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POLYTECHNIQUE MONTRÉAL

affiliée à l'Université de Montréal

The relationship between built environment characteristics and parents' perceptions of children's traffic safety for active travel

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Mémoire présenté en vue de l'obtention du diplôme de *Maîtrise ès sciences appliquées*

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Ce mémoire intitulé :

The relationship between built environment characteristics and parents' perceptions of children's traffic safety for active travel

présenté par **Yasser AMIOUR**

en vue de l'obtention du diplôme de *Maîtrise ès sciences appliquées*

a été dûment accepté par le jury d'examen constitué de :

Geneviève BOISJOLY, présidente

Owen WAYGOOD, membre et directeur de recherche

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Marie-Soleil CLOUTIER, membre

DEDICATION

"In the name of allah, the most beneficent, the most merciful"

To my parents, who have helped me in every step of my life,

To "Amiour" and "Bouzit" families.

ACKNOWLEDGEMENTS

Dr. E. Owen D. Waygood, has been an ideal teacher, mentor, and thesis supervisor, offering advice and encouragement with a perfect blend of insight and humor. I’m proud of, and grateful for, my time working with you (Owen).

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RÉSUMÉ

Introduction: Les déplacements actifs et indépendants présentent de nombreux avantages pour la santé et le bien-être des enfants. Cependant, la sécurité est une condition préalable aux déplacements actifs (scolaires) des enfants. L'environnement bâti affecte à la fois la sécurité routière objective (collisions impliquant des enfants) et la sécurité routière subjective/ perçue (la perception de la sécurité routière par les parents). Cependant, la relation entre l'environnement bâti et la sécurité routière objective et subjective/perçue n'a pas été bien clarifiée. Il est important de déterminer quelles caractéristiques de l'environnement bâti peuvent influencer la sécurité routière objective et la perception de la sécurité routière des parents pour augmenter les déplacements actifs des enfants. Cette étude examine d'abord la relation entre la sécurité routière objective et subjective/ perçue, puis l'influence des caractéristiques de l'environnement bâti sur la perception de la sécurité routière des parents pour les déplacements actifs des enfants vers l'écoles.

Méthodes: Cette étude est basée principalement sur deux méthodes pour éteindre les objectifs tracés. D'abord, la littérature relative à l'influence de l'environnement bâti, le trafic sur la sécurité routière objective et perçue/subjective a été systématiquement examinée. Ensuite, une étude a été menée auprès de 546 participants à la ville d'Arnhem, aux Pays-Bas, pour examiner la relation entre les caractéristiques de l'environnement bâti et la perception parentale de la sécurité routière pour les déplacements des enfants vers l'écoles.

Résultats: Les résultats de la revue systématique mené pour clarifier la relation entre la sécurité routière objective et subjective ont été présentés dans cette étude. La vitesse élevée du trafic/ véhicules et la densité élevée du trafic sont les deux caractéristiques du trafic qui peuvent augmenter le risque des collisions impliquant des enfants d'une part, et la perception du danger par les parents et les enfants d'une autre part. Cependant, les résultats ont montré des différences dans l'effet des caractéristiques de l'environnement bâti sur la sécurité routière objective et subjective/perçue à l'exception de la présence des trottoirs qui a était liée à la sécurité des enfants (pour la sécurité routière objective et perçue).

La densité élevée des intersections était liée aux perceptions de danger, mais n'était pas statistiquement associée à la sécurité routière objective. En revanche, la densité élevée de la population était positivement liée aux collisions impliquant des enfants, mais pas aux perceptions de la sécurité routière. De plus, la présence des brigadiers et des routes principales (des routes

artérielles, et collectrices) était positivement liée à la sécurité perçue, mais était associée aussi à des taux plus élevés de blessures chez les enfants.

Les résultats de l'étude mené aux Pays-Bas montrent l'influence des caractéristiques de l'environnent bâti sur la perception de la sécurité des parents pour les déplacements des enfants vers l'école.

Une augmentation des routes à faible vitesse et des pistes cyclables séparées augmente la perception de la sécurité des parents. En revanche, l'utilisation résidentielle des terres et le nombre élevé des croisements des routes principales diminuent la perception de la sécurité des parents. De plus, pour les caractéristiques individuels/ ménages seul l'âge des enfants été significativement lié à la perception parentale de la sécurité routière des enfants.

Conclusion: Cette étude a contribué à comprendre le rôle de l'environnent bâti et du trafic sur la relation entre la sécurité routière objective et subjective/ perçue. L'étude a montré aussi l'influence des caractéristiques de l'environnement bâti autour des quartiers d'origine (maisons) et destination (écoles) sur la perception de la sécurité des parents.

La politique future devrait contribuer à réduire la vitesse limite autour des écoles et des maisons, ainsi de réduire le nombre des croisements des routes principales toute au long du chemin de l'école. Augmenter le pourcentage de routes avec des pistes cyclables séparées peut aussi améliorer la sécurité des enfants lors des déplacements actifs vers l'école.

ABSTRACT

Introduction: Active and independent travel has numerous benefits for children's health and wellbeing. However, safety is a prerequisite for children's active (school) travel. The built environment affects both objective traffic safety and parents' perception of safety. However, the relationship between the built environment and both objective and subjective/perceived traffic safety has not been well clarified. It is important to determine which built environment characteristics can influence the objective traffic safety and the parents' perceptions of children's traffic safety to go to school. This study examines first the link between objective and perceived traffic safety, and then the influence of built environment characteristics on the parental safety perception for children travel to school.

Methods: This research is based on two key methods. First, literature related to the built environment, traffic, and objective and perceived/subjective traffic safety was systematically reviewed. Then, a study was conducted with 546 participants in and around Arnhem, the Netherlands to examine the relationship between built environment characteristics and parents' perceptions of children's traffic safety on the trip to school.

Results: The results of the literature study showed that high vehicle speed and traffic density are the two most important traffic characteristics that are found to be related to collisions involving children and perceptions of danger by parents and children. Looking to built environment characteristics, only the presence of sidewalk was related to the safety of children's (for both objective and perceived traffic safety). Intersection density was related to perceptions of danger but was not statistically associated with objective traffic safety. Population density was found to be positively related to children's injuries, but not to perceptions of safety. The presence of a crossing guard and major roads were positively related to perceived safety but were associated with higher rates of children's injuries.

The data from the Netherlands resulted in various findings. The influence of the built environment characteristics on the parental safety perception for each home and school neighborhood level was examined based on survey data. More low speed and separated bicycle lanes increase the safety perception of parents. In contrast, residential land use and the high number of major road crossings decrease parental safety perception. In addition, looking to the individual/ household characteristics, only the age of children is significantly related to the safety perception of parents.

Conclusion: This study contributed to understanding the relationship between objective and perceived traffic safety for children. The study also showed the influence of built environment characteristics around each school and home neighborhood level on parental safety perception. Future policy should decrease the speed limit and the number of major road crossings and increase the percentage of roads with separated bicycle lanes to enhance the safety of children when travelling to/ from school.

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LIST OF SYMBOLS AND ABBREVIATIONS

AC	Active commuting
AT	Active travel/ transportation
ATS	Active transportation to school
CI	Confidence interval
CIM	Children's independent mobility
GIS	Geographic Information System
OR	Odds Ratio
PA	Physical activity
PMVC	Pedestrian-motor vehicle collisions
SES	Socioeconomic status

DEFINITION OF FUNDAMENTAL CONCEPTS

Active transportation	Travel using one's own power such as walking and cycling
Built environment	The man-made environment that provides the appropriate environment for human activity and needs, such as buildings and other major constructions, roads, bridges, etc
Child independent mobility (CIM)	Travel by a child without the accompaniment of an adult
Child independent mobility license	Allowing children to travel independently
Exposure of risk	"Any event, limited in time and space, that has the potential of becoming an accident" [1]
Injuries	Damage to or harm of the body
Marginalized people	People who are socially and economically excluded from society
Objective traffic safety	The number or risk of collisions or injuries
Risk of collisions/ injuries	The probability of collisions or injuries that could be measured by unit of road traffic exposure [2]
Social environment	The environment that pertains to culture, institutions, and relationships between individuals
Subjective /perceived traffic safety	The perception or feeling of traffic safety
Traffic safety measures	The methods or procedures which could avoid or reduce road collisions
Traffic	The movement of vehicles along roads in a particular area
Traffic calming	Measures (e.g. speed bumps) used which can reduce speed limit
Vulnerable road users	Non-motorized road users or persons with disability

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CHAPTER 1 INTRODUCTION

In view of a growing need of active and independent travel for children, traffic safety must be more considered. Focusing on the safety of children when walking or cycling is very important. Children are considered as vulnerable road users as their physical and mental capabilities are still developing. The characteristics of traffic and the built environment can influence the safety of children during active travel. The built environment which contains roadway designs and development patterns could help to increase or decrease the traffic speed and volume. Often, high vehicle speed is the main factor of crash severity, while the traffic volume could increase the crash frequency. Parents' perception of traffic and neighborhood safety also plays a role, knowing that parents would need to have a positive view of safety to let their children travel by active modes.

The relationship between built environment (and traffic) and traffic safety (objective and perceived) is not well clarified. Both objective and perceived traffic safety for children must be more considered.

It is important to understand which built environment (and traffic) characteristics increase safety for children when they are walking and cycling, and to know how those relate to parental perceptions of traffic safety. Therefore, it is critical also to understand which built environment variables may reduce or increase the sense of traffic safety of parents for school and home neighborhoods and along the route to school.

1.1 Research objectives

The main objective of this research is to examine the relationships between the built environment and traffic with objective and perceived safety. To accomplish this, two approaches were taken:

1) A systematic review of existing literature on these topics.
2) An analysis of data on parental perceptions of safety with built environment characteristics.

1.2 Research question

In this thesis, the following research question will be addressed:

> *How do built environment and traffic characteristics influence objective and perceived traffic safety for children's active travel?*

In order to answer this question, three sub-questions will be addressed:

A. Which built environment and traffic characteristics are related to collisions involving children?

B. Which built environment and traffic characteristics could influence the safety perception of parents and children?

C. What is the relationship between objective and perceived traffic safety for children?

D. Which built environment characteristics have an influence on the parents' perceptions of children's traffic safety on the trip to school?

CHAPTER 2 BACKGROUND

Independent mobility is very important for children. It could increase their well-being and experience by allowing them to discover new things during their travels and sharing such experiences with friends [3]. There are many definitions related to children independent mobility (CIM)**,** but the most common definition of (CIM) is presented by Hillman et al. as follows.

> "*Children's freedom to travel around in their neighborhood or city without adult or parental supervision*" [4].

Essentially all independent trips by children will include active travel (e.g., walking, cycling). Active transportation was defined by the Government of Canada as:

> "Using your own power to get from one place to another" (Government of Canada. 2014).

This definition includes walking, running, cycling, using non-motorized scooter, skating, and other non-motorized modes of transport. The most popular are walking and cycling. Previous systematic review on children's active transportation has focused on walking and cycling [5]. The benefits of active travel are numerous. Active travel reduces air pollution, it is also healthy and is associated with an increase physical activity [6], which is very important to reduce obesity. It is also an economical mode of transport compared to a motor vehicle or any motorized mode.

Children are considered as vulnerable road users as their physical capacities are still developing. For children to travel actively and independently, the environment must be safe, and it is important that parents perceive it as safe. Enhancing the safety of children when using active transportation could lead to a decrease in children's injuries and encourage more active and independent travel for children.

Previous studies focused on the correlation between the built environment and the likelihood of walking to school [7], [8], [9], [10]. However, parental safety perception plays a role as well, so we need to consider how this perception is formed. One part is likely linked to the built environment and traffic conditions where people live, but also at the destination.

Improving both objective traffic safety and perceived traffic safety could provide more safe travel for children.

McMillan [11] showed the importance of safety perception of traffic and neighborhood to parental decision-making for children's active and independent travel (Figure 2.1). The urban form could indirectly affect parental decision making by mediating factors such as neighborhood and traffic safety including real safety (e.g, collision, injuries) and perceived safety (e.g., parent's perception), and household mobility resources such as the availability of a particular mode. In this framework parents are a key determinant of children's travel to school, while other moderating factors such as sociodemographics or attitudes may contribute to parents' decision but not directly. Parents judge the neighborhood environment and then decide on how their children will travel to school. Often parents are more concerned for trips where children travel alone **[**12**]**. Parents' perception of traffic and crime-related safety was also associated with children's independent mobility using active transportation such as walking and cycling **[**13**]**. The perception of a safe route to school among adolescents and their parents was a key determinant of cycling to school, and it was found to be more important than distance to school among high school students **[**14**]**.

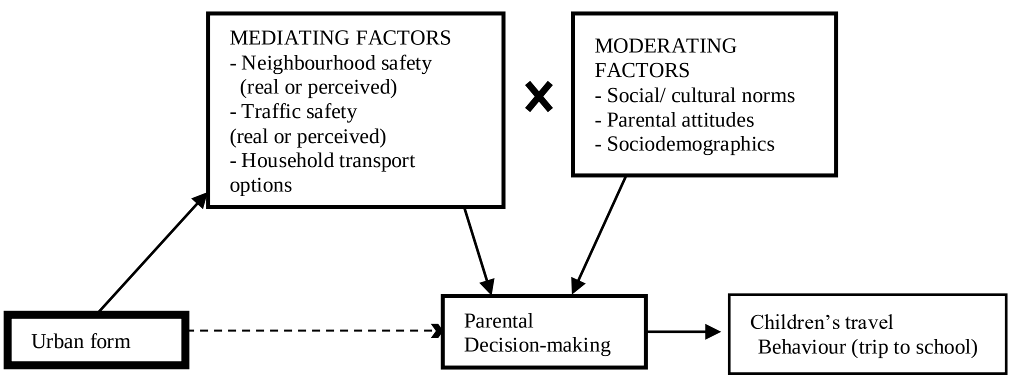

Figure 2.1 McMillan framework [11]

Other models such as Sirard and Slater [5] go into more detail but essentially present similar structures of influence. Mitra and Manaugh [15] developed a social-ecological model of children's independent mobility (CIM), in which the perception of traffic safety could play a role.

The built environment could influence the safety of children when using active transport mode [16]. Built environment characteristics such as streets that are one-way are related to more motor vehicle collision involving child pedestrian [17]. However, the presence of sidewalks around school is negatively related to motor vehicle collisions involving children [18]. Traffic characteristics such as traffic volume and speed could also influence the safety of children when walking or cycling independently [19].

A concept of built environment and traffic safety was presented by Ewing and Dumbaugh [20] (Figure 2.2). The built environment which contains roadway designs and development patterns can affect traffic safety by traffic volume, speed, and conflicts. The severity and frequency of crashes were the measures of traffic safety. Development patterns impact safety: first it affects traffic volume which is the key determinant of crash frequency, and second through traffic speed which is the key determinant of crash severity. Roadway design could also affect traffic safety. First through the speed of traffic, and second, through the traffic volume. Traffic conflicts also have an impact on the severity and frequency of crash but are not a determinant such as traffic speed and traffic volume. High speeds can decrease the available reaction time from drivers and may lead to greater crash severity including fatal injury. High traffic volumes could also increase the frequency of crash because of the high number of motor vehicles and thus potential interactions.

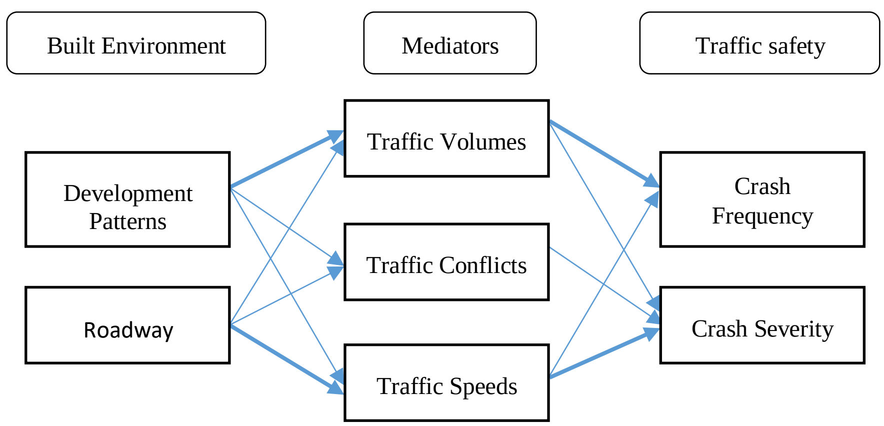

Figure 2.2 Conceptual Framework of built environment related to traffic safety [20]

Previous models mentioned above McMillan [11], Sirard and Slater [5], and Mitra and Manaugh [15] showed the importance of the parental safety perception of traffic and neighborhood for children active and independent travel. Previous research [16], [17], [18], [19], also showed the influence of built environment and traffic on objective traffic safety (collisions involving children). However, the relationship between the influence of the built environment (and traffic) on objective traffic safety and subjective/ perceived traffic is not well clarified**.** The following conceptual framework presents in more detail the relationship that must be studied and the research question that will be addressed.

2.1 Conceptual framework for research project

A conceptual framework for the research project is proposed (Figure 2.3).

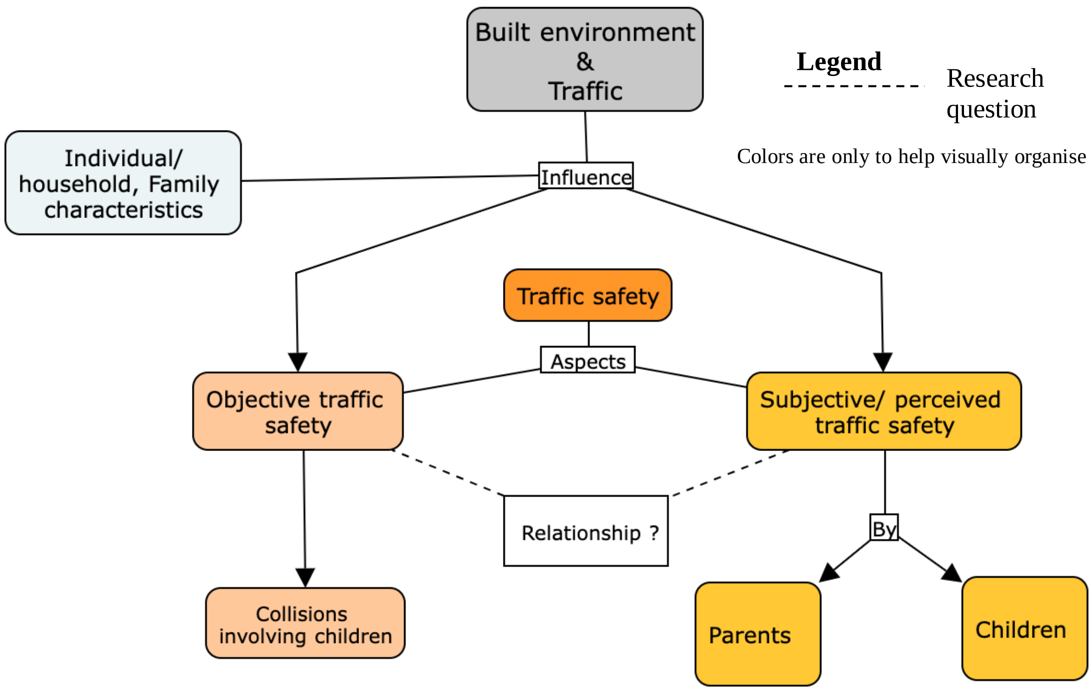

Figure 2.3 Proposed framework for research project

There are two aspects of traffic safety considered in this study: objective traffic safety and subjective/ perceived traffic safety. The first relates to collisions and could result in injuries or fatalities. The second aspect of traffic safety (subjective traffic safety) is the perception of parents or children of traffic safety.

Built environment and traffic characteristics are important elements that could influence traffic safety for children. In addition, individual and household characteristics (e.g., age of children, car ownership) could also influence children's travel safety. For example, Hagel et al. [21] showed the positive relationship between male child bicyclists and severe injury with 1.96 times higher fatality rates compared to female. Wazana et al. [22] identified that younger children between 5 and 9 years were more frequently injured compared to other age groups.

The literature review showed the influence of the built environment (e.g., roadway design) and traffic (e.g., traffic volume) characteristics on objective and perceived traffic safety. However, as shown in Figure 2.3, the relationship between objective and perceived traffic safety has not been well clarified. One of the main objectives is to understand this relationship after examining in depth which built environment characteristics could affect traffic safety for children.

CHAPTER 3 OVERALL DESCRIPTION

The structure of this thesis consists of six chapters, two of which are in article form (chapters 2 and 3).

- Chapter 1 presents a brief introduction of the research study
- Chapter 2 provides a concise background together with a research objective, and research questions.
- This chapter (chapter 3) presents an overall description and thesis structure.
- Chapter 4 presents a systematic literature review on the relationship between the built environment and objective (collisions involving children) and perceived traffic safety (safety perception of parents and children). Two types of research are conducted using five electronic databases. A systematic literature review is conducted to answer the research question which aims to understand the influence of built environment on objective and perceived traffic safety. This research directly aims at responding to the sub-questions A, B and C. The results of this research will further guide the analysis of data in the next step of this Master's thesis.
- Chapter 5 presents a study conducted in and around Arnhem, the Netherlands, with 546 children and their parents. Following the initial literature review (Chapter 2) and the more detailed systematic literature review (Chapter 4), it was apparent that limited research has examined the influence of the built environment on parents' perceptions of travel safety for their children. Thus, this chapter will directly address the question on which built environment characteristics have an influence on the parents' perceptions of children's traffic safety on the trip to school. Surveys were previously conducted where a number of questions on perceptions of safety were asked to their parents. Open access Geographic Information Systems (GIS) data will be used to provide detailed built environment measures for the school and home environment (distinctly). Appropriate statistical analysis are conducted to identify which measures relate to the different measures of safety. Finally, stepwise regression is conducted on a global measure of parents' safety perception. As such, this analysis will contribute to answering the final sub-question on

direct links between objective measures of the built environment and the perceptions of parents.

- Chapter 6 provides a general conclusion and discussion on the main findings of this study along with limitations and future research directions.

CHAPTER 4 ARTICLE 1: OBJECTIVE AND PERCEIVED TRAFFIC SAFETY FOR CHILDREN: A SYSTEMATIC LITERATURE REVIEW OF TRAFFIC AND BUILT ENVIRONMENT CHARACTERISTICS RELATED TO SAFE TRAVEL

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ABSTRACT

Children are one of the large groups of the population identified as vulnerable road users. To facilitate children's active travel, the objective relationships between context (traffic, the built environment) and the safety of children must be understood. This research aims to understand which traffic and built environment characteristics influence objective and subjective/ perceived traffic safety for children based on the analysis of previous studies in the field. Two types of research were used: the first examines the association between traffic and built environment characteristics with child pedestrian and/or cyclist collisions/injuries; the second relates to the perception of safety by parents and children for active transportation and, where studied, its relationship with built environment characteristics. A systematic review was conducted using five electronic databases. The total number of articles retrieved was reduced to 38 following the eligibility criteria and quality assessment, where 25 articles relate to children's injuries and 13 articles pertain to perception of safety. The results showed that high traffic volume and high vehicle speed are the main reasons children and parents feel unsafe when children use active travel, which matches the main findings on objective safety. Few articles on perception of safety related to the objective built environment were found. However, consistent findings exist. The presence of sidewalk was related to the safety of children. The presence of a crossing guard was positively related to perceived safety but were associated with higher rates of children's injuries. Intersection density was related to unsafe perceptions but was not statistically associated with objective traffic safety. Also, population density was found to be positively related to children's injuries, but not to perception of safety. The results help policy strategy to enhance the safety of children when using active transport modes.

Keywords: Injury, perception of safety, children, active transportation, traffic, road design.

4.1 Introduction

Children need to be able to safely travel in the environment where they live whether it is to go to school, play with friends, or engage in other activities. Over the past decade, considerable research has been focused on children's active transportation to school and how it relates to physical activity [23], [24], [25], [26], [9], [27]. Related to that, children's independent mobility continues to be an important topic [28] as children's independent mobility (CIM) could also increase children's well-being [3]. CIM is described as: "Children's freedom to travel around in their neighborhood or city without an adult or parental supervision" [4]. However, a key component of CIM is both perceived and objective traffic safety [29].

Parents are one of the determinants for children's independent mobility by making decisions on whether or not to let their children walk or bike to school or to other destinations [11]. Parents judge traffic, which they do not have control over, but they also train and socialize their children to use different modes [30]. As such, a parent's assessment of a child's skills is also important. Parents feel that long-distance and the danger of traffic are key barriers to walking and cycling to school [31], [32].

Two concepts of traffic safety can be considered. One relates to instances of danger or harm, such as near misses or crashes. The other relates to the individual evaluation of safety, or perceived traffic safety. In this paper, we will use the terms objective safety and perceived safety such as described in several studies [33] ,[34], [35]. Objective traffic safety, also referred to as "real traffic safety" [36], pertains to the number or risk of collisions and any resulting fatalities or injuries caused by road traffic. Perceived traffic safety on the other hand, is the perception of safety or risk caused by road traffic [33], [36], [34]. In the case of children, perceived traffic safety pertains to parents' and children's perception of safety.

The frequency and severity of collisions are often found to be significantly influenced by volume and speed [20]. However, distance plays a role as the longer the distance, the greater the exposure, whether that be the total distance of the trip or the distance crossing motorized traffic infrastructure. Various research has examined motor vehicle crashes involving child pedestrian and cyclist injuries **[**37**], [**38**], [**39**], [**17**]**. Such research often highlights that children are considered to be vulnerable road users as their physical and mental capacities are still developing. In order to create safe environments for all ages and abilities, and to promote active and independent mobility, children's traffic safety must be considered.

The characteristics of traffic and the built environment can influence the safety of children during active travel, but the relationship between objective traffic safety (i.e., instances of collisions) and subjective traffic safety (i.e., the perception of traffic/ road safety) poses a problem to manage the current situation well. For example: imagine that a specific road design characteristic such as one-way streets increases the number of injuries involving children. On the other side, suppose that parents believe that one-way streets are safe for their children to walk or cycle. That would be a problem because there is an inverse correlation between objective (collisions involving children) and subjective/ perceived traffic safety that would possibly increase children's travel in a dangerous environment. As such, one of our main objectives is to see where there is agreement and disagreement between objective and subjective measures of children's traffic safety while conducting active travel (primarily walking or cycling in studies).

Based on the literature review, no systematic review examined the relationship between one's built environment with objective and perceived/subjective traffic safety. A systematic review presented by Rothman et al. [40] examined the role of the built environment on child pedestrian injuries and walking, but they did not focus on perception of safety. This systematic review aims to understand which traffic and built environment characteristics could influence objective (collisions involving children) and perceived safety based on previous related studies.

4.2 Materials and Methods

The study was conducted using five electronic databases: Web of Science (2000-2020), PubMed (2000-2020), Compendex (2000-2020), ScienceDirect (2000-2020) and ProQuest Dissertations & Theses (2000-2020). Specific keywords cannot all be presented here (as they are too numerous), but followed these general themes: perception of safety, injury, traffic, built environment, social environment, children, and active transportation.

Figure 4.1 shows the flow diagram used to identify the relevant articles of the systematic literature review following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement.

The two types of research conducted in the present literature review aim to identify relevant articles of objective and subjective traffic safety for children. The first type of research was limited to articles that examine the association between child pedestrians' or child cyclists' collisions and measures related to traffic and the built environment. The second type of research considered was associated with subjective measures including the safety perception for children active travel and its relationship with traffic and built environment measures. For perceptions, those of parents and children were considered.

The total number of studies retrieved was reduced to 38 studies following eligibility criteria and quality assessment. Following that step, 25 studies for collisions/injuries involving child pedestrian and cyclists were retained and 13 studies contain perceptions of traffic safety. Among the 13 studies selected for perception of safety, there were only 5 studies that examined the statistical relationship between objective-built environment and perception of safety for children. The eight articles (four quantitative and four qualitative studies) contain the parents' and children's answers to questions related to traffic safety when using active transportation without examining the statistical relationship with the objective built environment characteristics. Checklists were used to address the risk of bias in the included studies.

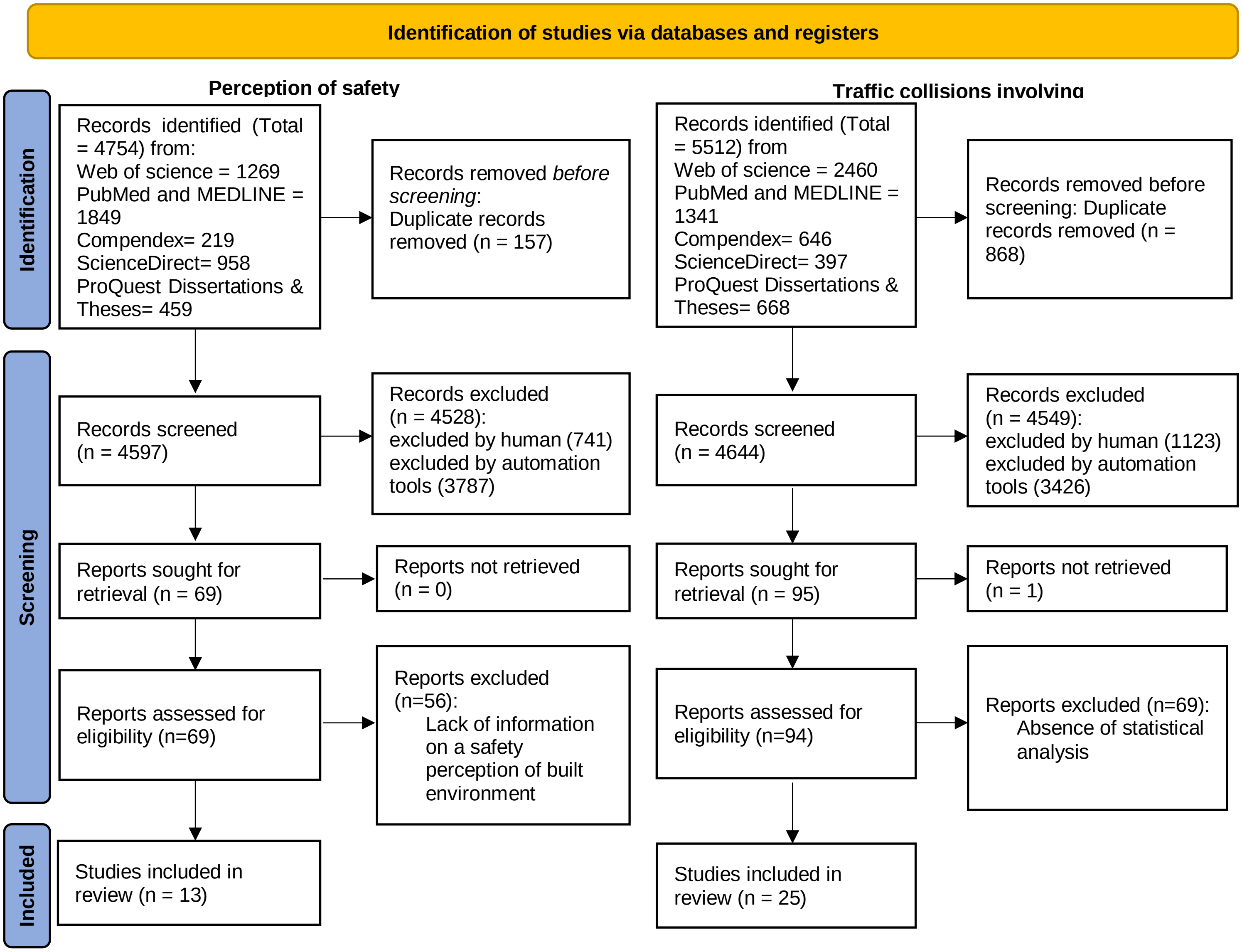

Figure 4.1 Flow diagram for the systematic review following PRISMA statement

4.2.1 Selection criteria

The initial number of studies that presented in Figure 4.1 has been reduced to 38 studies retained for analysis. All duplicate studies were removed in the first step before the screening. The second step was to exclude document types such as literature reviews, conference abstracts, book reviews, or encyclopedia entries. Articles that were not related to subject or articles of other disciplines (e.g. medical purpose) were excluded based on informations provided in databases.

The next step was to screen the articles by human. First, we screened articles based on their abstract. We included only articles that have a relationship between these following fields: objective traffic safety (e.g., collision, injuries) and/or perception of safety when using active travel modes (walking or/and cycling) with built environment and/or traffic. Articles that present the relationship between traffic safety and physical activity or obesity were excluded. Only articles related to active travel safety were retained. Children were limited to 18 years old or less, and samples that did not contain school-aged children were excluded.

In the final screening, we excluded articles based on the full text. For children collisions/injuries results, statistical analyses using various methods (e.g., multivariate analysis) were considered to examine the relationship between children collisions/injuries with built environment and/or traffic. For articles with perception of safety, both qualitative and quantitative studies were considered. The first are often based on parents' responses out of interviews or focus groups, while the second often used results from surveys that applied Likert scale/Point scale to measure perceptions. Some studies examined the association between perception of safety and objective measures of the built environment and traffic. Finally, articles that examine the relationship between objective built environment and either perception of safety or traffic collisions involving children are included and regrouped.

4.2.2 Analysis procedure

For the objective traffic safety (traffic collisions involving children), the outcomes were organized by the level of injury for children (e.g., the severity of injuries, the frequency of injuries). For subjective traffic safety (perception of safety), the outcomes were organized by the level of perceived safety (e.g., unsafe, traffic danger, or high risk to walk or bike). The results are summarized by using one term, children's traffic/ road safety to highlight the links with the traffic and built environment variables including infrastructure and road design features that had a relationship with children's safety for active transportation.

Based on the final relevant articles, to compare the objective and perceived safety results, we organized the results into one table that contains the variables of influence. The results of studies that pertain to each variable are described as unsafe/dangerous, no correlation, and safe/less dangerous. For results that examined a statistical relationship, the words unsafe or dangerous pertain to built environment variables that positively related to children's injuries (25 articles) or a perception of being unsafe (5 articles).

For perceived traffic safety, there were 13 studies in total. Eight studies did not examine any statistical relationship with the built environment. Five studies examined where a statistical relationship with built environment exists. The first used qualitative and quantitative methods (focus group, Likert scale), while the second considered only the quantitative methods.

4.3 Results and discussion

A total of 25 articles related to child pedestrian or bicyclist collisions (whether or not they resulted in injury or death), and a total of 13 articles related to perception of safety. Of the articles retrieved, 66% percent were from North America, representing a large majority. Table 4.1 shows the results of built environment characteristics related to objective and perceived traffic safety.

4.3.1 Traffic elements and children's safety

The two most common traffic variables that have a negative relationship with traffic safety for children, and thus a positive relationship with children's collisions were high traffic speed and high traffic volume.

4.3.1.1 Speed

Increased speeds were generally associated with worse outcomes. A previous review on child pedestrian collisions also found such associations [40]. Street segments with a high speed limit increase the probability of injuries among children who travel to school **[**41**]**, and increase the likelihood of injuries and fatalities for middle and high school-aged children compared to elementary school-aged children **[**42**].** Speeds often used in cities (> 45 km/h and > 50 km/h) are associated with child injuries and collisions **[**43**], [**19**]**. However, two studies did not find a relationship between children's injuries and speed [44], [21]. No correlation was found between the risk of injury and average traffic speed (> 50km/h) at both intersections and at midblock [44]. That study focused only on collisions likely related to school travel (weekday, between 7:00 am and 5:00 pm). The other [21] examined only cyclists omitted to emergency rooms and compared those who were severely injured (had to stay in the hospital) with those who were not. No differentiating relationship was found for posted speeds above 30 km/h between those two groups.

4.3.1.2 Traffic volume

Seven studies found a positive relationship between traffic volume and collisions of children. Two studies **[**45**], [**41**]** showed a positive relationship between traffic volume and children's injuries in two periods. However, a point of difference can be seen for the summer versus school period with one finding increased traffic was significant for both **[**41**],** while the other found it only during the summer period **[**45**]**. A positive impact of average traffic volume was found on the child pedestrian/cyclist casualty rate on classified and unclassified roads. In that study, a classified road is a main or principal road **[**46**]**. A high volume of vehicles was related to a higher risk of road traffic injuries involving child pedestrians **[**43**].** The density of traffic increased collision risk [47], and higher rates of collisions occurred in areas with high traffic volume **[**48**]**. High traffic flow and volume may create congestion, where high traffic congestion was associated with the location of traffic collisions around residential areas **[**19**]**. However, no relationship between children's injuries and average traffic flow (per 1000 vehicles) at midblock was found. However, there is a positive relationship between average traffic flow and children's injuries at intersections **[**44**]**. One study also found that high traffic flow (high number of arriving vehicles in area of focus) was not significantly related with objective safety **[**47**].**

Regarding perception of safety, no studies examined a statistical correlation between vehicle/traffic speed and perception of safety. Two studies examined a statistical relationship between traffic volume and parental perception of safety [49], [50]. Heavy traffic was negatively correlated with parental perception of safety only for boys near school [49], while it was not significantly correlated with parents perception of traffic danger along school route [50].

However, both parents' and children's perceptions of traffic safety were examined based on qualitative and quantitative studies. The results show that high vehicle speed and high traffic volume are the main factors that relate to unsafe perceptions for both children and parents. Parents feel that it is unsafe when children travel on roads with high vehicle speed [51], [52], [14]. Children also do not feel safe when walking or cycling with the presence of high speed vehicles [53], [54], [55], [14], except for one study [52] which found that children indicated their environment was less dangerous than parents (mothers) in the presence of high speed vehicles and high traffic volumes. Children [53], [14], [56], [55] and parents [51], [57], [52] both felt that high traffic volumes were unsafe.

4.3.1.3 Vehicle types

Motor vehicle collisions were associated with severe injury for child bicyclists **[**21**]**. Bicycling frequency (number of uses per time) was not statistically significant to severe injury in child bicyclists, but may decrease the likelihood of severe injuries in child bicyclists **[**21**]**. For child pedestrians, higher walking rates were not found to be associated with a higher risk of motor vehicle collisions **[**17**]**. Higher rates of walking to school were not linked to injuries, and there was no significant link between the proportion of students walking to school and vehicle-pedestrian crashes **[**16**]**. For perception of safety, parents feel that the high density of heavy vehicles could decrease the safety of children when using active transportation mode [14].

4.3.2 Built environment characteristics related to children's safety

The relationship between built environment characteristics with objective and perceived traffic safety for children was examined based on previous studies in the field. The variables were regrouped on sub-sections under this built environment theme: infrastructure (including traffic control, road class, and Street/Road design), the density of population, land use, and other variables (e.g. distance, school location).

4.3.2.1 Infrastructure

4.3.2.1.1 Traffic control

The density of traffic lights and the presence of traffic lights (versus no traffic light) were associated with more collisions involving children **[**17**]**, **[**16**]**. The reason may be because traffic lights are installed at dangerous crossings. In the previous review on child pedestrian injuries, traffic control devices were found to be protective against injuries [40]. In this review, we find that a higher density of traffic lights was identified as a risk factor in the inner suburbs (close to the center of the city) and had a positive association with motor vehicle collisions **[**17**]**. However, it may also increase the number of children who walk **[**16**]**. One study examined its statistical relationship with perception of safety; it showed a positive correlation between parental perception of safety and density of traffic light [50]. However, the absence of signals at intersections or crosswalks was perceived as safer by children [52].

The presence of stop and yield signs were related to a lower risk of collision involving child pedestrians at intersections **[**44**]**. One qualitative study found that children perceived the presence of stop signs as safe or less dangerous [55]. In another study, roads without traffic signs were one of the factors related to child pedestrian crashes **[**38**]**. On the other hand, traffic signs present at midblock were not statistically significant with child pedestrian collisions **[**44**]**. Regarding perception of safety, one study showed that the presence of a school zone sign was positively related to a high risk of child pedestrian crashes, and increased the perceived crash risk among children at intersections [58]. In that study, child participants were instructed to indicate the locations they believed had the highest risk of collision.

Intersections with no controls presented a lower risk of child pedestrian motor vehicle collisions [44], while uncontrolled mid-block crossings were related with a high severity of injuries among children compared to signalized intersection **[**59**]**. At signalized intersections, vehicles are obliged to stop in front of the red light, while at uncontrolled mid-block it may be that drivers were not obligated to stop vehicles such as traffic lights, or that the driver population is not well trained, or that the street design does not help them stop. Regarding perception of safety, only one study examined a correlation between midblock crossings and perception of safety [50]. The result of this study showed that dangerous midblock crossings were related to higher perceived route danger. It seems that uncontrolled mid-blocks are not safe places to cross compared to intersections.

- **Traffic calming**

The results of traffic calming for objective studies were mixed. Traffic calming is intended to control traffic, generally with the intention to improve safety. In the previous review on child pedestrian injuries [40], traffic calming was found to improve safety (reduce the incidence or severity of collisions). In two of the five studies in this review, a positive relationship was found between traffic calming and collisions **[**17**], [**16**]**. The finding that more traffic calming measures were positively associated with higher collision rates may be surprising. However, it is possible that traffic calming was installed in areas with high collision rates and high concentration of injuries. For one of the two studies **[**17**]**, no relationship was found when considering all locations, but a positive relationship with child pedestrian-motor vehicle collisions was observed for households in inner suburbs (not for those in the downtown core). In contrast to the above, three studies found a negative impact of traffic calming on children's injuries **[**60**], [**61**], [**62**]**. Examining the effect of traffic calming in deprived areas, traffic calming was related to higher reductions in injuries and there is a significant relationship between density of traffic calming and a reduction in child pedestrian injuries **[**60**]**. Traffic calming with speed bumps were found to reduce the occurrence of collisions with children **[**61**], [**62**]**. Speed bumps were related to a lower risk of child injuries in their neighborhood and in front of their home **[**61**]**, and the decrease in the number of pedestrian motor vehicle collisions was larger for children than for adults **[**62**].**

A total of three studies did not find a correlation between objective traffic calming and parental perception of safety [49], [50], [58]. One qualitative study [54] showed that children perceived traffic calming as safe or less dangerous.

- **Crossing guards**

Several studies **[**63**], [**17**], [**16**]** identified that the presence of a school crossing guard was associated with higher motor vehicle collisions involving child pedestrian. This is consistent with the previous review [40]. In agreement with that review, we suggest that school crossing guards may be put in place in dangerous crossings or intersections with high collision risk which may explain the positive relationship between the presence of school crossing guard and children's injuries in those studies. In somewhat contrast, two studies found no statistical relationship. One study **[**44**]** found that the presence of school crossing guards was not statistically significant and that there is no relationship with child pedestrian safety at intersections in general, while the other examined schools in residential areas **[**19**].**

Regarding perception of safety results for crossing guards, two studies of perception of safety showed that crossing guards increased the perception of safety of children. The presence of crossing guard was related to lower perceived danger by parents along school route [50]. One qualitative study [55] indicated that children feel safer when crossing guards are present. As such, there is possibly a conflict between the perceived safety and likelihood of collisions. Again, it may be that crossing guards are found at more dangerous intersections.

4.3.2.1.2 Road class

- **Road class for motor vehicle**

Main roads, including arterial and collector roads, were found to be related to children's injuries in several studies [18], [64], [41], [62]. This is consistent with the previous review on child pedestrian collisions [40]. Arterial roads, compared to local roads, may increase the probability of school-aged child pedestrian crashes near schools [18], [64], [41]. Collector roads, compared to local roads, were also related to more motor vehicle collisions involving child pedestrians [62]. Arterial roads may have a higher speed limit compared to local roads, which may influence the risk of collision. Collector roads may be dangerous because they often transfer traffic (higher traffic volume than local streets) from local streets to arterial roads. In contrast, there is no association between the risk of collision involving child pedestrians around schools and the density of arterials (arterials per area) **[**63**], [**16**]**. Highways or freeways were found to increase the probability of collision risk in one study **[**41**],** though in another they were not associated with children's injuries [19]. Local roads decreased the likelihood of collisions **[**47**]**, and they were associated with a lower risk of collision **[**41**],** [18].

However, one study found that schools located on local roadways were found to experience more collisions than other locations [65].

Regarding perception of safety results, only one study examined the correlation between road type and perception of safety [50]. In this study collector roads were found to be associated with parents perception of low danger along school route compared to arterial roads [50].

- **Road class for active transport**

Sidewalks are designated places to walk, though their relationship with safety is not always clear. The previous study on child pedestrians [40] found that they were associated with an increase in injury, though those authors point out that there may be more child pedestrians along such routes. In this review, sidewalks were related to fewer crashes involving children compared to roads without sidewalks around the school [41]. Streets with a high proportion of missing sidewalks were found to increase the probability of school-aged child pedestrian crashes [18]. Sidewalks and bike lanes are designated active travel infrastructure. However, in studies **[**41**], [**44**], [**16**],** sidewalks and bike lanes were not statistically significantly related to children's injuries. Crosswalk density could increase the probability of child pedestrian crashes near schools **[**18**]**, though it was not correlated with children's injuries around neighborhood environment [19]. Infrastructure with pedestrian bridges was related to fewer collisions **[**19**],** though they can be significant barriers to people with mobility problems such as parents with strollers, people with physical disabilities, etc.

Regarding perception of safety results, three studies examined the correlation between perception of safety and active transportation roads [58], [56], [50]. The presence of sidewalks was not statistically related to perceived traffic danger by children at intersections [58]. Density of missing sidewalks was not statistically related to perceived danger along school route by parents in Toronto, Canada [50]. In contrast children feel that sidewalks are a safer place to walk [56], [55], [66]. However, the presence of crosswalks was positively related to children's perception of crash risk [58]. The presence of pedestrian infrastructure was positively related to perception of a safe walk to school among adolescents [56]. Separate bicycle lanes and walking paths from roads were perceived safer for parents and children [14], [66].

4.3.2.1.3 Street/Road design

- **One-way streets**

One-way streets were associated with higher collision rates **[**17**]**. One-way streets were positively associated with more collisions, though they were also positively associated with walking to school **[**16**]**. As such, they may increase walking rates, but also increase collision risk which would be a bad combination if found to be a consistent finding. This may be because there are no conflicting movements and thus people drive at higher speeds or when arriving at an intersection with a one-way street they do not pay much attention to both directions of the road **[**22**]**. However, a different study found that one-way streets were not associated with children's injuries at intersections and midblock **[**44**]**.

One study examined the relationship between one-way streets and perception of safety. The result of that study showed that one-way streets were not associated with parental safety perception along school routes [50]. In contrast, a separate study found that parents feel that it is unsafe for their children to cycle in one-way streets [14].

- **Street width**

A street width under five meters (<5 m) or between five and eight meters was statistically significant and positively associated with traffic collisions involving children compared to wide street (>15m) in Iran **[**19**]**. In contrast, both parents and children in the US feel safe walking and cycling in narrow streets [66].

Absent lane demarcations were related to more children's injuries rates, and roads without lane demarcations may create more chaos on the way and contribute to uncontrolled traffic flow **[**43**]**.

- **Divided versus undivided roads**

The likelihood of a crash decreases on undivided roads as the number of lanes increases, where as it increases on divided roads **[**42**]**. This may be explained several influences. Drivers may speed more when the number of lanes increases on divided roads. Second, drivers may pay more attention when there is no median, which could reduce the likelihood of crash occurrence **[**42**]**. Another explanation is that multiple lane roads without a median are simply too dangerous, that people do not attempt to across. Wider road width was perceived to be positively associated with crash risk among school-aged children [58].

- **Intersection density**

An increase in the length of the road was related to higher risk of collision involving child pedestrians **[**44**]**. Longer roads (direct road without intersections) may increase the possible contact between pedestrian and vehicle. Straight roads are associated with high-risk locations for children's safety. Straight roads in this study were situated in areas with high traffic flow and speed which also increase the risk of children's injuries **[**38**]**.

High street connectivity with higher intersection density, average block length and connected node ratio appears to be a factor related with a low risk of child pedestrian and cyclist injuries compared to low street connectivity **[**67**]**, and it was measured in a 5 km buffer around school. It may increase safe active transportation among children as areas with high street connectivity offer more route choices and children may be able to avoid dangerous streets. However, intersection density was found to be not statistically significant for children's collisions for several studies **[**68**], [**16**], [**41**], [**18**]**. Further, intersection density was negatively associated with perception of safety [49], [56], [69], and it related to more unsafe crossing place for children.

- **Bus stop density**

Bus stop density was not associated to child pedestrian crashes across school-neighborhoods [18] and at mid-block crossing **[**44**]**. Streets with a higher density of transit stop increase crash risk for 100 feet buffer of each street segments around school **[**41**]**. Transit access, which was defined as the percentage of households in an area which are less than 0.5 miles from a transit stop, was not related to children's traffic safety, but it may decrease the crash risk of other pedestrian age groups [37].

- **Dead-end roads**

The density of dead-end roads was not associated with children's injuries [17]. For perception, the results are contradictory. One study showed that dead-end roads were positively related to parental perception of safety along school route [50]. In a different study, children and parents felt that routes with a high density of dead-end roads are dangerous [66].

- **Road density**

Road and network density were not associated with objective measures of safety **[**37**]**, **[**63**]**, **[**64**]**. Regarding perception of safety, road and network density were not correlated with perceived traffic safety [58].

4.3.2.2 Density of population

High multifamily dwelling density decreased the likelihood of child pedestrian collisions [16]. For perception of safety, high multifamily dwelling density is not related to perceived crash risk [50].

Several studies found a negative relationship between population density and children's injuries **[**37**]**, **[**63**]**, **[**45**]**, **[**18**]**, **[**65**]**, though it was also found to be related to risk of exposure in areas near public school **[**37**]**. This is in contrast to the previous review on child pedestrian injuries [40] though it is not clear which articles they base this finding on. High population density may increase walking proportions in areas around elementary schools, though such areas were found to be linked to high-risk exposure, and the high population density could be related to more trips for children to school. Youth population density was negatively associated with safety of children and increased injuries rates during the school year [45]. Also a study [63] found that population density and residential density were related to child pedestrian risk around schools.

For perception of safety, population density including residential density, were not associated with perceived safety in several studies [58], [50], [56]. However, one study [69] showed a negative relationship between residential density and perception of safety.

4.3.2.3 Land use

Many studies show that commercial land use was not related to either objective traffic safety **[**17**]**, **[**41**]**, **[**16**]** or perceived traffic safety [58], [50]. However, commercial land uses may generate more interactions between motor vehicles and pedestrian and increase the number of crashes within a 100 feet buffer along each street segment **[**41**]**, and injuries near school **[**18**]**. One study indicated that commercial access was related to a high severity of crashes within school neighborhoods involving adults because of high pedestrian demand, but it was not significant for children [37]. In Toronto, Canada retail density was not related to perception of safety [49]. High street vendor density increased the risk of injuries for child pedestrians in Lima, Peru [43], though this may be also related to such activities occupying the pedestrian infrastructure.

Arterial roads were more often associated with commercial land uses, while residential land uses were more often associated with local roads which are generally more disconnected from traffic [41].

For residential land use, studies [68], [17], [41] showed a negative relationship with children's injuries, while studies [19], [41], [18] indicated that there is no correlation with objective or perceived traffic safety [58]. In a separate study [17], areas with high residential land use had a protective influence and may be a safe place for children. Residential land use was associated with low speed limits and traffic flow [17]. Areas with high proportions of residential land use were found to be safer for child pedestrians, maybe because more traffic calming was located in high density residential areas [68]. Finally, one study [19] found that residential areas were not significantly associated with traffic collisions.

The effect of mixed and diverse land use showed a positive relationship with children's injuries [44], [62], [63], while other studies [44], [37], [18] indicated that there is no correlation. The previous review on child pedestrian injuries [40] suggested a positive relationship. For perception of safety, land use mix was found to be positively related to unsafe walking and cycling to school among adolescents in area within 500 m of school location [56]. In a similar study [69], land use mix was not related to unsafe walking and cycling to school among adolescents [69].

A positive relationship between mixed land use and motor vehicle collisions involving children was found after speed bump installation [62]. Mixed land use was defined as the distribution of all land use types such as residential, commercial, institutional, industrial, and other land use types. One study in Montreal found the same result, that the diversity of land use was positively associated with higher crash risk around schools [63]. A study [44] examined the effect of mixed land use and non-residential land use on children's traffic safety at intersections and midblock crossings. They found a negative effect of mixed land use on children's traffic safety at intersections, but it was not significant at midblock crossings. Mixed land use may contain various types of land uses including commercial centers which may generate more interaction and complex conflicts between vehicles and pedestrian at intersections compared to midblock **[**44**]**. The kind and severity of pedestrian injuries in children may be related to land use variables. One study **[**68**]** examined the. The results showed that secondary retail could be an issue for children’s active transportation safety. The educational sites including schools, libraries, and universities were related only to killed or serious injury. Primary retail such as shopping centers was related to slight injuries on the weekend.

- **Near schools**

Areas near schools were associated with more crashes, especially for middle and high school children. This was explained as the areas near middle and high schools were associated with high speed and multi-lane roadways compared to area nears elementary school **[**42**]**. Also, zones near or with schools were related with risk of injuries **[**70**], [**19**].** In contrast, **[**44**]** found that areas near schools (within 150m of school) were not related to children's injuries. That study investigated the child pedestrian collisions at intersection and mid-block locations.

- **Near parks**

Living near parks were related to high child pedestrian fatalities compared to living near a school in a study of six cities in the US **[**70**]**. This may be due to the existence of unsafe streets next to the parks. The authors of that study also suggest that it might be a lack of awareness that parks are associated with a high concentration of collisions in the US.

- **Public parking**

The existence of public parking was found to be statistically significant with traffic collisions in Iran **[**19**]**, while in two studies in North America found that there is no relationship between parking and children’s safety. The off-street parking lots were found to be not statistically significant for child pedestrian and all pedestrian ages **[**37**]**. On street parking was not statistically related to motor vehicle collisions involving children near the midblock location **[**44**]**. Regarding perception of safety results, one study [50] indicated that the existence of double parking along school routes was not related to parental perceived danger. Children [55], [53], and parents [51] feel that the presence of street parking along school route decreases safety for children.

- **Other land use**

Office, industrial and park land use were not related to motor vehicle collisions involving child pedestrians in many studies [37], [17], [41], [16], [18].

4.3.2.4 Other

Distance can be related to the amount of exposure to danger. The previous review [40] on child pedestrian injuries found that an increase in distance increased injury incidences or severity. In our review, a study **[**19**]** showed that closer distances <100 meters had fewer child injuries than farther distances. The distance between school and intersection or midblock was not related with children's safety. A one study showed that longer distances to/from school was negatively related to parental perception of safety for child boys and girls [49].

The rest of the result showed that light conditions, weather condition, weekday peak time, cycling destination, and traveling or crossing with companions were all not associated with children's injuries.

Figure 4.2 summary the main findings of the study. The main results were regrouped by the level of agreement between objective and perceived traffic safety.

Table 4.1 Statistical relationships between built environment related to objective and perceived traffic safety for children

Variables	Objective traffic safety (*collisions or injuries*)			Perceived traffic safety		
	Safer/ less dangerous	**No correlation**	**Unsafe/ dangerous**	**Safer/ less dangerous**	**No correlation**	**Unsafe/ dangerous**
1. Traffic						
Traffic elements						
High vehicle / traffic speed		[44][e, f], [21]	[43], [19], [42][n] [41][b*]	[52][2, (c)]		[53][2, (c)], [54][1, (c)], [55][1, (c)], [51][1, (p)], [52][2, (p)], [14][1, (p, c)]
High traffic volume / flow / Too much traffic		[47], [45][s], [44][f]	[43], [46], [48], [41], [45], [44][e], [19]	[52][2, (c)]	[49] (*) (girls), [50] (*)	[49] (*) (boys), [53][2, (c)], [14][1, (c)], [56][2, (c)], [55][1, (c)], [51][1, (p)], [57][2, (p)], [52][2, (p)]
Vehicle types						
Impact with motor vehicle			[21]			
Heavy vehicles						[14][1, (p)]
Active transportation						
Bicycling frequency		[21]				
Walking proportion (more walking)		[17], [16]				
2. Built Environment						
2.1. Infrastructure						
2.1.1. Traffic control						
Higher density of traffic lights		[17]	[17][j] , [16][j]	[50] (*)	[52][2, (p)]	[52][2, (c)]
Presence of traffic/ stop signs	[44][e], [38]	[44][f]		[55][1, (c)]		[58][e] (*)

Table 4.1 Statistical relationships between built environment related to objective and perceived traffic safety for children ***(Continued…)***

Variables	Objective traffic safety (*collisions or injuries*)			Perceived traffic safety		
	Safer/ less dangerous	**No correlation**	**Unsafe/ dangerous**	**Safer/ less dangerous**	**No correlation**	**Unsafe/ dangerous**
Uncontrolled intersection VS controlled	[44][e]					
Dangerous or uncontrolled mid-block locations			[59]			[50] (*)
Traffic calming	[60], [61], [62]	[17]	[17][j] , [16]	[54][1, (c)]	[49] (*), [50] (*), [58][e] (*)	
Crossing guard presence		[44][e], [19]	[63], [17], [16]	[50] (*), [55][1, (c)]		
2.1.2. Road class						
Road for motor vehicle						
Main roads (arterial / collector roads) VS local roads		[63], [16]	[64], [41], [62], [18],			
Collector roads VS arterial roads				[50] (*)		
Local roads / traffic	[47], [41][b*], [18]		[65]			
Highways or freeways		[41][b**], [19], [18]	[41][b*]			
Driveway		[37]				
Road for active transport						
Sidewalk	[41][b*], [18]	[41][b**], [44][f], [16]		[56][2, (c)], [55][1, (c)], [66][2,]	[58][e] (*), [50] (*)	

Table 4.1 Statistical relationships between built environment related to objective and perceived traffic safety for children ***(Continued…)***

Variables	**Objective traffic safety** (*collisions or injuries*)			**Perceived traffic safety**		
	Safer/ less dangerous	**No correlation**	**Unsafe/ dangerous**	**Safer/ less dangerous**	**No correlation**	**Unsafe/ dangerous**
Crosswalk		[19]	[18]		[50] (*), [52][2, (p)]	[58][e] (*) , [52][2, (c)]
Bicycle lane		[41], [44][f]		[56][2, (c)]		
Separate bicycle lane and walking path				[14][1, (p)], [66][2, (p, c)]		
Presence of pedestrian bridge and infrastructure (e.g., refuge island)	[19]			[56] (*)		
2.1.3. Street/Road design						
One-way street		[44][e, f]	[17], [16]		[50] (*)	[14][1, (p)]
Narrow streets			[19]	[66][2, (p, c)]		
Absence of lane demarcations			[43]			
Bigger / wider road width			[42][n]			[58][e] (*)
Road length (longer)			[44][f]			
Longer Block length			[18]			
Straight road sections			[38]			
Intersection place		[17]	[38]			
Presence of major road crossings					[49] (*) (boys)	[49] (*) (girls)
Low street connectivity			[67]			

Table 4.1 Statistical relationships between built environment related to objective and perceived traffic safety for children ***(Continued…)***

Variables	**Objective traffic safety** (*collisions or injuries*)			**Perceived traffic safety**		
	Safer/ less dangerous	**No correlation**	**Unsafe/ dangerous**	**Safer/ less dangerous**	**No correlation**	**Unsafe/ dangerous**
Density of transit stop		[44][f], [18], [41][b**], [37]	[41][b*]			
Dead-end roads/ No-cul-de-sacs		[17]		[50] (*)		[66][2, (p, c)]
Road / Network density		[37], [63], [64]			[58][e] (*)	
Intersection / junction density		[68], [16], [41][b**], [18]				[49] (*), [56] (*), [69] (*)
2.2. Density of population						
High street vendor/ retail density			[43]		[49] (*)	
High multifamily dwelling density	[16]				[50] (*)	
Population density			[37], [63], [45], [18], [65]		[58][e] (*), [50](*),[56] (*)	[69] (*)
2.3. Land use						
Land use type						
Walkability index						[56] (*)
Commercial land use		[17], [41][b**], [16]	[41][b*], [18]		[58][e] (*), [50] (*)	
Commercial access		[37]				
Residential land use	[68], [17], [41][b*]	[19], [41][b**], [18]			[58][e] (*)	
Mixed, diversity or non-residential land use		[44][f], [37], [18]	[44][e], [62], [63]		[69] (*)	[56] (*)

Table 4.1 Statistical relationships between built environment related to objective and perceived traffic safety for children ***(Continued…)***

Variables	**Objective traffic safety** (*collisions or injuries*)			**Perceived traffic safety**		
	Safer/ less dangerous	**No correlation**	**Unsafe/ dangerous**	**Safer/ less dangerous**	**No correlation**	**Unsafe/ dangerous**
Secondary retail			[68]			
Primary retail		[68]				
Educational sites		[68]				
Zone near school (School present)		[44][e, f]	[70], [19]			[53][2, (c)]
Living near park			[70]			
Street parking		[37], [44][f]	[19]		[50] (*)	[55][1, (c)], [53][2, (c)], [51][1, (p)]
Other land use						
Office land use		[18], [41]				
Industrial land use		[18], [41]				
Park land use		[37], [17], [41] [16], [18]			[58][e] (*)	
2.4. Other						
Distance to/from school			[19]			[49] (*)
Light conditions (lack or no lighting)		[21]		[52][2, (c)]	[52][2, (p)]	
Older-amalgamated city VS inner suburbs			[62]			
Traveling or crossing with companions		[21]		[55][1, (c)]		
Weather condition		[21]				

Table 4.1 Statistical relationships between built environment related to objective and perceived traffic safety for children ***(Continued…)***

Variables	**Objective traffic safety** (*collisions or injuries*)			**Perceived traffic safety**		
	Safer/ less dangerous	**No correlation**	**Unsafe/ dangerous**	**Safer/ less dangerous**	**No correlation**	**Unsafe/ dangerous**
Weekday peak time		[21]				
Cycling destination (school, work, shopping, other)		[21]				
Higher density of flashing beacon						[50] (*)
Elementary school (location)		[45]	[37]			
Middle school location		[37], [45]	[45][s]			
High school location		[45]				
Child pedestrian's activity			[44][e, f]			

(*). Statistical relationship with objective built environment
1. Qualitative (e.g.focus group / discussion).
2. Quantitative (e,g. Likert-scale / ratio or %)
(p). Parents perception
(c). Children perception
s. during school period
b. Within/ near school zone: ***b*.*** (< 100 feet buffer) ***b**.*** (< half mile buffer)
e. at or near intersection
f. at or near mid-block
j. inner suburbs
n. older children VS younger

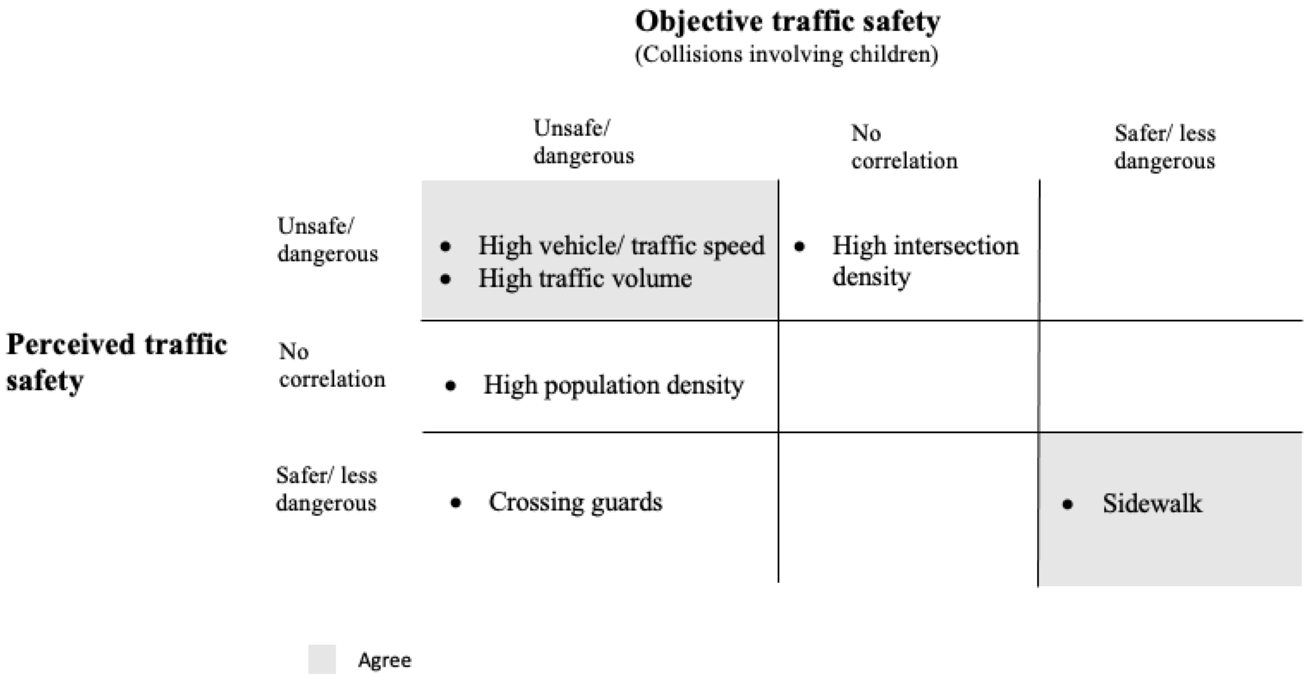

Figure 4.2 Main results for objective and perceived traffic safety (Agree/disagree)

4.4 Conclusion

This systematic review examined the relationship between objective and perceived traffic safety for children. Parents and children's perception of traffic safety indicated that they feel that high vehicle speed and high traffic volume are the key dangerous factors for children's traffic safety when walking or cycling.

The results of objective child traffic safety indicated that high vehicle speed and high traffic volume were the main determinants of children's injuries. For built environment variables, sidewalk was negatively related to motor vehicle collisions involving children. high traffic-light density and roads without signs also contributed to injuries according to some studies. In comparison to intersections with traffic lights, those with yield signs, stop signs, and even no intersection control were associated with greater children's safety. Arterials and collector roads are associated with more injuries, while local roads increase the safety of children. Intersection density and road or network density were not related to children’s injuries in several studies. For land-use characteristics, higher residential density was related to fewer children’s injuries in some studies and high multifamily dwelling density was positively associated with children's safety in one study.

The main results for perception of safety showed that sidewalk was related to safety perception. Intersection and junction density were related to perceptions of being less safe. Traffic calming, street parking, commercial and residential land use were not found to be statistically associated with perceived safety.

Comparing results between objective and perceived traffic safety showed that only sidewalk was related to safety perception and less risk of collisions involving children. The presence of a crossing guard, main roads including collectors and arterials, and high traffic light density were positively related to perceived safety but were not associated with more collisions involving children. Intersection density was related to unsafe perceptions but was not statistically associated with objective traffic safety. Also, population density was found to be related to children’s injuries, but not to perception of safety.

This study examined the association of the built environment and traffic safety for children. Many identified studies investigated the relationship between traffic collisions involving child pedestrians/cyclists, while few studies examined the link with safety perception. Future research should shed more light on the relationship between the built environment and safety perception as this can influence the likelihood of active and independent trips.

CHAPTER 5 THE RELATIONSHIP BETWEEN BUILT ENVIRONMENT CHARACTERISTICS AND PARENTS' PERCEPTIONS OF CHILDREN'S TRAFFIC SAFETY ON THE TRIP TO SCHOOL

ABSTRACT

Background: Active travel is an important matter for children's health and wellbeing. The safety of children is one of the main issues when they commute between home and school by active modes because, as vulnerable road users, various factors related to traffic can put them in danger during this trip. Numerous studies have focused on children's safety to identify characteristics that could increase the risk of injuries and collisions. However, parents have a major role in the safety of children because often, parents decide whether or not their children walk or cycle alone to school. It is very important to understand the safety perception of parents and its relationship with built environment characteristics because both are related to the safety of children's travel. However, few studies examined a relationship between built environment characteristics and safety perception of parents.

Objective: In this study, the relationship between parental safety perception and the built environment characteristics around the school and around the home are examined.

Methods: To achieve the objective of this study, a survey was conducted in and around Arnhem, the Netherlands, in fall 2018. The safety perception of parents was analyzed for 546 students. The required data about the built environment characteristics were collected and integrated using Geographic Information Systems (GIS). Built environment characteristics were determine for each school (15 schools in total) and for the home environment of each child. Regression analyses were carried out separately for the school and home environments. Individual and household characteristics were included for the home environment analysis.

Results: The results show that different built environment characteristics are important for the two levels. For the school environment, three variables were found to be significant. Intersection density and industrial land use were negatively related to parental safety perception, while roads with a speed limit of 30km/h could increase the safety perception of parents around the school. For the home environment, the results show that an increase in the age of children, the percentage of roads with separated bicycle lanes, and the percentage of roads that are low speed roads ($\leq$ 30km/h) increase

parental safety perception. In contrast, major road crossings and residential land use were negatively related to parental safety perception.

***Conclusion**:* In view of the important role of the built environment in contributing to the safe travel of children, parental safety perception must be considered in future strategies and plans. In addition, future policy should consider the necessary improvements in the built environment characteristics to enhance the safety of children when travelling to/ from school. Reducing the speed limit around each home and school neighborhood and providing a more separated bicycle lanes and decreasing the number of major road crossings between home and school is necessary for the safety perception of parents.

5.1 Introduction

Several positive effects of active travel and independent mobility on a child's health and well-being have been found [3]. The built environment influences the likelihood of children's independent mobility (CIM) [71]. Various studies have demonstrated a correlation between the built environment and the likelihood of walking to school, though safety was not always considered [7], [8], [9], [10]. Conceptual models of children's active and/or independent travel show the influence of the environment, but also suggest that the parental safety perception plays a role [5], [11] and **[**15**]**. Often parents are more concerned about children going alone in traffic **[**12**]**. Along with parents' perception of traffic safety, crime-related safety was associated with children's independent mobility using active transportation such as walking and cycling **[**13**].**

The urban form could indirectly affect parental decision making by mediating factors such as neighborhood and traffic safety including objective traffic safety (e.g., collisions, injuries) and perceived safety (e.g., parents' perceptions) [11]. The conceptual models mentioned above suggest a relationship between the built environment and parental safety perception, but it is rarely examined in detail. Knowing that parents would need to have a positive view of safety to let their children travel by active modes, it is necessary to understand which variables of built environment may reduce or increase the sense of traffic safety for parents.

Focusing on the safety of children when walking or cycling is very important because children are considered as vulnerable road users as their physical and mental capabilities are still developing. Vulnerable road users (VRU) are often defined as non-motorized road users such as pedestrians and cyclists [72]. These vulnerable road users are at risk due to their lack of protection if they are hit by a vehicle. Children could be injured in collisions with motor vehicles that cause road danger and traffic risks, in which the built environment and traffic play a role.

High vehicle speed and high traffic volume could increase motor vehicle collision involving children) [41], [43], [19]. Several built environment characteristics have also been found to be related to collisions involving children. High population density was related to more children collisions in many studies [37], [63], [45], [18], [65]. Main roads, including arterial and collector roads, were found to be related to motor vehicle collision involving children in several studies [18], [64], [41], [62]. In contrast, local roads were associated with a lower risk of collision **[**41**],** [18]. Several studies examined the influence of intersection and road network density on motor vehicle collisions involving children [68], [16], [41], [18], [37], [63], [64]. The results of those studies showed that both intersection and road/network density were not related to collisions involving children.

Five studies examined a relationship between objective built environment characteristics and safety perceptions of parents [49], [50], and children [58], [56], [69]. The main findings of those studies showed that intersection density was negatively related to safety perception of parents [49] and children [56], [69]. The presence of crossing guards and collector roads could increase safety perception of parents along routes to school [50]. In contrast, the presence of major road crossings decreases parental safety perception for girls [49]. Other qualitative study showed again that vehicle speed and traffic volume were associated with unsafe perception of parents [51], [52], and also for children [54], [55], [52],

This study investigates the relationship between parental safety perception and built environment characteristics for each home and school level.

5.2 Methods

5.2.1 Study area

The data for this study comes from a questionnaire conducted with parents in and around Arnhem city, Netherlands, in fall 2018. Arnhem is a steadily growing city situated in the southeast of the Netherlands with around 159,000 inhabitants. The Netherlands is considered among the countries that encourage the use of active transport modes, particularly through its developed and safe cycling network [73]. Fifteen primary schools participated in this study (Figure 5.1). To ensure data variability, the participants were selected in different school environments (e,g., city center, suburbs, etc.). The initial number of participants (676 participants) was reduced to 546 after cleaning and removing some incomplete surveys.

Figure 5.1 Distribution of schools

5.2.2 Survey

Children between 7- and 12-year-old (grades 5 to 8) and their parents participated in the study. Children received the questionnaire in the classroom in the morning and completed their section (for details on the children's travel please see [74], [75]. They then took the questionnaire home and asked their parents to fill the part of the questionnaire for parents.

This study used two groups of questions from the survey to investigate the relationships between parents' safety perception and objective built environment characteristics. The first type of questions was about the participant's characteristics, including individual and household characteristics. The second type of questions were about the parental safety perceptions.

5.2.2.1 Characteristics of participants

The descriptive information of participants is presented in Table 5.1. Among the 546 children who participated, 53 % were girls and the average age was 9.5 years. Most of the participants were Dutch (80 %). More than three-quarters of households had moderate or high incomes, and only 18 % had low incomes. Only 8 % of the households did not have a car. Of the sample, more than 90 % of parents were employed. Most households had two children (53 %). The favorite mode of transport among children was cycling. Most children (54%) preferred cycling to go to school compared to walking (17 %), using a car (18 %), or riding a bus (6 %). Most children traveled with a companion (sibling, parent, etc.), while only 24% went to school alone.

Table 5.1 Descriptive statistics of individuals and household characteristics

Variables	Number	Percent (%)	Variables	Number	Percent (%)
Children age:			***Parents employment:***		
7	23	4	1. Looking for work	11	2
8	115	21	2. One wage earner	125	23
9	150	27	3. Two wage earner	378	69
10	123	23	4. Other	32	6
11	115	21			
12	20	4			
Children gender:			**Car ownership:**		
1. Boy	258	47	1. No car	42	8
2. Girl	288	53	2. One car	239	44
			3. ≥ Two cars	265	48
Household income:			**Ethnicity**		
1. Low	98	18	Dutch	437	80
2. Moderate	223	41	Not Dutch	109	20
3. High	225	41			
Favorite mode			***Number of children in household:***		
1. Cycling	294	54	1. One	75	14
2. Walking	94	17	2. Two	290	53
3. Car	97	18	3. Three	132	24
4. Bus	31	6	4. ≥ Four	49	9
5. Other	30	5			

5.2.2.2 Parental safety perception

Information associated with parental safety perception was collected. The questions were about parental safety perception of traffic to/from school, pedestrian and bicycle infrastructure, connectivity of roads, perceptions of social safety, and children's travel skills. A five-point Likert scale was used to measure these perceptions, where 1 means "Strongly disagree " and 5 means "Strongly agree". Table 5.2 presents perception items used in the questionnaire and their statistical description. All questions in Table 5.2 are regrouped in one variable, "total parental safety perception", using the Cronbach's alpha method. For each parental safety perception of: traffic to school, pedestrian and bicycle path, child travel skills, social safety, the questions were also combined in one variable. For traffic to school, parents were asked (on a five-point scale) for their safety perception of traffic between home and school including traffic speed and volume. For the active travel path, parents were asked about the safety and quality of bicycle and pedestrian path. Parents were asked also about different routes in the neighborhood that child can take safety to go to school. For child skills, parents responded to four questions about their perception of their child's travel skills. Two questions about the safety of neighborhood and stranger danger safety were used to measure the parental perception of social safety.

Cronbach's alpha was used to measure the internal consistency of the perception questions. Table 5.3 shows that the Cronbach's alphas value were good (≥ 0.8) or acceptable (≥ 0.7), though for pedestrian and bicycle paths it was questionable (0.65) for the selected items.

Table 5.2 Descriptive statistics of parental safety perception

Variables	Five-point Likert scale [1-5]*	
	Mean	**SD**
1. Traffic and crossings		
There are enough safe crossings	3.11	1,12
Cars do not drive too fast	2.53	1.03
Not too much traffic intensity to walk/bicycle with my child	3.50	1.04
Not too much traffic intensity to let my child walk or cycle alone	3.49	1.27
Drivers of cars look out for pedestrians and cyclists	2.85	0.93
2. Pedestrian and bicycle path		
Most pedestrian paths are separated from the road	3.12	1.09
Most streets have safe bicycle paths	3.09	1.03
Most bicycle and pedestrian paths are well maintained	3.38	0.88
3. Multiple safe routes		
There are many different roads my child can safely take to school	3.23	0.97
4. Child travel skills		
My child cycles well	4.18	0.78
When my child walks, s/he pays proper attention	3.94	0.81
When my child cycles, s/he pays proper attention	3.84	0.84
My child knows how to estimate danger	3.51	0.89
5. Social safety		
My neighborhood is safe enough for child to be alone outside	3.89	0.76
I don't fear strangers if my child is outside alone	3.56	0.90
Total parental safety perception	3.41	0.46

* [1 = Strongly disagree to 5 = Strongly agree]

Table 5.3 Reliability test of questionnaire

Variables			Cronbach's alpha
1.	*Traffic and crossings*	There are enough safe crossings Cars do not drive too fast Not too much traffic intensity to walk/bicycle with my child Not too much traffic intensity to let my child walk or cycle alone Drivers of cars look out for pedestrians and cyclists	0.70
2.	*Pedestrian and bicycle path*	Most pedestrian paths separated from road Most streets have safe bicycle paths Most bicycle and pedestrian paths are well maintained	0.65
3.	*Multiple safe routes*	Different roads child can take to school safely	-
4.	*Child skills*	My child cycles well When my child walks, he pays proper attention When my child cycles, he pays proper attention My child knows how to estimate danger	0.87
5.	*Social safety*	Neighborhood is safe enough for child to be alone outside I don't fear for strangers if my child is outside alone	-
Total parental safety perception			0.756

5.2.3 Built environment variables

Data were collected from the CBS (Statistics Netherlands) and Open Street Map (OSM). The data were integrated into QGIS to form the built environment characteristics: along the route to school, around each child's home and school neighborhood using a radius of 500 meters.

The built environment variables in this study are categorized around each home and school (within 500 meters). Three built environment variables along the route to school (distance, separated bicycle lanes, and major roads crossings) were also examined. The school neighborhood is shared among all students of that school, so is not individually distinct. The home environment is distinct for each individual. The road to school is determined using the shortest path between home and school. It is also distinct for each student. As such, the analysis will be separated into two: one for the school environment and one with the home environment including the route to school.

For each school and home neighborhood separately, various measures were calculated. The methodology used and the descriptive statistics of built environment variables which can be seen in

Table 5.4. In addition, a shortest path algorithm in GIS was used to calculate the shortest distance between home and school (Figure 5.2). For the assumed route to school (shortest network path), the number of intersections with the existence of at least one main road that have a high speed limits (e.g., arterial, highway) was calculated for each child. As well for the route to school, the percentage of road length with separated bicycle lanes was determined for each child. Figure 5.3 and Figure 5.4 show an example of road type characteristics around two different schools.

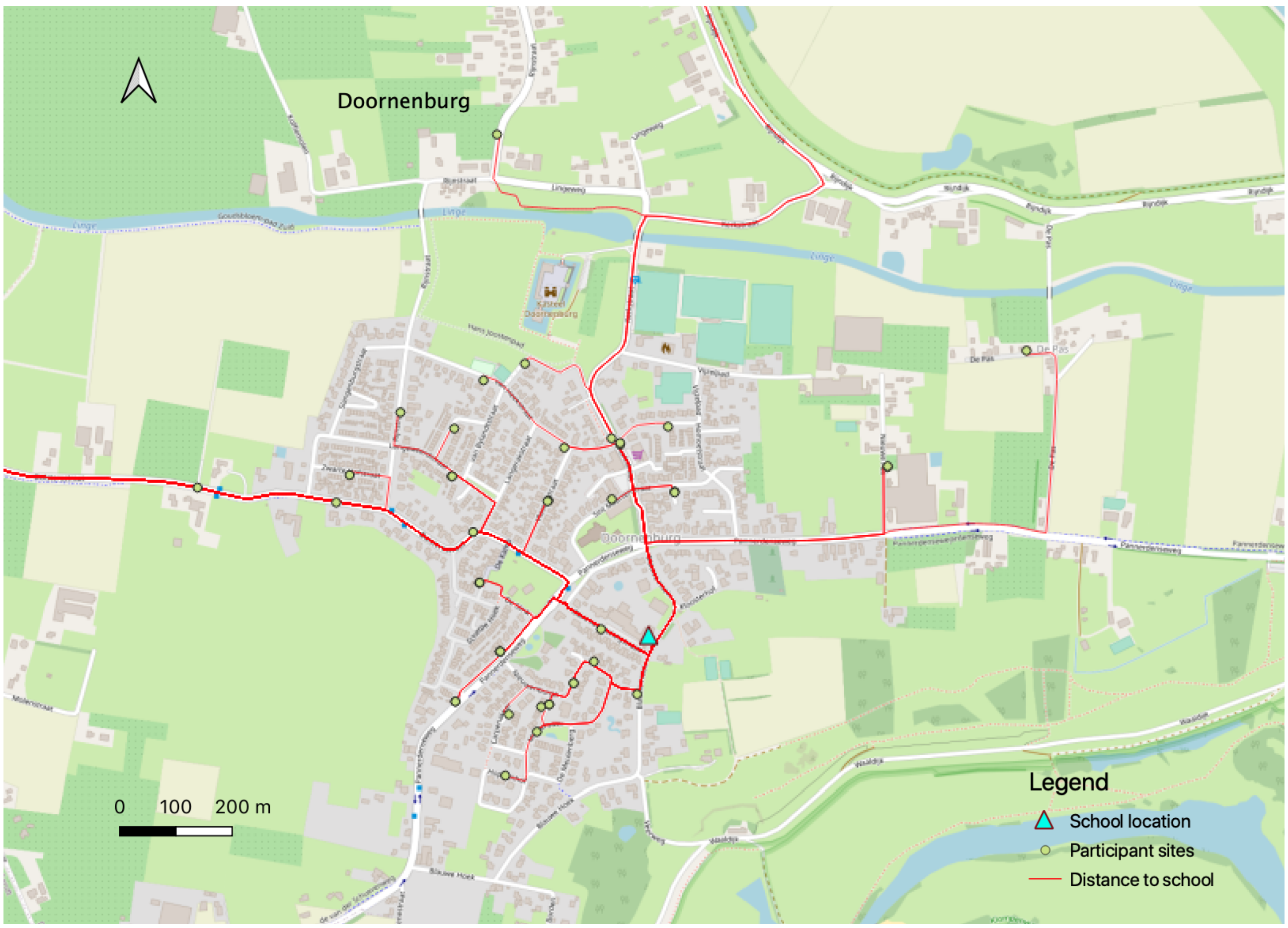

Figure 5.2 Distance to school

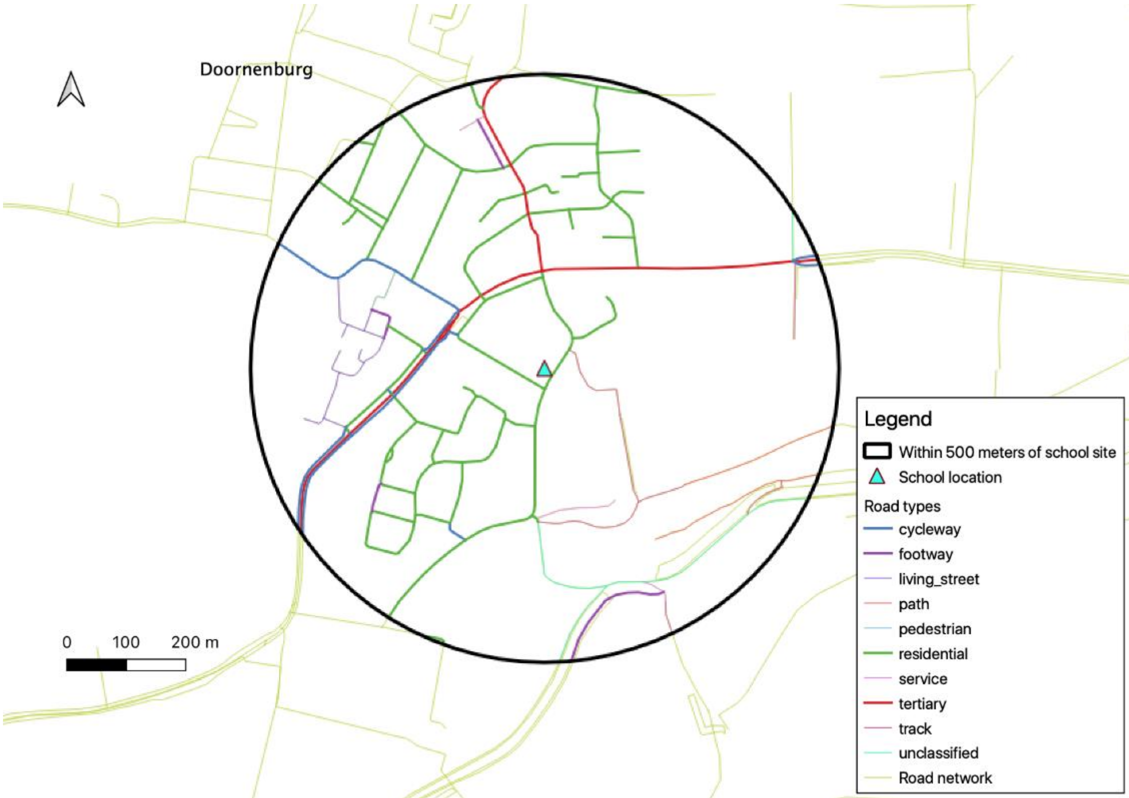

Figure 5.3 Road types around The Doornick school

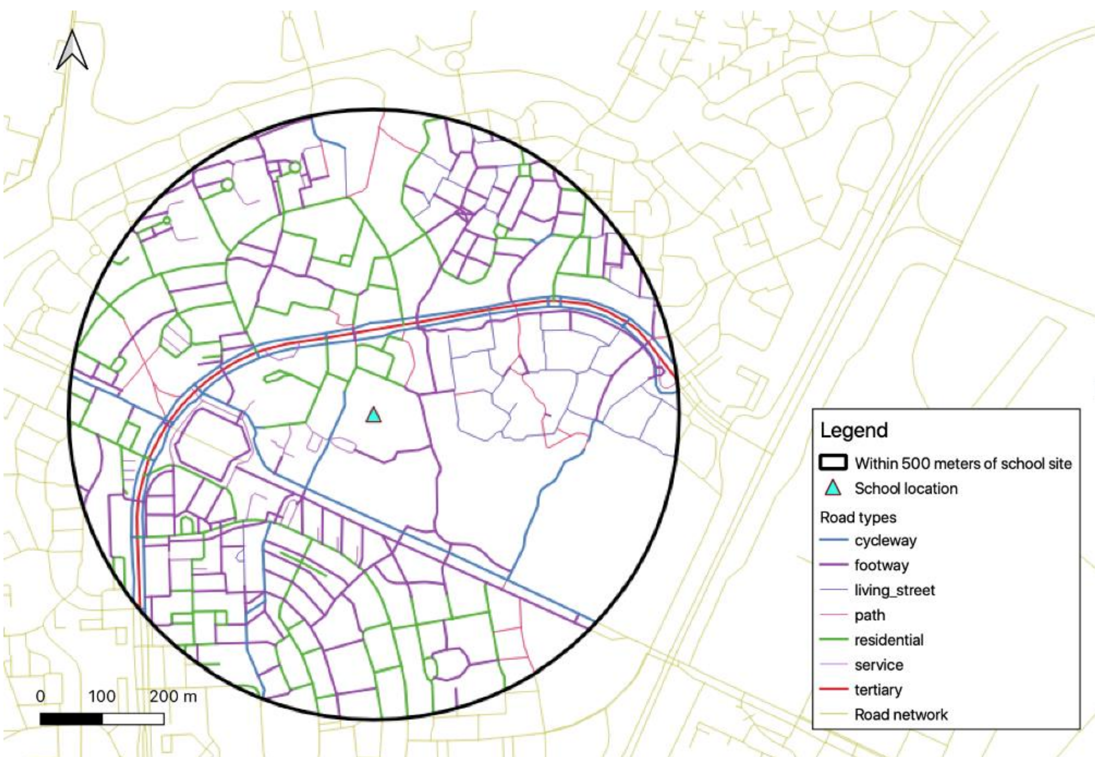

Figure 5.4 Road types around The IKC De Klimboom school

Table 5.4 Description of built environment variables

Variables	Methodology	Mean	SD	Min	Max
1. Built environment					
1.1. Road to school (shortest network path to school)					
Distance to school	Distance between home and school in km following route	1.469	1.655	0.023	10.185
% of roads with separated bicycle lane	km of roads with separated bicycle line / km of route, using shortest network distance between home and school	9.481	17.30	0.00	84.120
Major road crossings	# number of the intersections between the main roads (with high-speed limit) using shortest network distance between home and school	3.33	5.24	0.00	49.00
1.2. Home neighborhood					
Road density	km of road / km^2 (home area)	14.23	3.76	1.31	22.25
Road type:					
Local road density	km of local roads / km road around home	0.79	0.13	0.00	1.00
Collector roads density	km of collector roads / km road around home	0.15	0.09	0.00	0.95
Arterial roads density	km of arterial roads / km road around home	0.05	0.09	0.00	0.66
Active travel infrastructures:					
ATF density	km of active travel friendly infrastructures / km of road network	0.71	0.15	0,08	0.97
Intersection:					
Intersection density	Number of intersections /km^2 area around home	149.15	58.22	2.62	309.3
Speed limit:					
≤ 30 km/h (%)	% of roads (within home area) with a speed limit of 30 km/h or less	78.03	15.04	0.00	99.9
Land use type:	Land use area / area in home buffer				
Residential use (%)	-	43.55	24.48	0.03	99.54
Green use (%)	-	25.33	14.70	2.68	99.9
*Industrial use (%)_*	-	0.97	3.35	0.00	24.27
Commercial use (%)	-	0.27	0.75	0.00	7.52
Urban density	Urban density in postal code area child	N		(%)	
1. Low	(< 1000 addresses/km2)	145		27	
2. Moderate	(1000-1500 addresses/km2)	229		42	
3. High	(> 1500 addresses/km2)	172		31	
1.3. School neighborhood					
Road density	km of road / km^2 (school area)	15.25	2.27	11.13	19.14
Road type:					
Local road density	km of local roads / km road around school	0.56	0.09	0.34	0.67
Collector roads density	km of collector roads / km road around school	0.12	0.08	0.02	0.29
Arterial roads density	km of arterial roads / km road around school	0.02	0.08	0.00	0.12
Active travel infrastructures:					
Active travel friendly density	km of active travel friendly infrastructure / km of road network	0.74	0.12	0.44	0.88
Intersection:					
Intersection density	Number of intersections /km^2 area around school	150.49	32.88	82.21	208.4
Cul-de-sac (dead-end) density	Number of dead-end roads / km^2 area around school	9.45	4.49	0.00	19.63
Speed limit:					
≤ 30 km/h (%)	% of road (within school area) with a speed limit of 30 km/h or less	81.30	12.02	57.65	99.72
Land use:	Land use area / area in school buffer				
Residential land use (%)	-	40.93	29.97	8.161	84.42
Green land use (%)	-	25.25	15.07	7.29	44.13
*Industrial land use (%)_*	-	0.55	1.35	0.00	4.50
Commercial land use (%)	-	0.37	0.68	0.00	2.02
Total school population	Number of child population for each school	229.8	73.09	60	323

5.3 Statistical analysis

To examine which built environment variables are significantly related to parental safety perception, different statistical tests using R were applied. Before performing multivariate analysis, bivariate analysis was first conducted (Table A4 & A5 -Appendices-). The aim was to test the correlation between all the selected independent variables and safety perceptions and use the results to prepare the multivariate regression analyses after checking all the assumptions required. A significance level of $P < 0.05$ was used. To avoid the problem of multicollinearity, highly correlated variables (> 0.65) were excluded in the multivariate regression analysis (Table A6 & A7 -Appendices-). The strategy used to eliminate one variable was to test each predictor variable separately with safety perception. If the log-likelihood of the first model is greater than the second, the first variable was kept and the second eliminated. For example, land use variables were often highly correlated such as green space and residential space. In such cases, each variable was tested separately, and the more significant variable was kept.

Once all the insignificant variables were eliminated along with variables suffering from multicollinearity, separate multivariate regression models were developed for the school and home levels. The aim here is to investigate the relationship between safety perception with the built environment characteristics of the origin (home; unique) and destination (school; shared amongst students). For the multiple linear regression, only variables that were significantly correlated in the bivariate analysis were included. However, in the stepwise regression, all variables were included as this method can quickly test a vast number of potential influences. The results of the two methods were compared for coherency.

In this final step the stepwise regression was used to confirm the selection of the remaining independent variables and determine a final model. In this method, insignificant variables are excluded one at a time. Due to the large number of potential variables and the similarity in results, only the results of the step-wise analyses are presented in the results section.

5.3.1 Description of multivariate regression analysis

To examine the association between the predictor variables and parental safety perception, six models will be made for each level using multiple and stepwise linear regression after checking all the assumptions required. Six models were conducted for each level. The first model examined influences on the parental safety perception of traffic to/from school. The second model was for the parental perception of the quality and safety of pedestrians and bicycle paths to school. The third model is for the parental perception of different safe routes to school. The fourth and the fifth model are for the safety perception of social neighborhood and child skills, respectively. The last model shows the association between independent variables and total parental safety perception.

The multiple linear regression could explain the relationship between the dependent variable and more than one independent variable. Equation (1) shows the multiple regression model.

$$Yi = \beta 0 + \beta 1 x_{i1} + \beta 2 x_{i2} + \ldots + \beta p x_{ip} + \epsilon \qquad (1)$$

where Yi represents the dependent variable (parental safety perception), $\beta 0$ is the intercept, $\beta 1$ is the regression coefficient for the first variable x_{i1}, and ϵ represents the prediction error [76]. For both models (the school environment and the home environment models) the dependent variables remain the same: the perceptions of the parents for the six main safety measures (Table 5.2).

In all models, control variables such as the schools in the school environment models or gender and age in the home environment models were tested. If they were not significant and had no measurable effect on the other outcomes, they were excluded so as to have parsimonious models.

The stepwise regression is also called "a step-by-step iterative construction" It is a regression model that helps identify the independent variables that could be used in the final model. It could help to remove potential variables in each iteration after testing for statistical significance.

5.4 Results and discussion

Following the bivariate to multiple linear regression analysis versus the stepwise regression, only the stepwise regression results were retained as they did not significantly differ and presented cleaner (more parsimonious) results. The results of the final models for the school and home characteristics level are presented in Table 5.5. After applying stepwise regression, a total of 5 variables for individual/ household characteristics and 7 variables for built environment characteristics were not significantly related to safety perception in any of the models. For individual/ household characteristics these were: children's gender, household income, parents' employment, ethnicity, and the number of children in the household. For built environment characteristics these were: distance to school, road type (including local, collector, and arterial road), cul-de-sacs, active travel infrastructure, and commercial land use.

Table 5.5 Result of stepwise regression on six measures of parental safety perception for the school environment and home/ individual environment characteristics

Variable	***Traffic to/from school***	***Pedestrians and bicycle path***	***Multiple safe routes***	***Social safety perception***	***Child skills***	***Total parental safety perception***
I. School neighborhood	***Est***	***Est***	***Est***	***Est***	***Est***	***Est***
1. Built environment						
Speed limit						
≤ 30 km/h	*0.009* **	*0.0182* ***	*0.037* ***	--	--	***0.008*** ***
Land use						
Industrial land use	*-0.079* ***	*-0.165* ***	*-0.262* ***	--	--	***-0.089*** ***
Green land use	--	*0.008* ***	--	--	--	--
Intersection						
Intersection density	*-0.003* ***	--	*-0.004* ***	*-0.003* ***	*-0.002* **	***-0.003*** ***
School size						
Total population school	--	--	--	*0.001* **	--	--
Adjusted R Square	0.138	0.309	0.605	0.028	0.014	**0.305**

Variable	***Traffic to/from school***	***Pedestrians and bicycle path***	***Multiple safe routes***	***Social safety perception***	***Child skills***	***Total parental safety perception***
II. Home neighborhood	***Est***	***Est***	***Est***	***Est***	***Est***	***Est***
1. Individual characteristics						
Age	--	--	*0.118* ***	--	*0.110* ***	***0.041*** **
Favorite mode (reference = car)						
Cycling	--	--	--	--	0.172 *	--
Car ownership (reference = no car)						
One car	--	--	--	0.236 *	--	--
≥ two cars				0.288 *	--	--
2. Built environment						
Route to school						
% of roads with separated bicycle lane	*0.008* ***	*0.006* ***	*0.010* ***	--	--	***0.007*** ***
Major road crossings	*-0.015* *	--	--		*-0.017* **	***-0.020*** ***
Road						
Road density	*-0.024* **	--	*-0.043* ***	--	--	--
Speed limit	--					
≤ 30 km/h	--	--	*0.017* ***	--	--	***0.002*** *
Land use						
Residential land use	--	*-0.005* ***	*-0.003* *	--	--	***-0.002*** **
Urban density (reference = low)						
Moderate	--	--	--	*0.212* **	--	--
High	--	--	--	*-0.037*	--	--
Adjusted R Square	*0.05*	0.05	0.182	0.035	0.075	**0.110**

* indicates p < .05.
** indicates p < .01.

Note: a) Other possible favourites were not significant and are not presented.

5.4.1 School neighborhood level

Six models were calculated based on the parents' perceptions: traffic to/from school, pedestrians and bicycle path, multiple safe routes, social safety perception, child skills, and total parental safety perception. For the school environment, two models - social safety perception and child skills - showed a lower value of adjusted R square (below 10%). It seems that these two models do not explain well the variability for the school environment characteristics. Only one variable was related to the safety perception of child skills and two variables were related to social safety perception. It seems that school environment did not have a big influence on perceptions of child skills and social safety. This is not a surprise, as one would anticipate that child skills relate to direct measures of the child (age, experience with the mode, etc.) and social safety likely relates more to one's immediate (home) environment.

In general, the results show that roads with low-speed limits (≤ 30km/h) around the school (500 m buffer) and industrial land use were significant in four models, with the exception of the models for the safety perception of the social environment and for child skills. Intersection density was significant in five models, except the model for the safety perception of pedestrian and bicycle paths. Green land use and population density were significant only in one model (pedestrian and bicycle path perceptions).

The three models of perception of traffic safety, multiple safe routes, and total parental safety perception were found to have similar results. A total of three variables were found to be significant in these models. Two variables were negatively related to parental safety perception: industrial land use and intersection density. Roads with low speed limits (≤ 30km/h) around the school were associated with higher parental safety perception.

Roads with low speed limits could decrease the traffic danger for children compared to roads with high speed limits. The results are consistent with other research that found parents feel unsafe for their children to travel on roads with high vehicle speeds [51], [52], [14]. High vehicle speeds were also a critical factor in previous research that could increase collisions involving child pedestrians and cyclists around school **[**41**], [**42**].**

Intersections are often perceived as dangerous. Children feel unsafe when intersection density is higher around the school neighborhood [56], [69]. On the other hand, parents feel that industrial zone around school area not safe for their children. Green land use including parks, gardens, agriculture, and other types of green use increased the parental safety perception of active travel paths. Traffic may be higher in residential or industrial land-use areas compared to green land-use areas which could create a potential risk for children when using active travel modes. Green land use also can be related to fewer distractions that help a road user to anticipate traffic danger better.

Intersection density was not significant in the model that included the safety perception of pedestrian and bicycle paths. Intersection density was also found to be insignificant in collisions involving children around a school neighborhood with the existence of active travel path **[**16**], [**41**], [**18**].** In contrast, for the model with social safety perception, intersection density was negatively related to parental safety perception. For social safety perception, high population school size was positively associated with parental safety perception. An increase in the number of school children could help a child meet more students and encourage him to walk or cycle with their friends. Children feel comfortable and safe when walking with friends [55].

For the safety perception of the child's travel skills, only intersection density was significant and was found to be negatively associated with parental safety perception. Parents feel less confident about children's skills with an increase in the density of intersections around school neighborhood.

5.4.2 Home/ individual neighborhood level

Along with built environment measures from the home, individual and household characteristics were added for the home neighborhood level. However, only three variables were significant in at least one model: age, favorite mode, and car ownership.

The six models discussed above were also calculated for the home environment and personal/household characteristics. For this environment, a total of four models - traffic to/from school, pedestrians and bicycle path, social safety perception, and child skills - showed a lower value of adjusted R square (below 10%). Judging by the adjusted R square, it would appear that the school environment is a better measure than the home environment for these perceptions. The school is a point of concentration for these trips and may create more interactions. As such, the conditions near the school might be more important than those in the home environment for the perception of safety.

For the parental safety perception of traffic to/from school, the results show that only the percentage of roads with separated bicycle lane (using the shortest network distance between home and school) was associated with higher parental safety perception. Roads with separated bicycle lanes protect child cyclists from motorized vehicles, and parents feel that it is safer with separated bicycle lanes [14]. This result is consistent with other previous research [77] that found more separated bicycle lanes could increase the safety perception for child cyclists.

In contrast, an increase in major road crossings and road density were negatively associated with the traffic safety perception. Major road crossings are the intersections containing at least one major road (e.g., an arterial or collector road). Regarding previous findings of motor vehicle collisions involving children, numerous studies [64], [41], [62], [18], showed that main roads including collector and arterial roads could increase children's injury/collision. Only one study of safety perception showed that parents feel less dangerous along school routes with collector roads [50].

For the perception of pedestrian and bicycle infrastructure, two variables were significant. Roads with separated bicycle lanes were associated with higher safety perceptions, while residential land use was negatively related to this measure of active travel infrastructure. Separated bicycle lanes and active travel paths encourage children to commute by bicycle [77]. The road network of Arnhem (using GIS) showed that the majority of the separated bicycle lanes was in arterial and collector roads rather than residential roads, which might decrease the quality of active travel paths in residential areas. In previous research, the presence of residential use was not related to safety perception of children [58], while this study showed a negative association with parents' perceptions for multiple safe routes. Parents living in more residential areas were more likely to have a lower perception of pedestrian and bicycle infrastructure. What this relates to is unclear, though GIS data shows few bicycle lanes on local roads in such areas.

For the perception of different safe routes to school, both individual and built environment variables had some influence. The age of children was positively associated with this measure. Parents feel that older children could safely take many different roads to school. For the built environment characteristics, roads with low speed limits (≤ 30km/h) and separated bicycle lanes were associated with an increase in the perception of different safe routes to school. In contrast, residential land use and the high density of roads around the home were negatively associated with parental safety perception of different safe routes to school.

Previous research found that road or network density was not associated with collisions involving children **[**37**], [**63**], [**64**]**, or with the safety perception of children [58]. However, this study showed other findings for safety perception of parents. Parents in areas with high road density were less likely to feel that their were multiple safe routes to school. High road density could be associated with more traffic, which might increase the potential conflict between motor vehicles and children.

For the perception of social safety, only two variables were significant. Households with one or more cars were associated with a higher perception of social safety as compared to households without a car. The study found that parents in households with higher car ownership were more likely to rank the social safety of their neighborhood as higher. For built environment characteristics, only urban density was found to be significant in that model. Moderate density (1000-1500 addresses) was positively associated compared with low density (< 1000 addresses). Previous research [69] found that high density of residential addresses negatively affects the safety perception of children. From this analysis, these built environment variables do not seem to strongly influence this measure. Influences such as parental attitudes, personality, the type of buildings, etc. might better explain this.

For the perception of child skills, an increase of the age of children and cycling as a favorite mode compared to a car could increase the safety perception of parents. Parents feel that older children have more skills and more experience to estimate danger than younger children. This could be related to parental travel patterns, to the number of years a child has walked or cycled, or how long they have done this alone. Previous research [22] on motor vehicle collisions involving child pedestrians showed that younger children (5-9) had a higher injury rate compared to older children (10-14). When children prefer to cycle to school, the parental safety perception of child skills could increase. It could be that such children might cycle more, thus developing their skills more, and thus increasing parental perceptions of safety. Regarding built environment characteristics, only major roads crossing to school could decrease the parental safety perception of child skills. The high number of intersections with one or two major roads (with high speed limit) along the route to school could decrease parents' sense of safety, negatively reflecting the perception of child skills.

The association between individual/household variables and built environment characteristics around the home neighborhood and the total parental safety perception was examined. The results show that only the age of children was found to be significant for individual and household characteristics. When the age of children increases, the total parental safety perception increases, and parents feel that it is safer. Regarding built environment characteristics, a total of four variables were significant. The increase of the percentage of roads with low speed (≤ 30km/h) and separated bicycle lanes between home and school were associated with the total parental safety perception. In contrast, an increase in the number of major roads crossing between home and school and residential land use were negatively related to total parental safety perception.

5.5 Conclusion

The relationship between parental safety perceptions with built environment characteristics for each school neighborhood and participants' home neighborhood was examined. A total of six dependent variables were examined using multivariate regression for each context: traffic to/from school, active travel path, multiple safe routes, social perception, child skills, and total parental safety perception. The effect of the built environment on the safety perception of parents differs for each model. However, when looking at all safety perception measures, the main findings showed that three variables of the built environment were significantly related to total parental safety perception for the school neighborhood level. A high percentage of roads with a low-speed limit (≤ 30 km/h) could increase parental safety perception, while industrial land use and intersection density decrease the parents' safety perceptions. For the home neighborhood model, only children's age among individual/household characteristics was significant and could increase total parental safety perception. Four variables of built environment characteristics were significantly related to total parental safety perception. The high percentage of roads with separated bicycle lanes and low speed increased this measure of safety perception. Residential land use and a high number of major road crossings during the school trip were related to parents perceiving it as less safe.

The evidence presented in this study showed the relationship exist between perceptions of safety by parents with school and home attributes. Most findings of this research are consistent with many of the existing studies in the field. The study's main finding is the difference in influential characteristics for each built environment level and parental safety perception. Study area characteristics provided an excellent opportunity for the analysis. Despite this, there are some limitations of the study. Not all built environment characteristics have been studied, such as traffic density, street parking, traffic light density, population density, and school crossing guards. The variables selected in the study were based on the availability and quality of existing data.

In view of the growing need for active travel for children, the results of this study can be used to contribute to building a safe environment around the school and home neighborhood and along the route to school. Future policy should consider the necessary improvements in the built environment characteristics to enhance safety of children when traveling to/ from school. Decreasing the speed limit around each school and home neighborhood could increase the sense of safety among parents. One means of accomplishing this would be installing more traffic calming around each school and home neighborhood. Building and providing a more protected built environment around each school and home neighborhood and between home and school is necessary for the safety perception of parents. An increase in roads with separated bicycle lanes might increase the safety perception of parents, and the objective safety of children when traveling to school. The high number of major-road crossings could increase the parents' sense of traffic danger. However, providing more traffic control at the dangerous intersection could decrease the traffic danger for children.

CHAPTER 6 CONCLUSIONS, RECOMMENDATIONS & LIMITATIONS

6.1 Conclusions

This study aimed to understand the relationship between the built environment and traffic with objective and perceived/subjective traffic safety. Furthermore, there was the aim to identify the influence of the built environment (at the school and at home) on the parents' perceptions of children's traffic safety on the school trip. The main benefit of enhancing the safety of children when using active transportation could lead to safe travel and encourage more active and independent travel for children as such travel is an important source of children's health and wellbeing.

The main research question was:

> *How do built environment and traffic characteristics influence objective and perceived traffic safety for children's active and independent travel?*

A systematic literature review was conducted to answer the question and understanding the built environment's influence on objective and perceived traffic safety for children. Three sub-questions were addressed:

- Which built environment and traffic characteristics are related to collisions involving children?
- Which built environment and traffic characteristics could influence the safety perception of parents and children?
- What is the relationship between objective and perceived traffic safety for children?

The results of this research identified the influence of the built environment and traffic on objective (collisions involving children), and subjective/ perceived traffic safety. The systematic review results further showed a few studies that examined a relationship between the built environment and safety perception.

For traffic characteristics, the results demonstrated an agreement between objective and subjective/perceived traffic safety, particularly for traffic volume and vehicle/traffic speed. The high vehicle/ traffic speed and high traffic volume were the main factors of traffic that related to unsafe perception and more collisions involving children. However, the results showed the differences in the effect of the built environment characteristics on both objective and subjective/perceived traffic safety except, the presence of sidewalk that related to safety of children’s (for both objective and perceived traffic safety). Intersection density was related to perceptions of danger, but was not associated with objective traffic safety. In contrast, population density was found to be positively related to children’s collisions, but not to perceptions of safety. While the presence of crossing guards and major roads were positively related to perceived safety, they were associated with higher rates of children’s collisions.

The systematic review results also showed the importance of further studying the influence of the built environment on parental safety perception. A further question was addressed to understand which built environment characteristics have an influence on the parents’ perceptions of children’s traffic safety on the trip to school.

An additional and complementary study was conducted in and around Arnhem, the Netherlands, to examine the influence of built environment characteristics on parental safety perception for children's trips to school. The results showed that a high percentage of roads with separate bicycle lanes between home and school (using shortest network distance) increased the parental perception of safety. In addition, a high percentage of roads with low speed limits (≤ 30 km/h) around each school and home neighborhood increased the parent’s sense of traffic safety. In contrast, residential land use, and a high number of major roads crossings between home and school decreased the parents’ sense of traffic safety for their children. For individual and household characteristics, only the age of children was significant and related to parental perceptions of safety. Finally, parents have more positive views of safety for older children than younger.

It is important to mention that there is a large agreement between the main findings of the analytical study and the systematic review results.

High traffic/vehicle speed was identified as one of the main factors that could increase children's collisions and decrease the safety perception. The study conducted in and around Arnhem showed the positive effect of the high percentage of roads with low speed limits on improved parental safety perception. Intersection density, which is related to perceptions of increased danger in the literature review, could also decrease the parental safety perception around school neighborhoods, even though it was not statistically related to collisions involving children in many studies.

The main road crossings that were not examined in depth in the systematic review were found to be one of the factors that could decrease the sense of safety perception for parents. However, main roads, including arterial and collector roads, increased the collisions involving children compared to local roads. The analytical study also confirmed the results found in the systematic review about the positive effect of separated bicycle lanes on safety perception.

6.2 Recommendations

This study showed the importance of providing a more protected built environment for children's travel safety. Reducing high speed limits around home and school environments, and increasing the percentage of roads with separate bicycle lanes along the route to school could help to increase the parental perception of safety. However, a low number of major roads to cross along the route to school is recommended to increase the perception of safety by parents. Long distances to school have previously been found to be one of the largest barriers of children’s active travel and this could also increase the number of major roads crossings between home and school.

6.3 Discussions and limitations

High vehicle/traffic speed is an important issue for children's safe travel to school. Decreasing the speed limit is one of the measures to improve the safety of children using active and independent travel. Various measures have been developed to address this problem. Traffic calming measures using road design such as speed humps, curb extensions, and median islands could help decrease the vehicle speed. Such features should be applied around the school neighborhood as the school is a point of concentration for children’s trips. One of the interesting results of this study is reducing the high percentage of major road crossings along the route to school. Children could be in danger when crossing major roads. Major roads with high speed limits such as arterials could put children in danger, especially when they try to cross them.

Long distances to school have previously been demonstrated as on of the largest barriers to children’s active travel. However, the influence of distance was not found to be significant for parents’ perceptions. In our study though, it may be that the number of major road crossings is capturing what might influence parental perception. As distances increase, the likelihood of more major road crossings being encountered increases.

Furthermore, not all built environment and traffic characteristics have been studied in and around Arnhem, such as traffic volume, traffic density, street parking, traffic light density, population density, and school crossing guards. The variables selected in the study were based on the availability and quality of existing data.

High traffic volume was also identified in the systematic review as one of the main characteristics of traffic that increases collision involving children. However, it was not available and thus not included in the study conducted in and around Arnhem, the Netherlands, to measure the parental safety perception. Traffic volume might affect other variables if was included. For example, a high number of vehicles at major road crossings could increase the potential danger for children. High road density that was negatively related to the parental perception of traffic safety could be associated with more traffic. An increase in traffic around the residential area seems to create more risk for children.

The other interesting result is that a high percentage of roads with separated bicycle lanes along the school route could increase the sense of safety for parents. Separated bicycle lanes could avoid, or at least reduce, the risk of traffic along segments (though not necessarily at intersections). A pedestrian path such as a maintained sidewalk could also help improve children's safety when walking.

Other variables that could influence parental safety perception that were unavailable include street parking, population density, and crossing guards. Crossing guards are often placed at dangerous intersections to decrease the risk of potential conflicts with motor vehicles for example. Street parking may give a false sense of safety as parents may think that they shield their child, but if vehicles are close to intersections/points of crossing they can limit the view of the driver and the ability of the child to see oncoming traffic.

Even though this study has some limitations, it has provided insight into the influence of the built environment (and traffic) on the objective and perceived traffic safety for children. Furthermore, the study helps to understand the built environment characteristics that could influence parental safety perception to promote safer school travel.

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APPENDIX A SYSTEMATIC REVIEW DETAILS

A.1. Research strategy

Table A.1 Search terms used in systematic review by database

Databases	Strategies used for objective traffic safety	Strategies used for perceived traffic safety
Web of science (2000-2020)	AB=(child* OR school* OR infant OR Adolescent* OR youth) AND AB=(injur* OR accident* OR crash* OR collision OR death* OR casualt* OR fatal*) AND AB=(traffic OR environment* OR build OR built OR design OR socio* OR street OR road OR location OR geograph* OR gis OR area OR Neighbo* OR spatial OR urban OR intersection* OR infrastructure* OR sidewalk* OR way OR ways OR crosswalk* OR path OR paths OR pathway OR land OR speed OR signs OR densit* OR flow OR vehicle OR vehicles OR car OR cars) AND AB=(pedestrian* OR walk* OR cyclist* OR bicycling OR bicycl* OR cycling OR "active transport*" OR "active commut*" OR travel)	AB=(parent* OR mother* OR father* OR child* OR infant OR Adolescent* OR school) AND AB= (perception OR subject OR view* OR perceived OR qualitative Or subjective) AND AB=(safet* OR risk* OR securit* OR unsafe* OR danger* OR barriers) AND AB=(transport* OR traffic OR speed OR signs OR densit* OR flow OR vehicle OR vehicles OR car OR cars OR environment* OR Build* OR design OR socio* OR street* OR road* OR location OR geograph* OR Neighbourhood* OR neighborhood* OR intersection* OR infrastructure* OR sidewa* OR sidewalk* OR way OR ways OR crosswalk* OR path OR paths OR pathway OR land) AND AB=(pedestrian* OR walk* OR cyclist* OR bicycling OR bicycl* OR cycling OR "active transport*" OR "active commut*" OR travel)
PubMed and Medline (2000-2020)	(((child*[Title/Abstract] OR school*[Title/Abstract] OR infant[Title/Abstract] OR Adolescent*[Title/Abstract] OR youth[Title/Abstract]) AND (injur*[Title/Abstract] OR accident*[Title/Abstract] OR crash*[Title/Abstract] OR collision[Title/Abstract] OR death*[Title/Abstract] OR casualt*[Title/Abstract] OR fatal*[Title/Abstract]) AND (traffic[Title/Abstract] OR environment*[Title/Abstract] OR build[Title/Abstract] OR built[Title/Abstract] OR design[Title/Abstract] OR socio*[Title/Abstract] OR street[Title/Abstract] OR road[Title/Abstract] OR location[Title/Abstract] OR geograph*[Title/Abstract] OR gis[Title/Abstract] OR area[Title/Abstract] OR Neighbo*[Title/Abstract] OR spatial[Title/Abstract] OR urban[Title/Abstract] OR intersection*[Title/Abstract] OR infrastructure*[Title/Abstract] OR land[Title/Abstract] OR speed[Title/Abstract])) AND (pedestrian*[Title/Abstract] OR walk*[Title/Abstract] OR cyclist*[Title/Abstract] OR bicycling[Title/Abstract] OR bicycl*[Title/Abstract] OR cycling[Title/Abstract] OR "active transport*"[Title/Abstract] OR "active commut*"[Title/Abstract] OR travel[Title/Abstract]) AND (("2000/01/01"[Date - Publication] : "2020/12/31"[Date - Publication])	((("safety"[Title/Abstract] OR risk[Title/Abstract] OR security* [Title/Abstract] OR unsafe[Title/Abstract] OR danger[Title/Abstract]) AND (Traffic [MeSH Major Topic] OR environment [MeSH Major Topic] OR Build [MeSH Major Topic] OR Built [MeSH Major Topic] OR design [MeSH Major Topic] OR socio [MeSH Major Topic] OR street [MeSH Major Topic] OR road [MeSH Major Topic] OR location [MeSH Major Topic] OR geograph [MeSH Major Topic] OR Neighbourhood [MeSH Major Topic] OR neighborhood [MeSH Major Topic] OR intersection [MeSH Major Topic] OR infrastructure [MeSH Major Topic] OR sidewalk [MeSH Major Topic] OR way [MeSH Major Topic] OR ways [MeSH Major Topic] OR crosswalk [MeSH Major Topic] OR path [MeSH Major Topic] OR paths [MeSH Major Topic] OR pathway [MeSH Major Topic] OR land[MeSH Major Topic]) AND pedestrian [MeSH Major Topic] OR walk [MeSH Major Topic] OR cyclist [MeSH Major Topic] OR bicycling [MeSH Major Topic] OR bicycl [MeSH Major Topic] OR cycling [MeSH Major Topic] OR "active transport" [MeSH Major Topic] OR "active commut" [MeSH Major Topic] OR travel [MeSH Major Topic]) AND (parent[Title/Abstract] OR mother[Title/Abstract] OR father[Title/Abstract] OR infant[Title/Abstract] OR child[Title/Abstract] OR adolescent[Title/Abstract] OR school[Title/Abstract])) AND (("2000/01/01"[Date - Publication] : "2020/12/31"[Date - Publication]))

Table A.1 Search terms used in systematic review by database ***(Continued…)***

ScienceDirect	(child OR school) AND (injur OR crash OR collision OR accident) AND (traffic OR environment OR geographic)	(parent OR child) AND (perception OR perceived) AND (traffic OR environment OR geographic)
ProQuest Dissertations & Theses Global (2000-2020)	TI (child* OR school OR Adolescent*) AND AB (injur* OR accident* OR crash* OR collision OR death* OR casualt* OR fatal*) AND ab(traffic OR environment OR Build* OR design OR socio* OR street* OR road* OR location OR geograph* OR Neighbourhood* OR neighborhood* OR intersection* OR infrastructure*) AND ab(pedestrian* OR walk* OR cyclist* OR bicycling OR bicycl* OR cycling OR "active transport" OR "active transportation" OR "active transporters" OR "active commut*" OR travel)	AB (parent* OR child* OR Adolescent* OR school) AND AB (perception OR subject OR view* OR perceived OR qualitative) AND AB(safet* OR risk* OR securit* OR unsafe* OR danger*) AND ab(traffic OR environment OR Build* OR design OR socio* OR street* OR road* OR location OR geograph* OR Neighbourhood* OR neighborhood* OR intersection* OR infrastructure*) AND ab(pedestrian* OR walk* OR cyclist* OR bicycling OR bicycl* OR cycling OR "active transport" OR "active transportation" OR "active transporters" OR "active commut*" OR travel)
Compendex (2000-2020)	((parent* OR mother* OR father* OR child* OR infant OR Adolescent* OR school) wn KY AND (injur* OR accident* OR crash* OR collision OR death* OR casualt* OR fatal*)wn KY AND (traffic OR speed OR signs OR densit* OR flow OR vehicle OR vehicles OR car OR cars OR environment* OR build* OR built* OR design OR socio* OR street* OR road* OR location OR geograph* OR neighbourhood* OR neighborhood* OR intersection* OR infrastructure* OR sidewa* OR sidewalk* OR way OR ways OR crosswalk* OR path OR paths OR pathway OR land) wn KY AND(pedestrian* OR walk* OR cyclist* OR bicycling OR bicycl* OR cycling OR "active transport*" OR "active commut*" OR travel) wn KY)	((parent* OR mother* OR father* OR child* OR infant OR Adolescent* OR school) wn KY AND (perception OR subject OR view* OR perceived OR qualitative Or subjective)wn KY AND(safet* OR risk* OR securit* OR unsafe*)wn KY AND (traffic OR speed OR signs OR densit* OR flow OR vehicle OR vehicles OR car OR cars OR environment* OR build* OR built* OR design OR socio* OR street* OR road* OR location OR geograph* OR neighbourhood* OR neighborhood* OR intersection* OR infrastructure* OR sidewa* OR sidewalk* OR way OR ways OR crosswalk* OR path OR paths OR pathway OR land) wn KY AND(pedestrian* OR walk* OR cyclist* OR bicycling OR bicycl* OR cycling OR "active transport*" OR "active commut*" OR travel) wn KY)

A.2. Description of selected studies

Table A.2 Description of studies on objective measures of child pedestrian and cyclist collisions or injuries

Study	Location	Outcome	Pedestrian/ cyclist	Subject/ Participants (number of collisions/ injuries)	Data sources	Year of data	GIS	Study design	Statistic description
Abdel-Aty, M., S.S. Chundi, and C. Lee, 2007 [42]	Florida, USA	Crash frequency	Pedestrians/ Bicyclists	**Age:** 4-18 years; number of children's injuries = 451 **School level:** Elementary (4-11), Middle (12-14), High school (15-18) children; number of schools = 157	Police crash reports	1999–2003	✓	Cross sectional	Log-linear models, (p-value < 0.05)
Bennet, S.A. and N. Yiannakoulia, 2015 [44]	Hamilton, Ontario, Canada	Crash frequency (minor collisions were not included)	Pedestrians	**Age:** 5–14 years **case =** 107 midblock injuries; 92 intersection injuries **School level:** Elementary public school	Police report	2002-2011	✓	Case-control study	Conditional logistic regression, using odds ratio, P was significant at 0,05 for intersection model, and 0,01 for mid-block model)
Blazquez, C.A. and M.S. Celis, 2013 [38]	Santiago, Chile	Crash frequency	Pedestrians	**Age:** 5-18 years **School level:** Elementary, Secondary, High school	Police officers fill out a paper	2000- 2008	✓	Cross sectional	Moran's I index test, *p < 0.005
Clifton, K.J. and K. Kreamer-Fults, 2007 [37]	Baltimore City, Maryland, USA	Crash frequency and severity	Pedestrians	**Age:** <5 and 5-15 years **School level:** 116 Elementary, 23 Middle, and 24 High school	Police reports	2000–2002	✓	Cross sectional	Statistically significant at the10% confidence level
Cloutier, M. et al, 2007 [64]	Montréal, Canada	Crash frequency (number of collisions)	Pedestrians	**Age**: 5-14 years **School level**: Elementary school Number of schools: 331	Police reports	1995-1999	✓	Cross sectional	Multivariate regression (p value) p < .05

Table A.2 Description of studies on objective measures of child pedestrian and cyclist collisions or injuries ***(Continued…)***

Cloutier, M.-S. and P. Apparicio, 2008 [63]	Montreal, Canada	Risk of collision	Pedestrians	**Age:** 5-14 years **School level:** Elementary public-school environment	Police report	1999-2003	✓	Cross sectional, ecologi-cal	Poisson géographiquement pondérée (GWR)
Dissanayake, D., J. Aryaija, and D.P. Wedagama, 2009 [68]	Newcastle city, UK	Crash severity: Slight, Serious and fatal events ; KSI: killed or serious injuries	Pedestrians	**Age:** < 16 years	Police Force area	2000-2005	✓	Case study, ecological study	Poisson, negative binomial, bernoulli Methods, significant at 95% level of confidence
Donroe, J., et al, 2008 [43]	Lima, Peru	Injuries, risk of child pedestrian RTIs road traffic injuries	Pedestrians	**Age:** < 18 years Final participants: (5061 households and 10210 children; Children's injuries: **case = 100, controls = 200** Environments: **40 case and 80 control** **School level:** Elementary, Middle, and High school	completed surveys	2000-2005		Cross sectional , case control study,,	Logistic regression models, after adjustment (Multivariate, combination of personal and environmental risk factors), 95%CI
Ferenchak, N.N. and W.E. Marshall, 2017 [70]	6 American cities, USA	Crash frequency (fatalities concentrations)	Pedestrians	**Age:** < 18 years, number of schools with child pedestrian injuries = 332 schools **School level:** Elementary, Middle, and High school	2015 open data	1982-2012		Ecological study	Significant at 95% CIs (% differences) (schools or parks VS neither schools nor parks)
Hagel, B.E., et al, 2015 [21]	Alberta, Canada	Crash severity (severe injury)	Cyclists	**Age:** <18 years; total participants = 1470, boys (72,58%), females (27,42%); **cases =** 119 (8.1%), **controls =** 1351 (91.9%), total case and controls = 1470 **School level:** Elementary, Middle, and High school	Hospital medical charts, and face-to-face, and telephone interviews	May 2008 and October 2010		Case-control study	Logistic regression models (with multiple imputation) at 95% confidence intervals (CIs), and odds ratios
Hwang, J. et al, 2017 [18],	Austin, Texas, USA	Crash frequency (probability of injury)	Pedestrians	**Age:** ⩽18 years number of child injuries = 130	Department of transportation	2010-2014	✓	Cross sectional	Logistic regression analysis (p value) $P < .05$

Table A.2 Description of studies on objective measures of child pedestrian and cyclist collisions or injuries ***(Continued…)***

Jamshidi, E., A. Moradi, and R. Majdzadeh, 2017 [19]	Tehran, Iran	Crash frequency (Injury)	Pedestrians	**Age:** 5-15 years, 64.3% boys and 35.7% girls; **cases =** 280**, control =** 560, total number = 840	Hospital supervision and surveillance	2013		Case-control study	Conditional logistic regression model, 95% CI OR, P-value < 0,05
Jones, S.J., et al, 2005 [60]	2 cities (A and B) from UK (not specified)	Injuries and fatalities, (inequity of children's injuries)	Pedestrians	**Age:** 4–16 number of child injuries = 1560	Police data	1992-2000		Time series, ecological	Using 95% confidence intervals
LaScala, E.A., P.J. Gruenewald, and F.W. Johnson, 2004 [45]	California, USA	Crash frequency (Annual numbers of injuries)	Pedestrians and cyclists	**Age:** < 16 years. Number of collisions =717 **School level:** elementary schools (grades 1–5), middle schools (grades 6–8), and high schools (grades 9–12),	Police database	April 1992 - March 1996	✓	Ecological study	Combines the variables of socio demographics and environment using a separate t-test, (∗ P ≤ 0.05)
McArthur, A. et al, 2014 [65]	Michigan, USA	Crash frequency (probability of crash)	Pedestrian and Bicycle	**Age**: 5-14 years number of child pedestrians and Bicycle Crashes = 7781 crashes	Police databases	2007-2011	✓	Cross sectional	Random Effects Negative Binomial (p value) P < .05
Mecredy, G., I. Janssen, and W. Pickett, 2012 [67]	Canada	Crash frequency (Occurrence of injuries)	Pedestrians and cyclists	**Age:** 6-15 years; Final number of students = 9021 **School level:** elementary, middle and high school; number of schools = 180	hospital information, and cross-national survey (questionnaire distributed to children in classroom)	2006	✓	Cross-sectional study, (national study)	Multilevel logistic regression analysis, significant at p<0.01
Petch, R. and R. Henson, 2000 [46]	Salford city from United Kingdom	Crash frequency	Pedestrians and Cyclists	**Age:** < 15 years number of casualties = 556 children	Police and Hospital ;	1 May 1995-31 April 1998,	✓	Cross sectional, ecological study	Multiple regression, at the 90% confidence level

Table A.2 Description of studies on objective measures of child pedestrian and cyclist collisions or injuries ***(Continued…)***

Rothman, L., et al, 2012 [59]	Toronto, Canada	Crash severity (severe injury)	Pedestrians	**Age:** 0-17 years number of child pedestrian collision= 1394 **School level:** Primary, Secondary, high school	Police-report	1 January 2000-December 2009	✓	Cross sectional	Binary and multinomial logistic regression models, ORs of injury severity with 95% CI, significant at p<0.05 level
Rothman, L., et al, 2014 [16]	Toronto Canada	Crash severity (including minimal, minor, major,and fatal injuries)	Pedestrians	**Age:** 4-12 years number of children collision = 481 **School level:** elementary school; number= 118 schools, 22 (19%), and another 12 schools (10%) schools	Police report	2002 to 2011		Cross sectional	Negative binomial regression, significant at 0,05
Rothman, L., et al, 2015 [62]	Toronto, Canada	Crash severity (injury severity)	Pedestrians	**Age:** 0-14 years	Police-reported	2000-2011	✓	Quasi-experimental study	Rate ratio, 95 % CI
Rothman, L., et al, 2017 [17]	Toronto, Canada	Crash frequency (injuries)	Pedestrians	**Age:** 4-12 years**;** children collision: **case =** 513, **Control =** 88 **School level**: Primary school; **case =** 50, **control =** 50	Police-report	2000-2013		Case- control study	Multivariate logistic regression modelling (adjusted model), significant at p ≤ 0.2 level
Tester, J.M., et al, 2004 [61]	Oakland, USA	Injuries including fatality	Pedestrians	**Age:** < 15 years **cases =** 100 children, mean age = 6.8 (SD = 3.5), **Contols =** 200 children; mean age = 6.6 (SD = 3.7)	Pediatric ambulance trauma, and Police Department	1995-2000		Case-control	Multivariate conditional logistic regression, significant at p<0,05
Yiannakoulias, N., et al, 2002 [48]	Edmonton, Alberta, Canada	Minor injuries	Pedestrians	**Age:** 0-15 years; number of child injured = 258	Hospital surveillance	1995-1999	✓	Cross-sectional, ecological	Empirical bayes estimation, with incidence ratios
Yiannakoulias, N. and D.M. Scott, 2013 [47]	Toronto, Canada	Crash frequency (injuries risk)	Pedestrians	**Age:** 5-14 years **School level:** Elementary and secondary school aged children; n = 140 collision area	Police reported	2001-2008	✓	Cross-sectional, ecological design	Negative binomial regression, significant at the 0.1 level

Table A.2 Description of studies on objective measures of child pedestrian and cyclist collisions or injuries ***(Continued…)***

Yu, C.-Y, 2015 [41]	Austin (TX), USA	Injury (Crash risk)	Pedestrians	**Age:** 5-12 years **School level:** 78 Elementary schools (2 types: community-centered schools and suburban schools)	Officer's Crash Report	2008-2012	✓	Cross sectional	Bivariate analysis coefficient (p value) *p < .05

Table A.3 Description of studies of the perception of traffic safety for children's active travel

Study	Location	Walking or/and Cycling	Outcome (perception of safety)	Perception given by	Participants	Data source	Year of data	Study design
Basbas, S., A. et al, 2009 [53]	Municipality of Kalamaria, Thessaloniki, and Larissa, Greece	Walking and Cycling	Unsafe/safe to walk and cycle	Children (Students)	**Age**: 11-12 years (sixth grade school) **School level:** 9 Elementary school	Data from Survey; No GIS	2001	Cross-sectional
Christie, N., et al. 2007 [51]	10 low socioeconomic areas, UK	Walking and cycling	Perceived risk of traffic injuries	Parent's	**Age:** 10 to 14 years	Focus groups	The project started in 2004	
Guliani, A., et al, 2014 [49]	Toronto, Canada	Walking	Danger to walk	Parents (Mostly mothers)	**Age:** 10 and 11 years (average age 10.58), (720 students, Grade 5 and 6), (52% girls and 47.5% boys) **School level:** 16 publics school (8 inner-urban, and 8 inner-suburban)	survey (the project BEAT)	April 2010-June 2011	Cross sectional
Hopkins, D. and S. Mandic, 2017 [14]	Dunedin, South Island, New Zealand	Cycling	Traffic danger to cycling	Parents and Children students	6 parental focus groups (Total = 25 participants), 10 student focus groups (Total = 54 students), 5 co-educational schools, 5 single-sex schools (3 girls' schools, 2 boys' schools),10 groups of **Schools level**: high school	Online survey Interview focus group discussions	June 2014-April 2015	Cross sectional
Lee, G., et al, 2016 [58]	Ulsan, Korea	Walking	Safety concern to walk (related with crash risk)	Child's (student's)	**Age**: 10-12 (53.9% Boys); 799 children **School level:** 8 elementary school	**Perception** from questionnaire was distributed in the classroom **Crash data** from police-reported for crash	July 2015	Cross sectional

Table A.3 Description of studies of the perception of traffic safety for children's active travel ***(Continued…)***

Study	**Location**	**Walking or/and Cycling**	**Outcome (perception of safety)**	**Perception given by**	**Participants**	**Data source**	**Year of data**	**Study design**
Napier, M.A., et al, 2011 **[**66**]**	University of Utah, USA	Walking	Traffic unsafe to walk	Parents and children	**Age**: 10-11 year (n = 193); parents (n = 177) **School level:** elementary school	Survey (questionnaire was distributed in classroom); GIS measures	Spring 2007	Cross sectional
Olvera, N., et al, 2012 **[**52**]**	East End district, East side of Houston, Texas, USA	Walking and cycling	Safety concern related to walking and cycling	Children and mothers	**Age**: 3rd to 5th grade; 132 children (55 boys and 77 girls) average age 10 years and; 102 mothers (mean age = 36.2 ± 77.3) **School level:** elementary schools	Self-reported surveys	2008–2009	Cross sectional
Pocock, T., et al, 2019 **[**56**]**	Dunedin (New Zealand)	Walking, bicycling	Concern's (Traffic danger, unsafe) to walking and bicycling	Adolescents' (Students)	**Age:** 15.2 ± 1.4 years; data from 471 adolescents; 56.3% female **School level:** secondary schools	Online survey using GIS	2014–2015	Cross sectional
Rahman, M.L., et al. 2020 [69]	Otago, New Zealand	Walking and cycling	Safety concerns	Children	**Age:** 15.2 ± 1.4 years **School level**: 23 high schools	Online survey	2014 and 2018	
Rothman, L., et al, 2015 **[**50**]**	Toronto, Canada	Walking	Traffic danger to walk ; Collision rates	Parent's	**Age**: 9-11 years (grade 4-6); final sample of parent's n = 733 parent surveys **School level:** 20 elementary (primary school) schools	Data from parents survey (a written questionnaire) ; No GIS	2011	Cross sectional
Soori, H. 2000 [57]	Newcastle upon Tyne, UK	Walking and cycling	Perceived risk (safe / unsafe)	Parents and children	**Age:** 7 and 9 years **Participants:** children = 471; Parents = 416 **School level:** nine primary school	Surveys (self-completed)		Cross-sectional
Torres, J. et al. 2020 [54]	Quebec, Canada	Walking and cycling	Safe / unsafe to walk or cycle	Children	**Age:** 11-12 years	Focus groups	2014-2015	Cross-sectional

Table A.3 Description of studies of the perception of traffic safety for children's active travel ***(Continued…)***

Study	**Location**	**Walking or/and Cycling**	**Outcome (perception of safety)**	**Perception given by**	**Participants**	**Data source**	**Year of data**	**Study design**
Wilson, K., et al. 2019 [55]	Southwestern Ontario, Canada	Walking and cycling	Safe / unsafe to walk or cycle	Children	**Age**: 10 to 12 years Total of 158 students	Focus groups		

APPENDIX B BIVARIATE ANALYSES

Description of bivariate regression analysis

The bivariate regression analysis or "simple linear regression" is a linear equation used to test the correlation between two variables (e.g. Independent and dependent variable).

Bivariate analysis was used to investigate the relationship between all the selected independent variables and the various measures of parental safety perceptions. The results of this step show which variables are possibly relevant before applying stepwise regression. A p-value less than 0.05 was used to determine which variable was significantly related (relevant) to one or more dependent variables.

The dependent variables (parental safety perception) were an interval/ratio scale. Most built environment variables were continuous, except one ordinal variable (urban density). The individual and household characteristics differ in measurement scale between binary variable (2 categories), nominal (≥ 2 categories), and ordinal measurement scales.

Several analysis techniques were used for bivariate regression analysis. Figure A.1 presents the bivariate analysis techniques used based on the measurement scale of dependent and independent variables.

<table>
<tr><th></th><th colspan="4">Dependent variables</th></tr>
<tr><th>Independent variables</th><td>Binary variable (2 categories)</td><td>Nominal (≥ 2 categories)</td><td>Ordinal</td><td>Interval/ratio</td></tr>
<tr><td>Binary variable (2 categories)</td><td rowspan="3" colspan="3">Chi-square (χ2) test</td><td>Two sample t-test (Independent t-test)</td></tr>
<tr><td>Nominal (≥ 2 categories)</td><td>One way ANOVA test</td></tr>
<tr><td>Ordinal</td><td>Spearman's correlation</td></tr>
<tr><td>Interval/ratio</td><td>Two sample t-test (Independent t-test)</td><td colspan="2">One way ANOVA test</td><td>Pearson's correlation</td></tr>
</table>

Figure A.1 Bivariate analysis for each measurement scale

Table A.4 presents the result of bivariate regression analysis between individual, household variables and parental safety perception. The positive value means that independent variable was perceived safe by parents, while a negative value indicated unsafe perception.

Table A.5 presents the result of bivariate regression analysis between parental safety perception and built environment characteristics for school and home neighborhood level.

Table A.4 Bivariate analysis of safety perception and individual, household characteristics

Variables	**Traffic to/from school**		**Pedestrians and bicycle path**		***Multiple safe routes***		**Social perception**		**Child skills**		**Total Parental Safety Perception**	
Individual and household characteristics	**Spearman's correlation**											
	r	P-value	r	P-value	r	P-value	r	P-value	r	P-value	r	P-value
Age	0.0196	0.647	0.024	0.572	**0.177****	0.000	0.003	0.941	**0.187*****	0.000	**0.111****	0.008
	Independent t-test											
	t	P-value	t	P-value	t	P-value	t	P-value	t	P-value	t	P-value
Gender	-0.879	0.379	-0.356	0.721	-0.269	0.788	0.472	0.636	-0.354	0.722	-0.668	0.504
	Spearman's correlation											
	r	P-value	r	P-value	r	P-value	r	P-value	r	P-value	r	P-value
Income	0.059	0.161	0.0012	0.976	**0.101***	0.017	**0.085***	0.045	0.076	0.075	**0.112****	0.008
Car ownership	0.059	0.166	0.050	0.240	**0.084***	0.048	**0.109***	0.010	0.002	0.961	**0.094***	0.027
Number of children in household	-0.031	0.465	-0.066	0.121	-0.042	0.319	-0.059	0.163	0.016	0.699	-0.051	0.228
	ANOVA test											
	Welch ANOVA		**One-way ANOVA**						**Welch ANOVA**			
	F	Sig	F	Sig	F	Sig	F	Sig	F	P-value	F	Sig
Work situation	1.939	0.138	1.255	0.303	2.329	0.088	1.893	0.147	2.514	0.072	**10.101**	**0.000****
	One-way ANOVA											
	F	Sig	F	Sig	F	Sig	F	Sig	F	P-value	F	Sig
Favorite mode	0.359	0.836	**2.804**	**0.025***	1.994	0.10	0.296	0.880	**5.132**	**0.000****	**2.772**	**0.030***
	One-way ANOVA										**Welch ANOVA**	
	F	Sig	F	Sig	F	Sig	F	Sig	F	P-value	F	Sig
Ethnicity	1.198	0.302	1.378	0.252	1.682	0.186	0.230	0.793	0.404	0.667	1.131	0.331

[CI, 95%]
* indicates p < .05. ** indicates p <0.01

Table A.5 Bivariate analysis of built environment and parental safety perception

Variable	Traffic to/from school		Pedestrians and bicycle path		Multiple safe routes		Social perception		Child skills		Total Parental Safety Perception	
I. Route to school neighborhood	**Pearson's correlation**											
	r	[CI]	r	[CI]	r	[CI]	r	[CI]	r	[CI]	r	[CI]
Distance to school of roads	.00	[-.08, .09]	-.05	[-.13, .04]	-.01	[-.09, .08]	-.06	[-.14, .03]	-.15**	[-.23, -.06]	-.09*	[-.17, -.00]
with separated bicycle lane	.17**	[.09, .25]	.16**	[.07, .24]	.19**	[.11, .27]	.01	[-.07, .10]	-.02	[-.11, .06]	.16**	[.08, .24]
Major road crossings	-.02	[-.10, .07]	-.05	[-.13, .03]	-.01	[-.09, .08]	-.10*	[-.18, -.01]	-.15**	[-.23, -.07]	-.11*	[-.19, -.03]
II. School neighborhood	**Pearson's correlation**											
	r	[CI]	r	[CI]	r	[CI]	r	[CI]	r	[CI]	r	[CI]
Road type												
Road density	-.28**	[-.35, -.20]	.39**	[-.46, -.32]	-.51**	[-.57, -.44]	-.09*	[-.17, -.01]	-.13**	[-.21, -.05]	-.42**	[-.49, -.35]
Local road density	.05	[-.04, .13]	.18**	[.10, .26]	.31**	[.23, .38]	.07	[-.01, .15]	-.00	[-.09, .08]	.14**	[.06, .22]
Collector road density	-.11*		-.18**	[-.26, -.10]	-.29**		-.12**	[-.20, -.03]	-.00	[-.09, .08]	-.19**	
Arterial road density	-.16**	[-.24, -.08]	-.33**	[-.41, -.26]	-.36**	[-.43, -.29]	.01	[-.08, .09]	-.09*	[-.17, -.00]	-.28**	[-.36, -.20]
Active travel infrastructures												
FAT density	-.03	[-.11, .06]	.05	[-.03, .14]	.07	[-.01, .15]	.07	[-.02, .15]	.04	[-.04, .13]	.05	[-.04, .13]
Intersection												
Intersection density	-.31**	[-.38, -.23]	-.34**	[-.41, -.27]	-.51**	[-.57, -.45]	-.13**	[-.21, -.05]	-.13**	[-.21, -.04]	-.43**	[-.49, -.36]
Cul de sac density	.05	[-.03, .14]	.02	[-.07, .10]	-.06	[-.15, .02]	.04	[-.04, .12]	.00	[-.08, .09]	.03	[-.05, .12]
Speed limit												
≤ 30km/h	.32**	[.24, .40]	.47**	[.40, .53]	.69**	[.65, .73]	.13**	[.05, .22]	.04	[-.05, .12]	.47**	[.40, .53]
> 30km/h	-.32**	[-.40, -.24]	-.47**	[-.53, -.40]	-.69**	[-.73, -.65]	-.13**	[-.22, -.05]	-.04	[-.12, .05]	-.47**	[-.53, -.40]
Land use type												
Residential land use	-.12**	[-.21, -.04]	-.33**	[-.40, -.25]	-.25**	[-.32, -.17]	.02	[-.06, .10]	-.02	[-.11, .06]	-.22**	[-.29, -.13]
Green land use	.12**	[.03, .20]	.34**	[.26, .41]	.26**	[.18, .34]	-.02	[-.11, .06]	.03	[-.05, .12]	.22**	[.14, .30]
Industrial land use	-.25**	[-.33, -.17]	-.43**	[-.50, -.36]	-.58**	[-.63, -.52]	-.07	[-.15, .02]	-.08	[-.16, .01]	-.40**	[-.47, -.33]
Commercial land use	-.18**	[-.26, -.09]	-.24**	[-.32, -.16]	-.54**	[-.59, -.47]	-.00	[-.09, .08]	-.05	[-.14, .03]	-.27**	[-.35, -.19]
Other												
Total school population	-.06	[-.14, .03]	.01	[-.08, .09]	-.02	[-.11, .06]	.09*	[.01, .18]	.05	[-.03, .14]	.01	[-.07, .10]
	Independent t-test											
	t	P-value	t	P-value	t	P-value	t	P-value	t	P-value	t	P-value
Separated bicycle lane (yes-no)	0.942	0.346	-0.198	0.843	2.13*	0.034	0.874	0.382	-1.197	0.231	0.393	0.693

Table A.5 Bivariate analysis of built environment and parental safety perception ***(Continued…)***

Variable	**Traffic to/from school**		**Pedestrians and bicycle path**		**Multiple safe routes**		**Social perception**		**Child skills**		**Total Parental Safety Perception**	
III. Home neighborhood	**Pearson's correlation**											
	r	[CI]	r	[CI]	r	[CI]	r	[CI]	r	[CI]	r	[CI]
Road type												
Road density	**-.18****	[-.26, -.09]	**-.14****	[-.22, -.06]	**-.25****	[-.33, -.17]	**-.11***	[-.19, -.02]	.01	[-.08, .09]	**-.20****	[-.28, -.11]
Local road density	.00	[-.08, .09]	.01	[-.08, .09]	**.15****	[.07, .23]	.03	[-.06, .11]	.03	[-.06, .11]	.04	[-.04, .13]
Collector road density	.00	[-.08, .09]	.07	[-.02, .15]	**-.12****	[-.20, -.04]	-.08	[-.16, .01]	.03	[-.06, .11]	.00	[-.08, .09]
Arterial road density	-.00	[-.09, .08]	-.08	[-.16, .01]	**-.09***	[-.17, -.01]	.04	[-.04, .12]	-.07	[-.15, .02]	-.06	[-.14, .02]
Active travel infrastructures												
FAT density	**-.11***	[-.19, -.02]	-.05	[-.13, .04]	**-.09***	[-.17, -.01]	.02	[-.06, .11]	.04	[-.04, .13]	-.06	[-.15, .02]
Intersection												
Intersection density	**-.14****	[-.22, -.06]	-.06	[-.14, .03]	**-.18****	[-.26, -.10]	-.08	[-.17, .00]	.07	[-.01, .16]	**-.10***	[-.19, -.02]
Speed limit												
≤ 30km/h	.04	[-.05, .12]	.05	[-.03, .13]	**.23****	[.15, .30]	.04	[-.05, .12]	.02	[-.06, .11]	**.08***	[.00, .17]
>30km_H	-.04	[-.12, .05]	-.04	[-.13, .04]	**-.22****	[-.30, -.14]	-.03	[-.12, .05]	-.02	[-.11, .06]	-.08	[-.16, .00]
Land use												
Residential land use	**-.13****	[-.21, -.04]	**-.19****	[-.27, -.10]	**-.22****	[-.30, -.14]	-.03	[-.12, .05]	-.06	[-.15, .02]	**-.19****	[-.27, -.11]
Green land use	**.14****	[.06, .22]	**.16****	[.08, .24]	**.20****	[.12, .28]	.07	[-.01, .15]	.02	[-.07, .10]	**.18****	[.10, .26]
Commercial land use	.01	[-.07, .10]	.03	[-.05, .12]	-.00	[-.09, .08]	.03	[-.05, .11]	.07	[-.01, .16]	.05	[-.03, .14]
Industrial land use	-.01	[-.09, .08]	-.01	[-.09, .08]	-.05	[-.14, .03]	.00	[-.08, .09]	.05	[-.04, .13]	.01	[-.08, .09]
	Spearman's correlation											
Urban density	r	P-value	r	P-value	r	P-value	r	P-value	r	P-value	r	P-value
Urban density	**-0.13****	0.001	**-0.106***	0.012	**-0.25****	0.000	**-0.08***	0.044	-0.063	0.137	**-0.17****	0.000

[CI, 95%]
* indicates p < .05.
** indicates p < .01.

Table A.6 Correlation matrix of school neighborhood variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Road density															
2. FAT density	-.03 [-.12, .05]														
3. Local roads	-.15** [-.23, -.07]	**.69**** [.65, .74]													
4. Collector roads	.28** [.20, .35]	-.48** [-.54, -.41]	**-.68**** [-.73, -.64]												
5. Arterial roads	.38** [.31, .45]	-.35** [-.43, -.28]	-.15** [-.23, -.06]	-.19** [-.27, -.11]											
6. Intersection density	**.73**** [.69, .77]	.01 [-.08, .09]	.03 [-.05, .11]	.38** [.30, .45]	.20** [.12, .28]										
7. Cul de sac density	.37** [.30, .44]	-.00 [-.09, .08]	-.44** [-.51, -.37]	.28** [.20, .35]	.02 [-.06, .11]	-.19** [-.27, -.11]									
8. % ≤30km/h	-.62** [-.67, -.56]	.15** [.07, .23]	.46** [.39, .52]	**-.72**** [-.76, -.67]	-.22** [-.30, -.14]	-.61** [-.66, -.55]	-.31** [-.38, -.23]								
9. % >30km/h	.62** [.56, .67]	-.15** [-.23, -.07]	-.46** [-.52, -.39]	**.72**** [.67, .76]	.22** [.14, .30]	.61** [.55, .66]	.31** [.23, .38]	**-1.00**** [-1.00, -1.00]							
10. Residential use (%)	.64** [.59, .69]	-.11** [-.19, -.03]	-.46** [-.52, -.39]	.37** [.30, .44]	.26** [.18, .34]	.34** [.27, .41]	.57** [.51, .63]	-.43** [-.49, -.36]	.43** [.36, .49]						
11. Green use (%)	-.64** [-.68, -.58]	.22** [.14, .30]	.53** [.47, .59]	-.35** [-.42, -.28]	-.41** [-.48, -.34]	-.26** [-.34, -.18]	-.62** [-.67, -.57]	.43** [.35, .49]	-.43** [-.49, -.35]	**-.97**** [-.97, -.96]					
12. Industrial use (%)	.29** [.21, .36]	-.28** [-.36, -.20]	-.20** [-.28, -.11]	-.09* [-.18, -.01]	**.86**** [.84, .88]	.24** [.16, .31]	-.15** [-.23, -.07]	-.38** [-.45, -.31]	.38** [.31, .45]	.04 [-.05, .12]	-.19** [-.27, -.10]				
13. Commercial use (%)	.37** [.30, .44]	-.05 [-.14, .03]	-.25** [-.33, -.17]	-.21** [-.29, -.13]	.64** [.59, .69]	.06 [-.02, .14]	.28** [.21, .36]	-.23** [-.31, -.15]	.23** [.15, .31]	.25** [.17, .33]	-.37** [-.44, -.29]	**.67**** [.63, .72]			
14. Total school population	.06 [-.02, .15]	.35** [.28, .43]	.51** [.45, .57]	-.54** [-.60, -.48]	.40** [.33, .47]	.17** [.09, .25]	-.20** [-.28, -.11]	.14** [.06, .22]	-.14** [-.22, -.06]	-.17** [-.25, -.09]	.17** [.09, .25]	.25** [.17, .32]	.24** [.16, .32]		
15. Separated bicycle lane	-.22** [-.30, -.14]	-.20** [-.28, -.12]	.09* [.01, .18]	.18** [.09, .26]	-.05 [-.13, .04]	.04 [-.05, .12]	-.41** [-.47, -.33]	-.13** [-.21, -.05]	.13** [.05, .21]	-.56** [-.62, -.50]	.51** [.45, .57]	.18** [.10, .26]	-.38** [-.45, -.30]	.01 [-.08, .09]	

[CI, 95%] * indicates p < .05. ** indicates p < .01. Correlation level > 0.65

Table A.7 Correlation matrix of home neighborhood variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Distance to school																	
2. Roads with separated bicycle lane	.32** [.25, .40]																
3. Major road crossings	.78** [.74, .81]	.52** [.46, .58]															
4. Road density	-.01 [-.09, .08]	-.20** [-.28, -.12]	.10* [.01, .18]														
5. FAT density	-.18** [-.26, -.10]	-.35** [-.42, -.28]	-.16** [-.24, -.08]	.27** [.19, .35]													
6. Local density	-.20** [-.28, -.12]	-.33** [-.40, -.25]	-.19** [-.27, -.11]	.03 [-.05, .12]	.59** [.53, .64]												
7. Collectors density	.03 [-.05, .12]	.19** [.11, .27]	.04 [-.05, .12]	-.06 [-.14, .03]	-.34** [-.42, -.27]	-.71** [-.75, -.66]											
8. Arterial density.	.25** [.17, .33]	.27** [.19, .35]	.24** [.16, .31]	.01 [-.07, .10]	-.48** [-.54, -.41]	-.70** [-.74, -.66]	-.01 [-.09, .08]										
9. Intersection density	-.01 [-.09, .07]	-.19** [-.27, -.11]	.08 [-.01, .16]	.86** [.83, .88]	.21** [.13, .29]	.02 [-.06, .11]	-.09* [-.17, -.00]	.05 [-.03, .13]									
10. % ≤30km/h	-.26** [-.34, -.18]	-.21** [-.29, -.13]	-.23** [-.31, -.15]	.04 [-.05, .12]	.43** [.36, .50]	.86** [.84, .88]	-.56** [-.61, -.50]	-.66** [-.70, -.61]	-.01 [-.09, .08]								
11. %> 30km/h	.26** [.18, .34]	.21** [.13, .29]	.23** [.15, .31]	-.04 [-.12, .04]	-.43** [-.50, -.36]	-.86** [-.88, -.84]	.56** [.50, .61]	.66** [.61, .70]	.00 [-.08, .09]	-1.00** [-1.00, -1.00]							
12. Residential use (%)	.05 [-.03, .13]	-.08 [-.16, .00]	.10* [.02, .19]	.57** [.51, .62]	.13** [.04, .21]	-.04 [-.13, .04]	-.00 [-.09, .08]	.06 [-.02, .15]	.50** [.43, .56]	-.02 [-.11, .06]	.02 [-.06, .10]						
13. Green density use (%)	-.01 [-.10, .07]	.09* [.01, .18]	-.10* [-.18, -.01]	-.69** [-.73, -.64]	-.22** [-.29, -.13]	-.09* [-.17, -.01]	.08 [-.01, .16]	.05 [-.03, .14]	-.57** [-.62, -.51]	-.15** [-.23, -.06]	.15** [.07, .23]	-.73** [-.77, -.69]					
14. Commercial density use (%)	.07 [-.01, .16]	-.05 [-.13, .04]	.03 [-.06, .11]	.12** [.04, .20]	.14** [.05, .22]	-.03 [-.11, .06]	-.07 [-.16, .01]	.11* [.03, .19]	.18** [.10, .26]	-.01 [-.10, .07]	.01 [-.08, .09]	.13** [.05, .22]	-.17** [-.25, -.09]				
15. Industrial (%)	.20** [.11, .28]	.12** [.04, .20]	.16** [.08, .24]	-.01 [-.09, .07]	-.10* [-.18, -.02]	-.05 [-.13, .04]	.02 [-.07, .10]	.05 [-.03, .13]	-.05 [-.14, .03]	-.07 [-.15, .01]	.07 [-.01, .15]	-.01 [-.09, .08]	.01 [-.08, .09]	-.02 [-.10, .07]			
16. % of household with child	-.16** [-.24, -.07]	-.11* [-.19, -.03]	-.14** [-.22, -.06]	-.05 [-.14, .03]	.39** [.31, .46]	.29** [.21, .36]	-.21** [-.29, -.13]	-.20** [-.28, -.12]	-.07 [-.16, .01]	.29** [.21, .37]	-.29** [-.37, -.21]	-.14** [-.22, -.06]	.03 [-.06, .11]	.00 [-.08, .09]	-.06 [-.14, .03]		
17. Urban density	.27** [.19, .34]	-.01 [-.09, .08]	.24** [.16, .32]	.40** [.32, .47]	.07 [-.02, .15]	-.21** [-.28, -.12]	.01 [-.07, .10]	.27** [.20, .35]	.50** [.44, .56]	-.21** [-.28, -.12]	.20** [.12, .28]	.48** [.41, .54]	-.54** [-.60, -.48]	.14** [.06, .22]	.05 [-.03, .13]	-.13** [-.21, -.05]	

[CI, 95%].
* indicates p < .05. ** indicates p < .01. Correlation level > 0.6

Table A.8 Summary of bivariate analysis results

Variable	Traffic to/from school	Multiple safe routes	Total Parental Safety Perception
I. Route to school neighborhood			
1. Distance to school			(-)*
2.% of roads with separated bicycle lane	(+)**	(+)**	(+)**
3. Major road crossings			(-)*
II. School neighborhood			
Road type			
4. Road density	(-)**	(-)**	(-)**
5. Local roads density		(+)**	(+)**
6. Collector roads density	(-)*	(-)**	(-)**
7. Arterial roads density	(-)**	(-)**	(-)**
Active travel infrastructures			
13. FAT density			
Intersection			
8. Intersection density	(-)**	(-)**	(-)**
9. Cul de sac density			
Speed limit			
10. ≤30km/h	(+)**	(+)**	(+)**
11. > 30km/h	(-)**	(-)**	(-)**
Land use type			
13 Residential use	(-)**	(-)**	(-)**
14 Green use	(+)**	(+)**	(+)**
15. Industrial use	(-)**	(-)**	(-)**
16. Commercial use	(-)**	(-)**	(-)**
Other			
18. Total school population			
17. Separated bicycle lane (yes-no)		(+)*	
Variable	**Traffic to/from school**	**Multiple safe routes**	**Total Parental Safety Perception**
III. Home neighborhood			
Road type			
1. Road density	(-)**	(-)**	(-)**
2. Local density		(+)**	
3. Collectors density		(-)**	
4. Arterial density		(-)*	
Active travel infrastructures			
5. FAT density	(-)*	(-)*	
Intersection			
5. Intersection density	(-)**	(-)**	(-)*
Speed limit			
6. ≤30km_		(+)**	(+)*
7. >30km		(-)**	
Land use			
9. Residential use	(-)**	(-)**	(-)**
10. Green use	(+)**	(+)**	(+)**
11. Commercial use			
12. Industrial use			
Other			
13. % of household with child		(-)**	
Urban density			
14. Urban density	(-)**	(-)**	(-)**

* indicates p < .05.
** indicates p < .0

Table A.9 Variables and their methodologies from a literature review

Variables	**Methodology**	**Sources**
Distance to school	Distance between home and school in Km	[49]
Road type	# km / km road in school (or street) buffer	[41], [18], [16]
Intersection density	Number of intersection / km road in school (or street) buffer	[49], [41], [18], [50]
	Number of intersection / km2 (school area)	[56]
Dead-end	# number / km roads in school buffer	[50], [16]
Land use		
Residential land use	# area / area in school buffer	[41], [16]
Commercial land use	# area / area in school buffer	[41], [16]
Industrial land use	# area / area in school buffer	[41], [16]
Office land use	# area / area in school buffer	[41]
Park land use	# area / area in school buffer	[41], [16]
Traffic light	# number / km road in school buffer	[16]
Traffic calming	Presence of any traffic calming measures: speed humps, roundabout, school zone sign (Yes-No)	[49], [16]
Residential density	-Residences / km2	[56]
Missing sidewalks density	# km/km road in school buffer (proportion of school route without a sidewalk)	[50], [16], [49]
Crosswalk density	# number / km road in school buffer	[50], [16]
Walkability Index	z score of intersection density + z score of residential density + z score of land use mix	[69]
One way street density	# km/10 km road	[50]
Retail density	retail outlets/km	[49]
Major Road Crossing	Presence of Major Road Crossing (Yes- No)	[49]
Total school population	Number of child population for each school	[50], [16]
Population density	-boundary of multiple census blocks using the average	[58]