over operations.				
Metric: Designs, plans and programs instituted to prevent and monitor surface and groundwater contamination.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team conduct or acquire hydrologic delineation studies?	○	○	◉	?
Will spill and leak prevention and response plans and design be incorporated into the design?	○	○	◉	?
Will the project design reduce or eliminate potentially polluting substances from the project?	○	○	◉	?
Will the project team seek to reduce future contamination by cleaning up areas of contamination and instituting land use controls to limit the introduction of future contamination sources?	○	○	◉	?
Total	0	of	0	

NW 3.1 Preserve Species Biodiversity				
Intent: Protect biodiversity by preserving and restoring species and habitats.				
Metric: Degree of habitat protection.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team identify existing habitats on and near the project site?	○	○	◉	?
Will the project protect existing habitats?	◉	○	○	?
Will the project increase the quality or quantity of existing habitat?	○	○	◉	?
Will the project preserve, or improve, wildlife movement corridors?	○	○	◉	?
Total	1	of	1	

NW 3.2 Control Invasive Species				
Intent: Use appropriate non-invasive species and control or eliminate existing invasive species.				
Metric: Degree to which invasive species have been reduced or eliminated.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team specify locally appropriate and non-invasive plants on the site?	○	○	◉	
Will the project team implement a comprehensive management plan to identify, control, and/or eliminate, invasive species?	○	○	◉	
Will the project team implement a comprehensive management plan to prevent or mitigate the future encroachment of invasive species?	○	○	◉	
Total	0	of	0	

NW 3.3 Restore Disturbed Soils				
Intent: Restore soils disturbed during construction and previous development to bring back ecological and hydrological functions.				
Metric: Percentage of disturbed soils restored.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project restore 100% of soils disturbed during construction?	◉	○	○	
Will the project restore 100% of soils disturbed by previous development?	◉	○	○	
Total	2	of	2	

NW 3.4 Maintain Wetland and Surface Water Functions				
Intent: Maintain and restore the ecosystem functions of streams, wetlands, waterbodies and their riparian areas.				
Metric: Number of functions maintained and restored.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project maintain or enhance hydrologic connection?	○	○	◉	?
Will the project maintain or enhance water quality?	○	○	◉	?
Will the project maintain or enhance habitat?	○	○	◉	?
Will the project maintain or restore sediment transport?	○	○	◉	?
Will wetlands and surface water be maintained or restored so as to have a fully functioning aquatic and riparian ecosystem?	○	○	◉	?
Total	0	of	0	

A.5 Envision Rating System for Climate and Risk (Envision, 2016)

CR1.1 Reduce Greenhouse Gas Emissions				
Intent: Conduct a comprehensive life-cycle carbon analysis and use this assessment to reduce the anticipated amount of net greenhouse gas emissions during the life cycle of the project, reducing project contribution to climate change.				
Metric: Percent reduction of life-cycle net carbon dioxide equivalent (CO_2e) emissions.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will a life-cycle carbon assessment be conducted on the project?	◉	○	○	?
Based on that assessment, will the project be designed to reduce carbon emissions by at least 10%?	◉	○	○	?
Total	2	of	2	

CR 1.2 Reduce Air Pollutant Emissions				
Intent: Reduce the emission of six criteria pollutants; particulate matter (including dust), ground level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, lead, and noxious odors.				
Metric: Measurements of air pollutants as compared to standards used.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be designed in a way that substantially reduces dust and odors on the site?	●	○	○	?
Will the project be designed in a way that substantially exceeds the National Ambient Air Quality Standards (NAAQS) for the six criteria pollutants?	○	●	○	?
Total	1	of	2	

CR 2.1 Assess Climate Threat				
Intent: Develop a comprehensive Climate Impact Assessment and Adaptation Plan.				
Metric: Summary of steps taken to prepare for climate variation and natural hazards.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team develop a Climate Impact Assessment and Adaptation Plan?	○	●	○	?
Total	0	of	1	

CR 2.2 Avoid Traps and Vulnerabilities				
Intent: Avoid traps and vulnerabilities that could create high, long-term costs and risks for the affected communities.				
Metric: The extent of the assessment of potential long-term traps, vulnerabilities and risks due to long-term changes such as climate change and the degree to which these were addressed in the project design and in community design criteria.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will a comprehensive review be conducted to identify the potential risks and vulnerabilities that would be created or made worse by the project?	●	○	○	?
Is there an intent by the owner or the project team to alter the design to reduce or eliminate these risks and vulnerabilities?	●	○	○	?
Total	2	of	2	

CR 2.3 Prepare for Long-Term Adaptability				
Intent: Prepare infrastructure systems to be resilient to the consequences of long-term climate change, perform adequately under altered climate conditions, or adapt to other long-term change scenarios.				
Metric: The degree to which the project has been designed for long-term resilience and adaptation.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be designed to accommodate a changing operating environment throughout the project life cycle?	◉	○	○	?
Total	1	of	1	

CR 2.4 Prepare for Short-Term Hazards				
Intent: Increase resilience and long-term recovery prospects of the project and site from natural and man-made short-term hazards.				
Metric: Steps taken to improve protection measures beyond existing regulations.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will a hazard analysis be conducted covering the likely natural and man-made hazards in the project area?	◉	○	○	?
Will the project be designed so that is it is able to recover quickly and cost-effectively from short-term hazard events?	○	◉	○	?
Total	1	of	2	

CR 2.5 Manage Heat Island Effects				
Intent: Minimize surfaces with a low solar reflectance index (SRI) to reduce localized heat accumulation and manage microclimates.				
Metric: Percentage of site area that meets SRI Criteria.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be designed to reduce heat island effects by reducing the percentage of low solar reflectance index (SRI) surfaces?	○	○	◉	?
Total	0	of	0	

Appendix B : Application of Envision on Retrofitted Neighborhoods at Gulshan, Dhaka

B.1 Envision Rating System for Quality of Life (Envision, 2016)

QL 1.1 Improve Community Quality of Life				
Intent: Improve the net quality of life of all communities affected by the project and mitigate negative impacts to communities.				
Metric: Measures taken to assess community needs and improve quality of life while minimizing negative impacts.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Are the relevant community needs, goals and issues being addressed in the project?	◉	○	○	?
Are the potentially negative impacts of the project on the host and nearby communities been reduced or eliminated?	◉	○	○	?
Has the project design received broad community endorsement, including community leaders and stakeholder groups?	◉	○	○	?
Total	3	of	3	

QL 1.2 Stimulate Sustainable Growth and Development				
Intent: Support and stimulate sustainable growth and development, including improvements in job growth, capacity building, productivity, business attractiveness and livability.				
Metric: Assessment of the project's impact on the community's sustainable economic growth and development.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project contribute significantly to local employment?	◉	○	○	?
Will the project make a significant increase in local productivity?	◉	○	○	?
Will the project make the community more attractive to people and businesses?	◉	○	○	?
Total	3	of	3	

QL 1.3 Develop Local Skills and Capabilities				
Intent: Expand the knowledge, skills and capacity of the community workforce to improve their ability to grow and develop.				
Metric: The extent to which the project will improve local employment levels, skills mix and capabilities.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Does the project team intend to hire and train a substantial number of local workers?	◉	○	○	?
Does the project team intend to use a substantial number of local suppliers and specialty firms?	◉	○	○	?
Will the project, through local employment, subcontracting and education programs, make a substantial improvement in local capacity and competitiveness?	◉	○	○	?
Total	3	of	3	

QL 2.1 Enhance Public Health and Safety				
Intent: Take into account the health and safety implications of using new materials, technologies or methodologies above and beyond meeting regulatory requirements.				
Metric: Efforts to exceed normal health and safety requirements, taking into account additional risks in the application of new technologies, materials and methodologies.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Does the owner and the project team intend to identify, assess and institute new standards to address additional risks and exposures created by the application of new technologies, materials, equipment and/or methodologies?	◉	○	○	?
Total	1	of	1	

QL 2.2 Minimize Noise and Vibration				
Intent: Minimize noise and vibration generated during construction and in the operation of the completed project to maintain and improve community livability.				
Metric: The extent to which noise and vibration will be reduced during construction and operation.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project reduce noise and vibration to levels below local permissible levels during construction and operation?	○	◉	○	?
Total	0	of	1	

QL 2.3 Minimize Light Pollution				
Intent: Prevent excessive glare, light at night, and light directed skyward to conserve energy and reduce obtrusive lighting and excessive glare.				
Metric: Lighting meets minimum standards for safety but does not spill over into areas beyond site boundaries, nor does it create obtrusive and disruptive glare.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be designed to reduce excessive lighting, prevent light spillage and preserve/restore the night sky?	○	○	●	?
Total	0	of	0	

QL 2.4 Improve Community Mobility and Access				
Intent: Locate, design and construct the project in a way that eases traffic congestion, improves mobility and access, does not promote urban sprawl, and otherwise improves community livability.				
Metric: Extent to which the project improves access and walkability, reductions in commute times, traverse times to existing facilities and transportation. Improved user safety considering all modes, e.g., personal vehicle, commercial vehicle, transit and bike/pedestrian.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project provide good, safe access to adjacent facilities, amenities and transportation hubs?	●	○	○	?
Will the project design take into consideration the expected traffic flows and volumes in and around the project site to improve overall mobility and efficiency?	●	○	○	?
Has the project team coordinated the design with other infrastructure assets to reduce traffic congestion, and improve walkability and livability?	●	○	○	?
Total	3	of	3	

QL 2.5 Encourage Alternative Modes of Transportation				
Intent: Improve accessibility to non-motorized transportation and public transit. Promote alternative transportation and reduce congestion.				
Metric: The degree to which the project has increased walkability, use of public transit, non-motorized transit.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be within walking distance of accessible multi-modal transportation?	●	○	○	?
Through its design, will the project encourage the use of transit and/or non-motorized transportation?	●	○	○	?
Total	2	of	2	

QL 2.6 Improve Accessibility, Safety and Wayfinding				
Intent: Improve user accessibility, safety, and wayfinding of the site and surrounding areas.				
Metric: Clarity, simplicity, readability and broad-population reliability in wayfinding, user benefit and safety.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project contain the appropriate signage for safety and wayfinding in and around the constructed works?	◉	○	○	?
Will the project address safety and accessibility in and around the constructed works for users and emergency personnel?	◉	○	○	?
Will the project extend accessibility and intuitive signage to protect nearby sensitive sites or neighborhoods?	◉	○	○	?
Total	3	of	3	

QL 3.1 Preserve Historic and Cultural Resources				
Intent: Preserve or restore significant historical and cultural sites and related resources to preserve and enhance community cultural resources.				
Metric: Summary of steps taken to identify, preserve or restore cultural resources.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project minimize negative impacts on historic and cultural resources?	○	○	◉	?
Will the project be designed so that it fully preserves and/or restores historic/cultural resources on or near the project site?	○	○	◉	?
Total	0	of	2	

QL 3.2 Preserve Views and Local Character				
Intent: Design the project in a way that maintains the local character of the community and does not have negative impacts on community views.				
Metric: Thoroughness of efforts to identify important community views and aspects of local landscape, including communities, and incorporate them into the project design.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be designed in a way that preserves views and local character?	◉	○	○	?
Will the project be designed to improve local character, views or the natural landscape through preservation and/or restorative actions?	◉	○	○	?
Total	2	of	2	

QL 3.3 Enhance Public Space				
Intent: Improve existing public space including parks, plazas, recreational facilities, or wildlife refuges to enhance community livability.				
Metric: Plans and commitments to preserve, conserve, enhance and/or restore the defining elements of the public space.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project make meaningful enhancements to public space?	◉	○	○	?
Will the project result in a substantial restoration to public space?	◉	○	○	?
Total	2	of	2	

B.2 Envision Rating System for Leadership (Envision, 2016)

LD1.1 Provide Effective Leadership and Commitment				
Intent: Provide effective leadership and commitment to achieve project sustainability goals.				
Metric: Demonstration of meaningful commitment of the project owner and the project team to the principles of sustainability and sustainable performance improvement.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Has the project team issued public statements stating their commitment to sustainability?	◉	○	○	?
Is the project team's commitment to sustainability backed up by examples of actions taken or to be taken?	◉	○	○	?
Do these commitments and actions demonstrate sufficiently that sustainability is a core value of the project team?	◉	○	○	?
Total	3	of	3	

LD 1.2 Establish a Sustainability Management System				
Intent: Create a project management system that can manage the scope, scale and complexity of a project seeking to improve sustainable performance.				
Metric: The organizational policies, authorities, mechanisms and business processes that have been put in place and the judgment that they are sufficient for the scope, scale and complexity of the project.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Does the project team intend to establish a sound, workable sustainability management system that meets the requirements of the project?	◉	○	○	?
Total	1	of	1	

LD 1.3 Foster Collaboration and Teamwork				
Intent: Eliminate conflicting design elements, and optimize system by using integrated design and delivery methodologies and collaborative processes.				
Metric: The extent of collaboration within the project team and the degree to which project delivery processes incorporate whole systems design and delivery approaches.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Are the project owner and the project team intending to take a systems view of the project, considering the performance relationship of this project to other community infrastructure elements?	◉	○	○	?
Will the project owner and the project team establish a collaborative relationship on the project to achieve higher levels of sustainable performance?	◉	○	○	?
Will the project owner and the project team institute a whole systems design and delivery process with the objective of maximizing sustainable performance?	◉	○	○	?
Total	3	of	3	

LD 1.4 Provide for Stakeholder Involvement				
Intent: Establish sound and meaningful programs for stakeholder identification, engagement and involvement in project decision making.				
Metric: The extent to which project stakeholders are identified and engaged in project decision making. Satisfaction of stakeholders and decision makers in the involvement process.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will key stakeholders in the project be identified and lines of communication established?	◉	○	○	?
Does the project team plan to engage with stakeholders and solicit stakeholder feedback?	◉	○	○	?
Will the project team establish a strong stakeholder involvement process designed to involve the public meaningfully in project decision-making?	◉	○	○	?
Total	3	of	3	

LD 2.1 Pursue By-Product Synergy Opportunities				
Intent: Reduce waste, improve project performance and reduce project costs by identifying and pursuing opportunities to use unwanted by-products or discarded materials and resources from nearby operations.				
Metric: The extent to which the project team identified project materials needs, sought out nearby facilities with by-product resources that could meet those needs and capture synergy opportunities.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team establish a program to locate, assess and make use of unwanted by-products and materials on the project?	◉	○	○	?
Total	1	of	1	

LD 2.2 Improve Infrastructure Integration				
Intent: Design the project to take into account the operational relationships among other elements of community infrastructure which results in an overall improvement in infrastructure efficiency and effectiveness.				
Metric: The extent to which the design of the delivered works integrates with existing and planned community infrastructure, and results in a net improvement in efficiency and effectiveness.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team seek to optimize sustainable performance at the infrastructure component level?	◉	○	○	?
Will the project team seek to optimize sustainable performance by designing the project as an integrated system?	◉	○	○	?
Will the project be planned and designed so that its operation and functions are fully integrated with all infrastructure elements in the community?	◉	○	○	?
Total	3	of	3	

LD 3.1 Plan For Long-term Maintenance and Monitoring				
Intent: Put in place plans and sufficient resources to ensure as far as practical that ecological protection, mitigation and enhancement measures are incorporated in the project and can be carried out.				
Metric: Comprehensiveness and detail of long-term monitoring and maintenance plans, and commitment of resources to fund the activities.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project have a plan for long term monitoring and maintenance?	◉	○	○	?
Will that plan be sufficiently comprehensive, covering all aspects of long-term monitoring and maintenance?	◉	○	○	?
Total	2	of	2	

LD 3.2 Address Conflicting Regulations and Policies				
Intent: Work with officials to Identify and address laws, standards, regulations or policies that may unintentionally create barriers to implementing sustainable infrastructure.				
Metric: Efforts to identify and change laws, standards, regulations and/or policies that may unintentionally run counter to sustainability goals, objectives and practices.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will an assessment of applicable regulations, policies and standards be done, identifying those that may run counter to project sustainable performance goals, objectives and targets?	●	○	○	?
Do the owner and the project team intend to approach decision-makers to resolve conflicts?	●	○	○	?
Total	2	of	2	

LD 3.3 Extend Useful Life				
Intent: Extend a project's useful life by designing a completed project that is more durable, flexible, and resilient.				
Metric: The degree to which the project team incorporates full life-cycle thinking in improving the durability, flexibility, and resilience of the project.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be designed in ways that extend substantially the useful life of the project?	●	○	○	?
Total	1	of	1	

B.3 Envision Rating System for Resource Allocation (Envision, 2016)

RA1.1 Reduce Net Embodied Energy				
Intent: Conserve energy by reducing the net embodied energy of project materials over the project life.				
Metric: Percentage reduction in net embodied energy from a life cycle energy assessment.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Does the project team plan to conduct an assessment of the embodied energy of key materials over the project life?	●	○	○	?
Will the project achieve at least a 10% reduction in net embodied energy over the life of the project?	○	●	○	?
Total	1	of	2	

RA 1.2 Support Sustainable Procurement Practice				
Intent: Obtain materials and equipment from manufacturers and suppliers who implement sustainable practices.				
Metric: Percentage of materials sourced from manufacturers who meet sustainable practices requirements.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team establish a preference for using manufacturers, suppliers and service companies that have strong sustainable policies and practices?	○	●	○	?
Will the project team establish a sound and viable sustainable procurement program?	●	○	○	?
Does the project team intend to source at least 15% of project materials, equipment, supplies and services from these companies?	○	○	●	?
Total	1	of	2	

RA 1.3 Use Recycled Materials				
Intent: Reduce the use of virgin materials and avoid sending useful materials to landfills by specifying reused materials, including structures, and material with recycled content.				
Metric: Percentage of project materials that are reused or recycled.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team consider the appropriate reuse of existing structures and materials and incorporated them into the project?	○	●	○	?
Will the project team specify that at least 5% of materials with recycled content be used on the project?	○	●	○	?
Total	0	of	2	

RA 1.4 Use Regional Materials				
Intent: Minimize transportation costs and impacts and retain regional benefits through specifying local sources.				
Metric: Percentage of project materials by type and weight or volume sourced within the required distance.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team work to identify local/regional sources of materials?	○	●	○	?
Are at least 30% of project materials locally sourced?	○	○	●	?
Total	0	of	1	

RA 1.5 Divert Waste from Landfills				
Intent: Reduce waste and divert waste streams away from disposal to recycling and reuse.				
Metric: Percentage of total waste diverted from disposal.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team identify potential recycling and reuse destinations for construction and demolition waste generated on site?	○	●	○	?
Will the project team develop an operations waste management plan to decrease and divert project waste from landfills and incinerators during construction and operation?	○	○	●	?
Will the project divert at least 25% of project waste from landfills?	○	○	●	?
Total	0	of	1	

RA 1.6 Reduce Excavated Materials Taken Off Site				
Intent: Minimize the movement of soils and other excavated materials off site to reduce transportation and environmental impacts.				
Metric: Percentage of excavated material retained on site.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be designed to balance cut and fill to reduce the amount of excavated material taken off site?	○	○	◉	?
When necessary, will the project team taken steps to identify local sources/receivers of excavated material?	○	○	◉	?
Will the project reuse at least 30% of suitable excavated material onsite?	○	○	◉	?
Total	0	of	0	

RA 1.7 Provide for Deconstruction and Recycling				
Intent: Encourage future recycling, up-cycling, and reuse by designing for ease and efficiency in project disassembly or deconstruction at the end of its useful life.				
Metric: Percentage of components that can be easily separated for disassembly or deconstruction.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team assess whether materials specified can be easily recycled or reused after the useful life of the project has ended?	◉	○	○	?
Will the project be designed so that at least 15% of project materials can be easily separated for recycling or readily reused at the end of the project's useful life?	◉	○	○	?
Will the project team incorporate methods for increasing the likelihood of materials recycling when the project is operating?	◉	○	○	?
Total	3	of	3	

RA 2.1 Reduce Energy Consumption				
Intent: Conserve energy by reducing overall operation and maintenance energy consumption throughout the project life cycle.				
Metric: Percentage of reductions achieved.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team conduct reviews to identify options for reducing energy consumption during operations and maintenance of the constructed works?	◉	○	○	?
Will the project team conducted feasibility studies and cost analyses to determine the most effective methods for energy reduction and incorporated them into the design?	○	◉	○	?
Is the project expected to achieve at least a 10% reduction in energy consumption?	◉	○	○	?
Total	2	of	3	

RA 2.2 Use Renewable Energy				
Intent: Meet energy needs through renewable energy sources.				
Metric: Extent to which renewable energy resources are incorporated into the design, construction and operation.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the owner and project team identify and analyze options to meet operational energy needs through renewable energy?	○	○	◉	?
Will the project meet at least 25% of its energy needs through renewable energy?	○	○	◉	?
Total	0	of	0	

RA 2.3 Commission and Monitor Energy Systems				
Intent: Ensure efficient functioning and extend useful life by specifying the commissioning and monitoring of the performance of energy systems.				
Metric: Third party commissioning of electrical/mechanical systems and documentation of system monitoring equipment in the design.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Does the owner and project team intend to conduct an independent commissioning of the project's energy and mechanical systems?	○	○	◉	?
Will the project team assemble the necessary information needed to train operations and maintenance workers in a way that facilitates proper training and operations?	○	○	◉	?
Will the design incorporate advanced monitoring systems, such as energy sub-meters, to enable more efficient operations?	○	○	◉	?
Total	0	of	0	

RA 3.1 Protect Fresh Water Availability				
Intent: Reduce the negative net impact on fresh water availability, quantity and quality.				
Metric: The extent to which the project uses fresh water resources without replenishing those resources at their source.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team assess project water requirements?				?
Does the project team plan to conduct a comprehensive assessment of the project's long-term impacts on water availability?				?
Will the project only access water that can be replenished in both quantity and quality?				?
Will the project consider the impacts of fresh water withdrawal on receiving waters?				?
Will the project discharge into receiving waters meet quality and quantity requirements for high value aquatic species?				?
Will the project achieve a net-zero impact on water supply quantity and quality?				?
Will the project restore the quantity and quality of fresh water surface and groundwater supplies to an undeveloped native ecosystem condition?				?
Total	0	of	0	

RA 3.2 Reduce Potable Water Consumption				
Intent: Reduce overall potable water consumption and encourage the use of greywater, recycled water, and storm water to meet water needs.				
Metric: Percentage of water reduction.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team conduct planning or design reviews to identify potable water reduction strategies?				?
Will the project team conduct feasibility and cost analysis to determine the most effective methods for potable water reduction and incorporated them into the design?				?
Will the project achieve at least a 25% reduction in potable water consumption?				?
Will the project result in a net positive generation of water, and water up-cycling, as a result of on-site purification or treatment?				?
Total	0	of	0	

RA 3.3 Monitor Water Systems				
Intent: Implement programs to monitor water systems performance during operations and their impacts on receiving waters.				
Metric: Documentation of system in the design				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the owner and project team conduct an independent commissioning/monitoring of the project's water systems in order to validate the design objectives?	○	○	●	?
Will the project design incorporate the means to monitor water performance during operations?	○	○	●	?
Will the project integrate long-term operations and impact monitoring to mitigate negative impacts and improve efficiency?	●	○	○	?
Will specific strategies be put in place to utilize monitoring and leak detection in order for the project to be more responsive to changing operating conditions?	○	○	●	?
Total	1	of	1	

B.4 Envision Rating System for Natural World (Envision, 2016)

NW 1.1 Preserve Prime Habitat				
Intent: Avoid placing the project – and the site compound/temporary works – on land that has been identified as of high ecological value or as having species of high value.				
Metric: Avoidance of high ecological value sites and establishment of protective buffer zones.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team take steps to identify and document areas of prime habitat near or on the site?	●	○	○	?
Will the project avoid development on land that is judged to be prime habitat?	●	○	○	?
Will the project establish a minimum 300 ft. natural buffer zone around all areas deemed prime habitat?	●	○	○	?
Will the project significantly increase the area of prime habitat through habitat restoration?	●	○	○	?
Will the project improve habitat connectivity by linking habitats?				?
Total	5	of	5	

NW 1.2 Protect Wetlands and Surface Water				
Intent: Protect, buffer, enhance and restore areas designated as wetlands, shorelines, and waterbodies by providing natural buffer zones, vegetation and soil protection zones.				
Metric: Size of natural buffer zone established around all wetlands, shorelines, and waterbodies.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project avoid development on wetlands, shorelines, and waterbodies?	◉	○	○	?
Will the project maintain soil protection zones (VSPV) around all wetlands, shorelines, and waterbodies?	◉	○	○	?
Will the project restore degraded existing buffer zones to a natural state?	◉	○	○	?
Total	3	of	3	

NW 1.3 Preserve Prime Farmland				
Intent: Identify and protect soils designated as prime farmland, unique farmland, or farmland of statewide importance.				
Metric: Percentage of prime farmland avoided during development.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will this project avoid development on land designated as prime farmland?	◉	○	○	?
Total	1	of	1	

NW 1.4 Avoid Adverse Geology				
Intent: Avoid development in adverse geologic formations and safeguard aquifers to reduce natural hazards risk and preserve high quality groundwater resources.				
Metric: Degree to which natural hazards and sensitive aquifers are avoided and geologic functions maintained.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team identify and address the impacts of sensitive or adverse geology?	◉	○	○	?
Will the project be designed to reduce the risk of damage to sensitive geology?	◉	○	○	?
Will the project be designed to reduce the risk of damage from adverse geology?	◉	○	○	?
Total	3	of	3	

NW 1.5 Preserve Floodplain Functions				
Intent: Preserve floodplain functions by limiting development and development impacts to maintain water management capacities and capabilities.				
Metric: Efforts to avoid floodplains or maintain predevelopment floodplain functions.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project avoid or limit development within the design frequency floodplain?	◉	○	○	?
Will the project maintain pre-development floodplain infiltration and water quality?	◉	○	○	?
Will the project design incorporate a flood emergency operations and/or evacuation plan?	◉	○	○	?
Will the project maintain or enhance riparian and aquatic habitat, including aquatic habitat connectivity?	◉	○	○	?
Will the project maintain sediment transport?	○	◉	○	?
Does the project team intend to modify or remove infrastructure subject to frequent damage by floods?	◉	○	○	?
Total	5	of	6	

NW 1.6 Avoid Unsuitable Development on Steep Slopes				
Intent: Protect steep slopes and hillsides from inappropriate and unsuitable development in order to avoid exposures and risks from erosion and landslides, and other natural hazards.				
Metric: The degree to which development on steep slopes is avoided, or to which erosion control and other measures are used to protect the constructed works as well as other downslope structures.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team use best management practices to manage erosion and prevent landslides?	◉	○	○	?
Will the project team minimize or avoid all development on or disruption to steep slopes?	◉	○	○	?
Total	2	of	2	

NW 1.7 Preserve Greenfields				
Intent: Conserve undeveloped land by locating projects on previously developed grey field sites and/or sites classified as brownfields.				
Metric: Percentage of site that is a grey field or the use and cleanup of a site classified as a brownfield.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team consider how the project can conserve undeveloped land?	◉	○	○	?
Will at least 25% of the project development be located on previously developed sites, that is, sites classified as grey fields or brownfields?	◉	○	○	?
Total	2	of	2	

NW 2.1 Manage Storm water				
Intent: Minimize the impact of infrastructure on storm water runoff quantity and quality.				
Metric: Infiltration and evapotranspiration capacity of the site and return to pre-development capacities.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be designed to reduce storm runoff to pre-development conditions?	◉	○	○	?
Will the project be designed to significantly improve water storage capacity?	○	○	◉	?
Total	1	of	1	

NW 2.2 Reduce Pesticides and Fertilizer Impacts				
Intent: Reduce non-point source pollution by reducing the quantity, toxicity, bioavailability and persistence of pesticides and fertilizers, or by eliminating the need for the use of these materials.				
Metric: Efforts made to reduce the quantity, toxicity, bioavailability and persistence of pesticides and fertilizers used on site, including the selection of plant species and the use of integrated pest management techniques.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will operational policies be put in place to control and reduce the application of fertilizers and pesticides?	○	○	◉	?
Will the project include runoff controls to minimize contamination of ground and surface water?	○	○	◉	?
Will the project team select landscaping plants to minimize the need for fertilizer or pesticides?	○	○	◉	?
Will the project team select fertilizers and pesticides appropriate for site conditions with low-toxicity, persistence, and bioavailability?	○	○	◉	?
Will the project be designed to eliminate the need for pesticides or fertilizers?	○	○	◉	?
Total	0	of	0	

NW 2.3 Prevent Surface and Groundwater Contamination				
Intent: Preserve fresh water resources by incorporating measures to prevent pollutants from contaminating surface and groundwater and monitor impacts over operations.				
Metric: Designs, plans and programs instituted to prevent and monitor surface and groundwater contamination.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team conduct or acquire hydrologic delineation studies?	○	○	◉	?
Will spill and leak prevention and response plans and design be incorporated into the design?	○	○	◉	?
Will the project design reduce or eliminate potentially polluting substances from the project?	○	○	◉	?
Will the project team seek to reduce future contamination by cleaning up areas of contamination and instituting land use controls to limit the introduction of future contamination sources?	○	○	◉	?
Total	0	of	0	

NW 3.1 Preserve Species Biodiversity				
Intent: Protect biodiversity by preserving and restoring species and habitats.				
Metric: Degree of habitat protection.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team identify existing habitats on and near the project site?	○	○	◉	?
Will the project protect existing habitats?	◉	○	○	?
Will the project increase the quality or quantity of existing habitat?	○	○	◉	?
Will the project preserve, or improve, wildlife movement corridors?	○	○	◉	?
Total	1	of	1	

NW 3.2 Control Invasive Species				
Intent: Use appropriate non-invasive species and control or eliminate existing invasive species.				
Metric: Degree to which invasive species have been reduced or eliminated.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team specify locally appropriate and non-invasive plants on the site?	○	○	◉	?
Will the project team implement a comprehensive management plan to identify, control, and/or eliminate, invasive species?	○	○	◉	?
Will the project team implement a comprehensive management plan to prevent or mitigate the future encroachment of invasive species?	○	○	◉	?
Total	0	of	0	

NW 3.3 Restore Disturbed Soils				
Intent: Restore soils disturbed during construction and previous development to bring back ecological and hydrological functions.				
Metric: Percentage of disturbed soils restored.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project restore 100% of soils disturbed during construction?	◉	○	○	?
Will the project restore 100% of soils disturbed by previous development?	◉	○	○	?
Total	2	of	2	

NW 3.4 Maintain Wetland and Surface Water Functions				
Intent: Maintain and restore the ecosystem functions of streams, wetlands, waterbodies and their riparian areas.				
Metric: Number of functions maintained and restored.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project maintain or enhance hydrologic connection?	○	○	◉	?
Will the project maintain or enhance water quality?	○	○	◉	?
Will the project maintain or enhance habitat?	○	○	◉	?
Will the project maintain or restore sediment transport?	○	○	◉	?
Will wetlands and surface water be maintained or restored so as to have a fully functioning aquatic and riparian ecosystem?	○	○	◉	?
Total	0	of	0	

B.5 Envision Rating System for Climate and Risk (Envision, 2016)

CR1.1 Reduce Greenhouse Gas Emissions				
Intent: Conduct a comprehensive life-cycle carbon analysis and use this assessment to reduce the anticipated amount of net greenhouse gas emissions during the life cycle of the project, reducing project contribution to climate change.				
Metric: Percent reduction of life-cycle net carbon dioxide equivalent (CO_2e) emissions.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will a life-cycle carbon assessment be conducted on the project?	◉	○	○	?
Based on that assessment, will the project be designed to reduce carbon emissions by at least 10%?	◉	○	○	?
Total	2	of	2	

CR 1.2 Reduce Air Pollutant Emissions				
Intent: Reduce the emission of six criteria pollutants; particulate matter (including dust), ground level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, lead, and noxious odors.				
Metric: Measurements of air pollutants as compared to standards used.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be designed in a way that substantially reduces dust and odors on the site?	◉	○	○	?
Will the project be designed in a way that substantially exceeds the National Ambient Air Quality Standards (NAAQS) for the six criteria pollutants?	○	◉	○	?
Total	1	of	2	

CR 2.1 Assess Climate Threat				
Intent: Develop a comprehensive Climate Impact Assessment and Adaptation Plan.				
Metric: Summary of steps taken to prepare for climate variation and natural hazards.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project team develop a Climate Impact Assessment and Adaptation Plan?	○	◉	○	?
Total	0	of	1	

CR 2.2 Avoid Traps and Vulnerabilities				
Intent: Avoid traps and vulnerabilities that could create high, long-term costs and risks for the affected communities.				
Metric: The extent of the assessment of potential long-term traps, vulnerabilities and risks due to long-term changes such as climate change and the degree to which these were addressed in the project design and in community design criteria.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will a comprehensive review be conducted to identify the potential risks and vulnerabilities that would be created or made worse by the project?	◉	○	○	?
Is there an intent by the owner or the project team to alter the design to reduce or eliminate these risks and vulnerabilities?	◉	○	○	?
Total	2	of	2	

CR 2.3 Prepare for Long-Term Adaptability				
Intent: Prepare infrastructure systems to be resilient to the consequences of long-term climate change, perform adequately under altered climate conditions, or adapt to other long-term change scenarios.				
Metric: The degree to which the project has been designed for long-term resilience and adaptation.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be designed to accommodate a changing operating environment throughout the project life cycle?	◉	○	○	?
Total	1	of	1	

CR 2.4 Prepare for Short-Term Hazards				
Intent: Increase resilience and long-term recovery prospects of the project and site from natural and man-made short-term hazards.				
Metric: Steps taken to improve protection measures beyond existing regulations.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will a hazard analysis be conducted covering the likely natural and man-made hazards in the project area?	◉	○	○	?
Will the project be designed so that is it is able to recover quickly and cost-effectively from short-term hazard events?	○	◉	○	?
Total	1	of	2	

CR 2.5 Manage Heat Island Effects				
Intent: Minimize surfaces with a low solar reflectance index (SRI) to reduce localized heat accumulation and manage microclimates.				
Metric: Percentage of site area that meets SRI Criteria.				
Assessment Questions:	**Yes**	**No**	**N/A**	
Will the project be designed to reduce heat island effects by reducing the percentage of low solar reflectance index (SRI) surfaces?	○	○	◉	?
Total	0	of	0w	