Operationalizing calculated and perceived accessibility in transport planning practice

Hisham Negm

School of Urban Planning

McGill University

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Abstract

Accessibility, the ability of individuals to reach destinations, has gained increasing prominence in transport planning. Over the past decade, attention has expanded beyond calculated measures of accessibility, which assess the performance of transport and land use systems, to include how individuals perceive accessibility based on their subjective experiences and personal characteristics. As accessibility becomes more integral to planning practice, understanding the impacts of both its calculated and perceived dimensions on travel behaviour is essential for professionals and decision-makers seeking to operationalize it effectively.

The main research aim of this dissertation is to contribute to transport planning research and practice by answering the overarching question: *How can calculated and perceived accessibility be operationalized in transport planning practice?* This question is examined through four research objectives:

1. To explore the connections and distinctions between perceived and calculated accessibility in transport research.
2. To assess the impact of calculated accessibility on aggregate travel behaviour in the post-pandemic era.
3. To examine the impact of calculated and perceived accessibility on individual-level travel behaviour.
4. To develop and operationalize calculated accessibility thresholds based on the interrelation between calculated and perceived accessibility.

Each objective corresponds to a chapter in this manuscript-based dissertation (Chapters 2–5). Together, these chapters build progressively to advance knowledge on how accessibility, both calculated and perceived, can be implemented in practice.

Following the introductory chapter outlining the research background, objectives, and contributions, Chapter 2 reviews the literature on perceived accessibility to establish a clear definition and develop a conceptual framework guiding empirical research on accessibility and travel behaviour. Considering COVID-19-related travel behaviour changes, Chapter 3 uses aggregate data from the 2016 and 2021 Canadian Census to examine the association between calculated accessibility and public transit mode share

in the three largest metropolitan regions in Canada in the post-pandemic context. Building on this validation, Chapter 4 investigates how calculated and perceived accessibility relate to travel behaviour at local and regional scales using disaggregate individual-level data from the Montréal Mobility Survey (N = 4,679). Motivated by an operationalization gap between theory and planning practice, Chapter 5 develops and empirically tests a methodology for defining calculated accessibility thresholds using perceived accessibility data from the Canadian Mobility Survey (N = 15,960) and calculated accessibility measures across 12 Canadian regions. Chapter 6 synthesizes the findings of the four studies, highlighting their theoretical, empirical, and methodological contributions, along with policy implications and directions for future research.

Overall, this dissertation advances the theoretical understanding, empirical measurement, and practical application of accessibility in transport planning. It bridges calculated and perceived accessibility dimensions through a replicable methodology that informs planning practice, integrates individual perspectives, and generates actionable insights to promote equity and sustainability. It demonstrates that accessibility can be operationalized not only as a planning metric but also as a capability that shapes how individuals interact with their urban environments, thereby supporting more inclusive, effective, and sustainable transport planning practices. From a theoretical perspective, the dissertation advances a capability-based framework for equitable transport planning, integrating both aggregate and disaggregate analyses and extending the approach through principles of *sufficientarianism*.

Résumé

L'accessibilité, soit la capacité des individus à atteindre des destinations, a pris une importance croissante dans le domaine de la planification des transports. Au cours de la dernière décennie, l'attention ne s'est plus limitée aux mesures calculées de l'accessibilité, qui évaluent la performance des systèmes de transport et d'aménagement du territoire, mais s'est également portée sur la manière dont les individus perçoivent cette accessibilité en fonction de leurs expériences subjectives et de leurs caractéristiques personnelles. À mesure que l'accessibilité devient un élément central de la pratique en planification, il est essentiel de comprendre les effets de ses dimensions calculée et perçue sur le comportement de déplacement afin de permettre aux professionnels et aux décideurs de l'opérationnaliser efficacement.

L'objectif principal de cette thèse est de contribuer à la recherche et à la pratique en planification des transports en répondant à la question générale suivante : *Comment l'accessibilité calculée et perçue peut-elle être opérationnalisée dans la pratique de la planification des transports ?* Cette question est examinée à travers quatre objectifs de recherche :

1. Explorer les liens et les distinctions entre l'accessibilité perçue et l'accessibilité calculée dans la recherche en transport.
2. Évaluer l'impact de l'accessibilité calculée sur le comportement de déplacement agrégé dans l'ère post-pandémique.
3. Examiner l'impact de l'accessibilité calculée et perçue sur le comportement de déplacement à l'échelle individuelle.
4. Développer et opérationnaliser des seuils d'accessibilité calculée fondés sur l'interrelation entre l'accessibilité calculée et perçue.

Chaque objectif correspond à un chapitre de cette thèse par articles (chapitres 2 à 5). Ensemble, ces chapitres s'articulent de manière progressive afin de faire avancer les connaissances sur la mise en œuvre de l'accessibilité, tant calculée que perçue, dans la pratique.

À la suite du chapitre introductif présentant le contexte de recherche, les objectifs et les contributions, le chapitre 2 propose une revue de la littérature sur l'accessibilité perçue afin d'en établir une définition claire

et de développer un cadre conceptuel guidant la recherche empirique sur l'accessibilité et le comportement de déplacement. À la lumière des changements de comportement de déplacement liés à la COVID-19, le chapitre 3 utilise des données agrégées des recensements canadiens de 2016 et 2021 pour examiner l'association entre l'accessibilité calculée et la part modale du transport collectif dans les trois plus grandes régions métropolitaines du Canada dans le contexte post-pandémique. S'appuyant sur cette validation, le chapitre 4 analyse la relation entre l'accessibilité calculée et perçue et le comportement de déplacement aux échelles locale et régionale à partir de données désagrégées issues de l'Enquête mobilité Montréal (N = 4 679). Motivé par un écart entre la théorie et la pratique, le chapitre 5 développe et teste empiriquement une méthodologie visant à définir des seuils d'accessibilité en mobilisant des données d'accessibilité perçue provenant de l'Enquête canadienne sur la mobilité (N = 15 960) et des mesures d'accessibilité calculée couvrant 12 régions canadiennes. Le chapitre 6 synthétise les résultats des quatre études en mettant en lumière leurs contributions théoriques, empiriques et méthodologiques, ainsi que leurs implications pour les politiques publiques et les pistes de recherche futures.

Dans l'ensemble, cette thèse fait progresser la compréhension théorique, la mesure empirique et l'application pratique de l'accessibilité en planification des transports. Elle établit un pont entre les dimensions calculée et perçue de l'accessibilité grâce à une méthodologie reproductible qui éclaire la pratique de la planification, intègre les perspectives individuelles et génère des pistes d'action pour promouvoir l'équité et la durabilité. Elle démontre que l'accessibilité peut être opérationnalisée non seulement comme un indicateur de planification, mais aussi comme une capabilité qui façonne la manière dont les individus interagissent avec leur environnement urbain, contribuant ainsi à des pratiques de planification des transports plus inclusives, efficaces et durables. D'un point de vue théorique, la dissertation développe un cadre fondé sur *l'approche par les capabilités* pour une planification des transports équitable, en intégrant des analyses à la fois agrégées et désagrégées et en s'appuyant sur les principes du *suffisantisme.*

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Table of Contents

Index of Figures

Index of Tables

Glossary

CCF	Canadian population census and commuting flows
CMA	Canadian Mobility Survey
CT	Census Tract
DA	Dissemination Area
GTFS	General Transit Feed Specification
LI	Low income
MMS	Mobility Survey
OI	Other income
OSM	OpenStreetMap
PA-score	Perceived Accessibility Score
PMA	Perceived minimum accessibility
PSA	Perceived sufficient accessibility
PT	Public transit
TT	Travel time
TTM	Travel Time Matrix
WFH	Work from home

Publication details and author contributions

This dissertation consists of four manuscripts that have been published or submitted to peer-reviewed academic journals (**Table 1.1**). All four manuscripts were co-authored by Hisham Negm and Ahmed El-Geneidy, except for Chapter 2 that includes two other co-authors. Ahmed El-Geneidy contributed intellectually and provided comments and edits to all manuscripts. Hisham Negm was the primary author of the manuscripts, responsible for conceptualization, data collection and curation, analysis, interpretation of the results, and writing. Chapter 2 includes Jonas De Vos and Felix Pot as co-authors who contributed to the conceptualization and revision of the manuscript, providing feedback and suggestions for improvement.

Table 1.1 Manuscripts' publication/presentation details

Chapter	Publication/Presentation	Status
Chapter 2	Negm, H., De Vos, J., Pot, F., & El-Geneidy, A. (2025). Perceived accessibility: A literature review. *Journal of Transport Geography, 125, 104212.*	**Published**
Chapter 3	Negm, H., & El-Geneidy, A. (2024). Exploring the changes in the interrelation between public transit mode share and accessibility across income groups in major Canadian cities in the post-pandemic era. *Journal of Transport Geography, 115, 103792.*	**Published**
	Negm, H. & El-Geneidy, A. (2024). *Exploring the changes in the interrelation between public transit mode share and accessibility across income groups in major Canadian cities in the post-pandemic era* [Paper presentation]. Transportation Research Board 103rd Annual Meeting, Washington D.C., United States.	Presented
	Negm, H. & El-Geneidy, A. (2024). *Subjectivity Matters: An outlook on perceived regional accessibility in a travel behaviour framework* [Paper presentation]. 2024 World Symposium on Transport and Land Use Research, Bogota, Colombia.	Presented
Chapter 4	Negm, H., & El-Geneidy, A. (2025). Subjectivity matters: Investigating the relationship between perceived accessibility and travel behaviour. T*ransportation Research Part A: Policy and Practice*, *193, 104399.*	**Published**

Chapter	Publication/Presentation	Status
	Negm, H**.** & El-Geneidy, A. (2024). *Can I walk there? Studying perceived walkability in a travel behaviour framework* [Paper presentation]. 17th NECTAR Conference, Brussels, Belgium.	Presented
Chapter 5	Negm, H., & El-Geneidy, A. (Under review). Operationalizing accessibility thresholds: Identifying perceived minimum and sufficient accessibility in Canada.	Submitted

Chapter 1. Introduction

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Introduction

1.1 Overview

For much of the twentieth century, transport planning has focused on the notion of mobility, leading to continuous growth in road infrastructures (Downs, 2004). In recent years, growing concerns about sustainability has shed light on the social and environmental downside of this mobility-oriented planning approach (Banister, 2012). In turn, there has been a significant shift in the transport planning field, transitioning its focus from emphasizing the movement of vehicles (mobility) to prioritizing the provision of people with access to spatially and temporally dispersed opportunities (accessibility) (Handy, 2023; Miller, 2018). This dissertation builds on this paradigm shift by examining accessibility from both calculated and perceived dimensions to help in operationalize their use in transport planning practice.

Calculated accessibility is a land use and transport systems performance measure, representing the ability of individuals in different geographies, each with unique needs and circumstances, to reach destinations by different transport modes, while considering temporal components (Dalvi & Martin, 1976; Handy, 1992, 2023; Hansen, 1959; Levinson & Wu, 2020). Calculated measures of accessibility have been extensively used to study the impact of land use and transport systems on travel behaviour (Moniruzzaman & Páez, 2012; Owen & Levinson, 2015; Ton et al., 2020) and economic development (Deboosere et al., 2018; He, 2020). These measures are commonly used to evaluate the social equity aspects of transport systems (El-Geneidy et al., 2016; Foth et al., 2013; Luo et al., 2023), as well as policies and plans (Boisjoly & El-Geneidy, 2017a; Golub & Martens, 2014; Manaugh et al., 2015; Manaugh & El-Geneidy, 2012).

Defined as the individuals' perceptions of how easily a person can access their desired destinations using a (range of) specific mode(s) (Negm, De Vos, et al., 2025), perceived accessibility has been gaining attention in the literature as it accounts for individual perceptions, subjective experiences, and personal characteristics that mediate the relationship between land-use and transport system configurations and how people experience them (Lättman, Friman, et al., 2016; Pot et al., 2021; van Wee, 2016). Considering perceptions enables the examination of equity and social exclusion, which require individual-centered approaches, such as the *Capability Approach*, that reflect how people with diverse backgrounds and needs perceive the land use and transport systems around them (Vecchio & Martens, 2021).

As accessibility becomes increasingly integral in transport planning (Cournoyer et al., 2026), understanding the wide impacts of both its calculated and perceived dimensions on travel behaviour is essential for professionals and decision-makers to allow its operationalization in practice. While calculated accessibility is well-established, perceived accessibility remains conceptually and empirically ambiguous. Identifying its key components and establishing reliable and valid ways to measure and operationalize it in practice is crucial for sustainable transport planning. Understanding how perceived accessibility can be captured and its influence on travel behaviour enables stronger integration within travel behaviour frameworks. By clarifying its components and measurement, this research helps in developing strategies that address disparities in accessibility, ensuring equitable access to opportunities, promoting sustainable behaviour, and ultimately enhancing social equity.

The following section will present the background associated with calculated and perceived accessibility and their role, alongside other factors, in shaping travel behaviour. These concepts are then contextualized within the *Capability Approach*, which provides a framework for understanding how individuals perceive and utilize accessibility based on their diverse needs and capabilities. Finally, as a capability, accessibility is discussed in operational terms, with a discussion on how accessibility standards can be defined and implemented in planning practice.

1.2 Research background

1.2.1 Calculated and perceived accessibility

In his seminal work, which is considered a pivot to the concept until this day, Hansen (1959) defined accessibility as “the potential of opportunities for interaction” (p.73). In that sense, accessibility indicates how one can overcome distance barriers to reach spatial opportunities (e.g. jobs) distributed across space using different transport systems. Accessibility constitutes four main components: space (land use), movement (transport), time (temporal component), and subject (individuals) (Geurs & van Wee, 2004). Based on the interaction between these components, accessibility measures can be categorized and viewed from various perspectives embedded in different economic, transport, and social theories (El-Geneidy & Levinson, 2006; Geurs & van Wee, 2004; Horner, 2004).

Place-based measures (also referred to as geographical and location-based) are typically used at the aggregate/regional level and are the most used in practice (El-Geneidy & Levinson, 2022). They focus on the spatial distribution of activities and represent the levels of attractiveness of locations relative to one another (Horner, 2004). They mainly focus on the transport (travel time and costs) and land use (amount and spatial distribution of activities) components, with possibilities of integrating the spatial component (e.g., the daily fluctuations in public transit services) or an aggregate level of the individual component (e.g. by income groups). Their aggregate characteristic makes them easy to use as a planning tool that helps understand travel behaviour such as mode share and development impacts at the regional level (El-Geneidy & Levinson, 2022). These measures are mainly referred to as calculated measures of accessibility in the transport literature (Pot et al., 2021; Ryan & Pereira, 2021).

People-based accessibility focuses on the space-time restrictions of individuals, at the disaggregate level, using time geography as a theoretical framework (Ferreira & Batey, 2007; Geurs & van Wee, 2004; Miller, 2005). This approach challenges the notion that strong geographical connections between individuals and activities always imply high levels of accessibility between them due to personal spatial and temporal constraints (Ferreira & Batey, 2007). This approach is more accurate in representing individual accessibility as it accounts for the heterogeneity related to personal constraints (Fransen et al., 2018; Morris et al., 1979; Neutens et al., 2012; Neutens et al., 2010; Schwanen & Dijst, 2003). Despite this approach being challenging to operationalize at a regional level as it requires detailed data for each person, it can be used to provide deeper insights into individuals' travel behaviour, activity participation, and well-being. However, it still does not account for the subjective dimension of accessibility that relates to how personal preferences, past experiences, and psychological factors impact perceptions (Pot et al., 2021).

While the notion of perception in accessibility has been mentioned in the literature since the late 1970s (Ben-Akiva & Lerman, 1979; Morris et al., 1979), the introduction of the Perceived Accessibility Scale (PAC) by Lättman, Olsson, et al. (2016) sets a starting point for the recent empirical research done on perceived accessibility. The developers of this tool approach perceived accessibility as an outcome of the transport and land-use system, defining it "how easy it is to live a satisfactory life using the transport system" in a number of their papers (Friman et al., 2020b; Lättman, Friman, et al., 2016; Olsson et al., 2021). Incorporating "transport system" in this definition is crucial as it helps differentiate the level of accessibility in question, whether by local (e.g., walking and cycling) (De Vos et al., 2023; van der Vlugt et al., 2022) or regional modes (e.g., car and public transit). Taking a different perspective, the definition of perceived accessibility formulated by Pot et al. (2021) describes it as the "perceived potential to participate in spatially dispersed opportunities" (p.2). This descriptive definition emphasizes the perception of a quantity of opportunities available through spatial reach on which individuals make decisions, without reference to an eventual social outcome in terms of behaviour, participation or satisfaction.

Over the last decade, research on perceived accessibility has been gradually expanding, examining the factors that shape and influence it. These include individual characteristics (Fu et al., 2024; Lättman et al., 2018; Liu et al., 2021; Pot et al., 2023b; Tanimoto & Hanibuchi, 2021; Vafeiadis & Elldér, 2024a; van der Vlugt et al., 2019), travel behaviour (Mehdizadeh & Kroesen, 2025; Vafeiadis & Elldér, 2024a), travel attitude (Pot et al., 2023b), and public transport service quality (Friman et al., 2020b; Lättman, Friman, et al., 2016; Sukhov et al., 2023; Watthanaklang et al., 2024; Zhu et al., 2024). Additionally, studies have been attempting to understand the potential (mist)match between calculated and perceived accessibility (El Murr et al., 2023; Lättman et al., 2018; Pot et al., 2023a, 2023b; Vafeiadis & Elldér, 2024a, 2024b).

1.2.2 Accessibility and travel behaviour

To make a specific trip, an individual usually weighs their options through a matrix of objective and subjective determinants to select the mode they would use (Panter & Jones, 2010; Scheiner & Holz-Rau, 2007). These determinants include personal characteristics such as age, gender, income, and household attributes (Buehler, 2011; Cui et al., 2020; Ha et al., 2020; Legrain, Eluru, et al., 2015; Patterson et al., 2005; Scheiner, 2014). Among the objective determinants are spatial and temporal considerations. Spatial factors such as density, land use distribution, and the availability of a certain mode play a significant role in favouring one mode over the other (Cervero, 2002; Lin et al., 2017). Temporal factors include the flexibility in the time of departure and the travel time, which are major determinants of mode choices (Scheiner & Holz-Rau, 2007). Limited transport options at the time of travel often lead travelers to use certain modes despite their higher level of inconvenience because alternatives do not exist (Manaugh & El-Geneidy, 2011). Calculated accessibility combines these factors and has shown to be a major determinant of mode choice (Moniruzzaman & Páez, 2012; Owen & Levinson, 2015; Ton et al., 2020). It is crucial to note that disruptive events such as the COVID-19 pandemic had lasting impacts on travel behaviour (Javadinasr et al., 2022; Kapatsila, Bahamonde-Birke, et al., 2023; Kolarova et al., 2021; Paul et al., 2022; Shamshiripour et al., 2020), which could have negatively affected the impact of calculated accessibility on travel behaviour in the post-pandemic era.

Subjective measures that impact travel behaviour encompass travel attitudes and preferences, including residential self-selection (Cao et al., 2009; Handy et al., 2005; Kamruzzaman et al., 2015; Parkany et al., 2004). Attitudes and preferences mainly stem from personal beliefs (Mann & Abraham, 2012) and habits (Verplanken & Orbell, 2003). They represent the degree to which a person would favour a mode over another because they link it to some positive aspect in their life (De Vos et al., 2022). There is a constant debate in the literature on whether travel attitude influences behaviour or vice-versa. Kroesen et al. (2017) argue that they both mutually influence each other over time but that behaviour influences attitudes more. Based on the theory of cognitive dissonance (Festinger, 1957), people are likely to change their attitudes or behaviours to align with each other (McCarthy et al., 2023). Among the factors that can be classified under travel attitudes is the perception of the possible benefits and challenges of using a specific mode. Studies showed that the perception of challenges negatively impacts a certain mode choice (Ball et al., 2007; Titze et al., 2008). Many studies focused on the perception of public transit quality (Gilbert & Foerster, 1977; Habib et al., 2011; Zhao et al., 2013) and how positive perception increases transit use.

Meanwhile, the link between perceived accessibility by different modes and travel behaviour remains underexplored with only a few studies examining this notion (Mehdizadeh & Kroesen, 2025; Vafeiadis & Elldér, 2024a). Vafeiadis and Elldér (2024a) argue that frequent car users have high levels of perceived accessibility by car and low levels by all other modes. They found the same pattern for other modes where individuals tend to have the highest perceived accessibility by the mode they use most. Using panel data, Mehdizadeh and Kroesen (2025) find that the relationship between perceived accessibility and travel behaviour is bidirectional. However, they argue that travel behaviour has a stronger influence on perceived accessibility than the reverse effect. It is important to note that this study uses a measure of perceived accessibility that focuses on "accessibility to the neighborhood", which may overlook how travel behaviour is shaped by the various destinations that people seek to reach by different transport modes. Overall, there is still limited research on perceived accessibility by different modes, whether used or unused.

1.2.3 Accessibility as a capability

Various social outcomes are likely to result from different transport planning policies, significantly impacting individuals' well-being (Krumholz, 1982; Lucas, 2012; Reardon et al., 2019). While questions of how to ensure equity in planning still roam the realm of the transport policy field, the *Capability Approach* has been recently given attention as a framework for integrating social equity into transport policy-making and evaluation (Beyazit, 2011; Nahmias-Biran & Shiftan, 2020; Pereira et al., 2017; Vecchio & Martens, 2021). Developed by Amartya Sen, the *Capability Approach* revolves around the freedom of choice for individuals to achieve what they deem valuable based on their available opportunities and capabilities with the end goal of achieving well-being (Nussbaum, 2009; Sen, 2008). According to Sen (1995b), a capability reflects "the freedom to achieve valuable functionings" (p.49). These capabilities are formed through utilizing different resources available based on an individual's own personal, social, and environmental conditions, including sociodemographic characteristics, personal skills, and knowledge (conversion factors) (Sen, 1995a).

Discussed in the transport field, resources can represent the land use and transport systems while accessibility can be viewed as a capability. In that case, activity participation would be considered as the functioning (i.e., the realized behaviour). Vecchio and Martens (2021) propose two approaches to analyze accessibility as a capability: top-down (aggregate level) and bottom-up (individual level).

The top-down approach analyzes accessibility based on transport and land use systems as a capability (ability to reach activities) and/or functioning (reached activities) on the aggregate level. It has been the most common approach in the literature where accessibility has been used to assess potential transport planning-related disadvantages (Grengs, 2015; Wachs & Kumagai, 1973). For example, using accessibility to evaluate the social equity aspect of different transport systems (El-Geneidy et al., 2016; Foth et al., 2013; Luo et al., 2023). The bottom-up approach focuses on the notion of perceived accessibility from an individual's perspective (Vecchio & Martens, 2021). Therefore, emphasis is given to individual heterogeneity, including sociodemographic characteristics, mobility means, attitudes and preferences, and previous experience (Pot et al., 2023b). While this approach adds a layer of complication and challenge to understanding accessibility as a capability, it would help in the formulation of policies that guarantee individuals a level of access that would ensure social inclusion (Lucas, 2012; Pereira et al., 2017).

Compared to the top-down approach that assumes equality in how people view and consider opportunities, the bottom-up approach provides a nuanced perspective that better represents reality. Both top-down and bottom-up approaches should then be considered when assessing policy alternatives as they complement each other. While aggregate measures help provide an overall picture of the functionings resulting from transport planning, considering accessibility as a human capability allows us to understand why people with similar spatial accessibility levels execute different behaviours (functionings).

1.2.4 Accessibility thresholds

The *Capability Approach* has been linked to sufficientarianism, which suggests that each individual should attain a basic level of access to essential activities and not be constrained by inadequate transport resources, services, safety conditions, or structural disadvantages (Golub & Martens, 2014; Grengs, 2010; Karner et al., 2024; Meyer & Roser, 2006). Integrating these perspectives calls for the definition of minimum accessibility thresholds aimed at reducing inequalities in opportunities while accounting for the diverse contexts and needs of different population group (Pereira et al., 2017). Framing accessibility as a capability thus shifts attention toward guaranteeing a baseline level of access that supports social inclusion (Lucas, 2012; Pereira et al., 2017). Defining this baseline is inherently subjective, representing a political decision that acknowledges the importance of transport in shaping a morally just city and requiring the integration of democratic deliberation (Karner et al., 2024; Martens, 2016). Although some studies have attempted to define accessibility thresholds in line with distributive justice principles (Martens, 2016; Pot et al., 2024; van der Veen et al., 2020), there remains limited consensus on a validated and operational methodology for establishing such thresholds for practice.

1.2.5 Research gap

The research background highlights three key gaps in the literature: the first concerns the impacts of calculated accessibility in the post-pandemic era, the second pertains to the links between calculated and perceived accessibility and travel behaviour, and the third involves the conceptualization and operationalization of perceived accessibility considering recent behavioural shifts.

While calculated accessibility is well-established in the literature, little is known about how its impact on travel behaviour has changed since the COVID-19 pandemic, particularly in the Canadian context. Additionally, its connection to perceived accessibility remains ambiguous, with unclear similarities and distinctions between the two concepts while accounting for the lasting impacts of the pandemic. Meanwhile, although empirical work on perceived accessibility is increasing, significant ambiguities persist regarding its definition, measurement, broader impacts, and practical implementation. There is limited evidence on how to integrate perceived accessibility into measurable and policy-relevant accessibility thresholds that achieve adequate levels of access and support equitable outcomes. Research on perceived accessibility is still in its early stages, and its influence on travel-related decisions, particularly from an equitable perspective that considers the diverse needs and capabilities of different populations, remains underexplored.

1.3 Research objectives

Building on the identified research gaps, this dissertation aims to contribute to the literature by examining the impact of both calculated and perceived dimensions of accessibility on different socioeconomic groups to help in operationalizing them in planning practice. To achieve this, the research will address the following overarching question:

How can calculated and perceived accessibility be operationalized in transport planning practice?

To address this question, the following objectives will be pursued:

1. Explore the connections and distinctions between perceived and calculated accessibility in transport research.
2. Assess the impact of calculated accessibility on aggregate travel behaviour in the post-pandemic era.
3. Examine the impact of calculated and perceived accessibility on individual-level travel behaviour.
4. Develop and operationalize calculated accessibility thresholds based on the interrelation between calculated and perceived accessibility.

The dissertation examines both calculated and perceived accessibility to understand how these dimensions influence travel behaviour and can be operationalized in transport planning practice. The first objective compares and defines the components of calculated and perceived accessibility and their impacts on travel behaviour, drawing from previous studies in the transport literature. Given that travel behaviour changed significantly during and after the COVID-19 pandemic, the second objective validates the influence of calculated accessibility on aggregate travel behaviour across different socioeconomic groups in the post-pandemic era. Since perceived accessibility is considered the true determinant of behaviour (Morris et al., 1979), the third objective explores its influence, along with calculated accessibility, on individual-level travel behaviour in the post-COVID era. Grounded in the *Capability Approach* and *sufficientarianism*, the fourth objective develops empirically grounded, practice-ready calculated accessibility thresholds using calculated and perceived accessibility data in Canada.

1.4 Dissertation structure and overview

The dissertation comprises seven chapters: an introductory chapter, four studies presented in four chapters, a discussion chapter, and a concluding chapter (**Figure 1.1**). Chapter 1 introduces the research topic, situates it within the literature, and outlines the research questions and objectives. Chapter 2 provides a literature review on perceived accessibility, linking calculated and perceived accessibility. Chapter 3 explores calculated accessibility by examining changes in the relationship between public transit mode share and accessibility across income groups in major Canadian cities in the post-pandemic era, using 2016 and 2021 data from the Canadian Census and Commute Flows for Toronto, Montréal, and Vancouver. Chapter 4 focuses on perceived accessibility and its impact on travel behaviour at the local and regional levels using 2023 survey data from Montréal. Chapter 5 develops perception-based accessibility thresholds, using 2024 nationwide survey data from Canada. Chapter 6 discusses the findings from the four studies and their implications for transport policy, emphasizing the contributions of the dissertation to the field. Chapter 7 concludes and summarizes the dissertation.

1.5 Contributions to original knowledge

Understanding how calculated and perceived accessibility influence travel behaviour, and how these two dimensions are interrelated, supports their operationalization in transport planning. By addressing the objectives of this research, the dissertation provides insights that can inform targeted strategies to encourage sustainable travel behaviour and promote equitable planning practices.

Chapter 2 of the dissertation, the literature review, highlights the research gaps in the field of perceived accessibility and establishes the confirmed and hypothetical relationships between calculated and perceived accessibility, travel-related aspects, and personal variables. It specifically highlights the connections and distinctions between calculated and perceived accessibility, paving the way for subsequent research. In light of a major recent disruptive event (COVID-19), Chapter 3 confirms the impact of calculated accessibility on travel behaviour, providing insights into how to plan by and for accessibility in the post-pandemic era. Chapter 4 highlights the role of perceived accessibility in shaping travel behaviour using data collected after the pandemic, suggesting that policymakers should not only focus on infrastructure improvements but also on how these changes are communicated and perceived by the public.

To adequately position perceived accessibility within transport planning practice, Chapter 5 draws on distributive justice frameworks to develop a methodology for identifying operational accessibility thresholds based on calculated and perceived accessibility in the Canadian context. It establishes empirically grounded minimum and sufficient levels of access that reflect different degrees of accessibility attainment. These thresholds are used to establish the potential to enhance sustainable mode share across socioeconomic groups. This chapter provides a practical and policy-relevant framework to support more equitable and sustainable transport and land-use planning.

Chapter 6, the discussion chapter, synthesizes the studies' theoretical, empirical, and methodological contributions with particular emphasis on policy implications for using accessibility, calculated and perceived, as a planning tool. It highlights the dissertations' policy implications and outlines directions for future research. The concluding chapter summarizes the dissertation, stating how the objectives of the research were met. The research will ultimately provide transport professionals and policymakers with actionable strategies to enhance equitable access to opportunities across various socioeconomic groups using sustainable transport modes. By grounding equity and sustainability in the lived experiences of diverse population groups, this research guides cities in measuring, planning for, and achieving equitable access to opportunities.

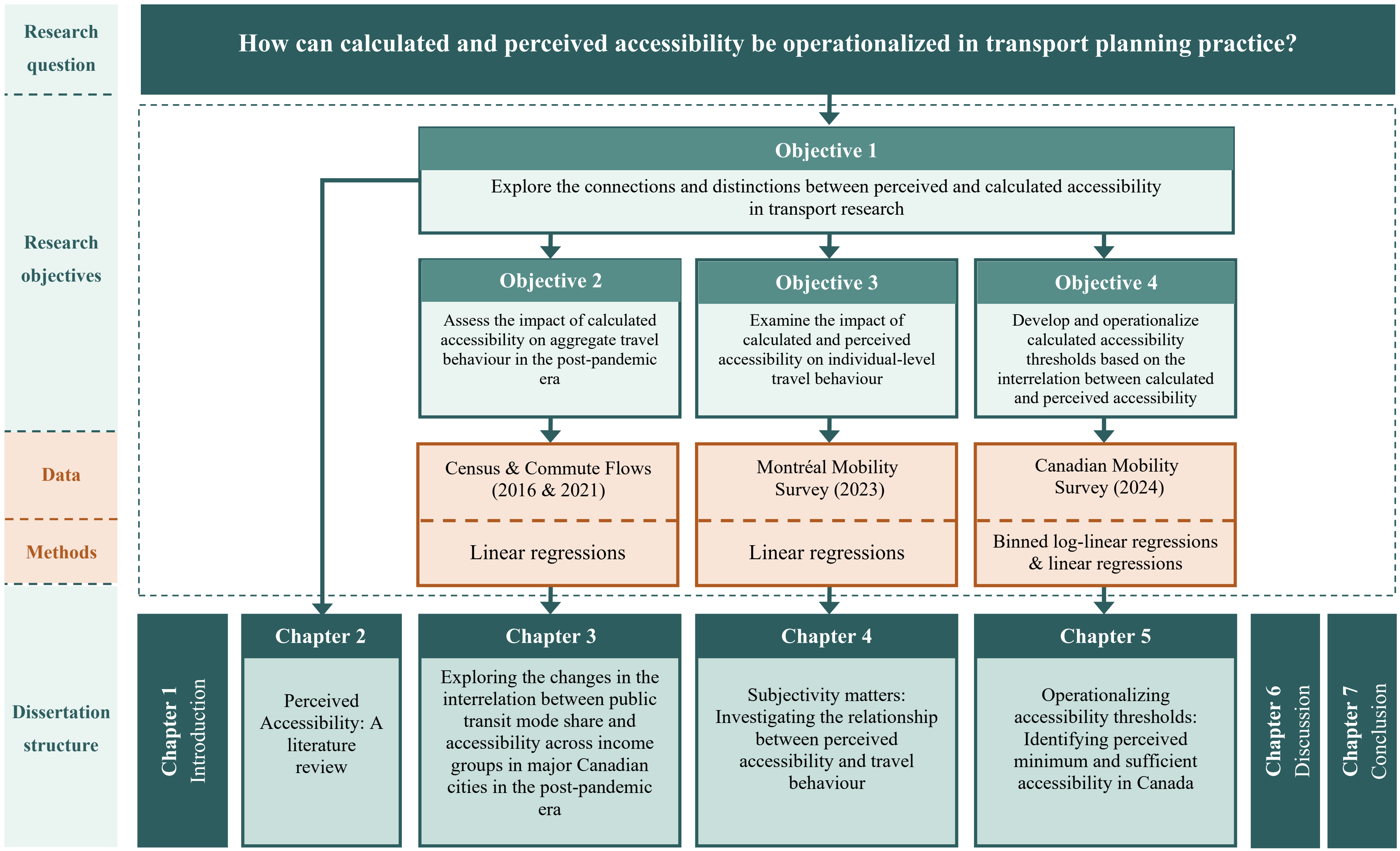

Figure 1.1 Dissertation outline

Chapter 2. Perceived accessibility: A literature review

Negm, H., De Vos, J., Pot, F., & El-Geneidy, A. (2025). Perceived accessibility: A literature review. *Journal of Transport Geography*, 125, 104212.

Perceived accessibility: A literature review

2.1 Chapter positioning

This chapter is a literature review article that explores the relationship between calculated and perceived accessibility, highlighting their similarities and distinctions, corresponding to the first objective of the dissertation. It presents the current state of knowledge in the field of accessibility, with a focus on perceived accessibility, and will serve as the literature review for the dissertation, corresponding to the first proposed dissertation objective. It reviews empirical studies that have examined perceived accessibility, with a focus on the regional scale. This review allows for an understanding of the definitions, measures, impacts, and determinants of perceived accessibility, as well as its (mis)match with calculated accessibility. Based on the review, a conceptual framework for accessibility (calculated and perceived) is proposed, which builds on existing relationships with other key transport-related concepts while introducing potential new ones.

2.2 Abstract

The integration of accessibility measures into transport planning has become prominent in many regions. However, accessibility evaluation is hampered by not having a comprehensive view on how accessibility is perceived by various population groups and how it impacts their choices given certain transport and land-use configurations. Recently, studies have emerged attempting to measure perceived accessibility and understand its determinants and how it relates to various aspects such as travel behavior and social inclusion using a variety of definitions and methods. In this paper, we review the empirical research on perceived accessibility, aiming to provide structure to future research on this topic. Based on 45 studies discussing perceived accessibility, we find that the concept is often ambiguously defined, and that measures lack robust validation regarding capturing the core aspects of accessibility and perception at the individual level. Moreover, results regarding the links between socioeconomic characteristics and perceived accessibility lack consistency and validity. The relationship between perceived accessibility and travel-related outcomes remains underexplored and requires further investigation, including indirect and bidirectional effects. Based on this literature review and earlier conceptualizations, we construct an empirical research framework that paves the way for future research by proposing relationships between perceived accessibility, calculated accessibility, travel behavior, residential choice, as well as individual sociodemographic characteristics and attitudes. Understanding how various population groups perceive accessibility is essential for developing more accurate land use and transport measures that impact their behavior and well-being.

2.3 Introduction

For the largest part of the 20th century, transport planning prioritized mobility as the key to enhancing access to social and economic opportunities, causing continuous growth in road infrastructures (Downs, 2004). In recent years, the call for sustainability and the development of equitable living spaces has shed light on the social and environmental downsides of this planning approach (Banister, 2012). In turn, there has been a significant shift in thinking within the transport planning field, moving away from merely emphasizing the movement of vehicles (mobility) toward explicitly prioritizing the provision of people with access to spatially and temporally dispersed opportunities (accessibility) (Dalvi & Martin, 1976; Handy, 2023; Miller, 2018).

Calculated measures of accessibility, which are based on spatial data, have shown promise as social indicators and equity evaluators (Foth et al., 2013; Wachs & Kumagai, 1973), with many aspects of equity and social exclusion yet to be studied and addressed (van Wee & Geurs, 2011). To address these aspects, individual-centered theoretical approaches, such as the *Capability Approach*, have been proposed to explore how accessibility is understood and utilized by people with diverse backgrounds and needs, stressing the importance of individual perceptions (Vecchio & Martens, 2021). In this light, the notion of perceived accessibility has been gaining attention in the literature as it accounts for individual perceptions, subjective experiences, and personal characteristics that mediate the relationship between land-use and transport system configurations and how people experience them (Lättman, Friman, et al., 2016; Pot et al., 2021; van Wee, 2016). Recently, Pot et al. (2021) laid the theoretical foundation for perceived accessibility, linking it to calculated measures and highlighting the potential mismatches that might exist between them.

Accessibility is typically analyzed at a local (mesoscale) or regional (macroscale) spatial level (Handy, 1992). Local accessibility presents the amount and variety of nearby amenities accessible in a neighbourhood through active travel modes (i.e., walking and cycling) (Forsyth & Krizek, 2010), while regional accessibility is more concerned with reaching destinations by passenger transport (i.e., car and public transit) (Geurs & van Wee, 2004). The key distinction between these two levels is not just the mode of travel but also the factors that influence accessibility levels. While the density, diversity, and design of the built environment play a major role in shaping local accessibility and impacting active travel (Cervero & Kockelman, 1997), regional accessibility depends on the interplay between transport networks and land use configurations such as the spatial distribution of job opportunities in a region (Geurs & van Eck, 2001; Geurs & van Wee, 2004; Miller, 2018). Perceived walkability (i.e., perceived accessibility for walking) was recently reviewed by De Vos et al. (2023); meanwhile, no comprehensive literature review has specifically examined perceived accessibility at the regional scale. This study will focus on perceived regional accessibility; therefore, any reference to accessibility throughout the manuscript will pertain to the regional level unless the local level is explicitly mentioned.

As perceived accessibility is an emerging topic, a growing number of studies are aiming to define it, quantify it, and explore its determinants and impacts. This study reviews 45 articles published between 2016 and early 2025 that have empirically examined perceived regional accessibility, highlighting the state of research concerning its definitions, measurements, determinants, and outcomes. Based on this review, we propose a conceptual framework for perceived accessibility that builds on previously examined relationships while introducing potential ones to be explored in future research. This framework helps identify research gaps and guide a research agenda for advancing the study of perceived accessibility in the field of urban planning and transportation. Understanding the current state of knowledge about perceived accessibility and its effect is crucial for researchers and transport professionals. For researchers, this study provides a comprehensive overview of the works exploring the topic, offering insights into potential areas of research. For policymakers and transport planners, perceived accessibility research can inform strategies that enhance equitable access to opportunities and encourage sustainable travel behaviour.

2.4 Background

The term "perceived accessibility" combines the notions of accessibility and perceptions. This section begins by separately discussing the definitions and key aspects of both concepts. Then, it delves into the idea of perceived accessibility as an amalgamation of these notions, examining how it has been discussed in prior research and how it can be defined.

2.4.1 Accessibility

Accessibility is regarded as a function of land-use and transport systems, representing the ability of different individuals—each with unique needs and circumstances— to reach destinations by different transport modes, while also considering temporal components such as time of travel, travel time, and the timing of available opportunities (Dalvi & Martin, 1976; Handy, 1992; Hansen, 1959; Levinson & Wu, 2020). In his seminal work, which is considered a pivot to the concept until this day, Hansen (1959) defined accessibility as "the potential of opportunities for interaction" (p.73). In that sense, accessibility indicates how one can overcome distance barriers to reach spatial opportunities (e.g. jobs) distributed across space using different transport systems. The heterogeneity in individual needs and abilities, combined with the complexity and variability of transport and land-use components has led to accessibility being described as "a slippery notion" (Gould, 1969, p. 64). This description has been used to stress how researchers and practitioners define it based on their objectives (Morris et al., 1979).

Wachs and Kumagai (1973) define accessibility as "the ease with which citizens may reach a variety of opportunities for employment and services" (p.437). However, they add that "such a concept is too vague and devoid of goal orientation" (p.441). They clarify that accessibility as a measurement is about the number or density of travel opportunities within certain time distances. Many subsequent researchers described measures of accessibility with the word "ease", referencing the work of Wachs and Kumagai. Morris et al. (1979), Handy and Niemeier (1997), Levinson and Wu (2020), and El-Geneidy and Levinson (2022) describe accessibility as the ease with which activities can be reached using a particular transport system.

Accessibility constitutes four main components: space (land use), movement (transport), time (temporal component), and subject (individuals) (Geurs & van Wee, 2004). Based on the interaction between these components, accessibility measures can be categorized and viewed from various perspectives embedded in different economic, transport, and social theories (El-Geneidy & Levinson, 2006; Geurs & van Wee, 2004; Horner, 2004). Place-based measures (also referred to as geographical and location-based) are typically used at the aggregate/regional level and are the most used in practice (El-Geneidy & Levinson, 2022). They focus on the spatial distribution of activities and represent the levels of attractiveness of locations relative to one another (Horner, 2004). They mainly focus on the transport (travel time and costs) and land use (amount and spatial distribution of activities) components, with possibilities of integrating the spatial component (e.g., the daily fluctuations in public transit services) or an aggregate level of the individual component (e.g. by income groups). Their aggregate characteristic makes them easy to use as a planning tool that helps understand travel behaviour such as mode share and development impacts on the regional level (El-Geneidy & Levinson, 2022).

Two of the most common place-based measures in the literature are cumulative opportunities and gravity-based measures (Miller, 2018). In cumulative opportunities measures, all the opportunities (destinations) available within a predefined travel time threshold are weighted equally while gravity-based accessibility weighs opportunities based on the travel time necessary to reach them (Geurs & van Eck, 2001). The latter method allows for the inclusion of opportunities that could be discarded in the cumulative measures but requires more data and is more challenging to compute, interpret, and communicate. Comparisons show high correlation between the two methods in North America (El-Geneidy & Levinson, 2006; Giannotti et al., 2021; Kapatsila, Palacios, et al., 2023; Palacios & El-Geneidy, 2022), suggesting that cumulative opportunities measures are adequate in presenting the built environment with easier interpretation and communication to the public and policy makers (El-Geneidy & Levinson, 2022).

People-based measures of accessibility focus on the space-time restrictions of individuals, at the disaggregate level, using time geography as a theoretical framework (Ferreira & Batey, 2007; Geurs & van

Wee, 2004; Miller, 2005). This approach challenges the notion that strong geographical connections between individuals and activities always imply high levels of accessibility between them due to personal spatial and temporal constraints (Ferreira & Batey, 2007). This approach is more accurate in representing individual accessibility as it accounts for the heterogeneity related to personal constraints (Fransen et al., 2018; Morris et al., 1979; Neutens et al., 2012; Neutens et al., 2010; Schwanen & Dijst, 2003). Despite this approach being challenging to operationalize at a regional level as it requires detailed data for each individual, it can be used to provide deeper insights into individuals' travel behaviour, activity participation, and well-being.

In many cases, the representation of the built environment through numbers and calculations, such as in these measures of accessibility, is referred to as an objective measure (Gim, 2011; Ma & Cao, 2019; McCormack et al., 2007; McGinn et al., 2007; Pacione, 1982; Scott et al., 2007). However, as accessibility is defined as the ´ease´ by which opportunities can be reached, accessibility is always conditioned by subjective perceptions (Pot et al., 2021). Consequently, objectivity in measurement does not exist and indicators based on spatial data using pre-set impedance thresholds will always be prone to the subjectivity of the researcher setting these thresholds (Muckler & Seven, 1992). With the rising interest in other aspects of accessibility (i.e., perceived accessibility), it has been lately proposed to label "objective" measures as "calculated" ones to avoid the subjective bias in objectivity (Pot et al., 2021; Ryan & Pereira, 2021). Nevertheless, we acknowledge that calculated measures inevitably involve a certain degree of subjectivity.

2.4.2 Perception

Building a perception, mental representation, of the world is a complicated process that is subjected to a wide array of influencers. While people physically live in a tangible real environment, they mentally live in and act based on a cognitive one that is filtered according to each individual's perceptual receptors and made sense of based on their attitudes and beliefs (Downs, 1970; Holloway & Hubbard, 2001), sociodemographic characteristics (Burnett, 1978; Lee, 1970; Nasar et al., 1985; Popp et al., 2004), lived experiences (Vernon, 1970), and vicarious experiences (Drakulich, 2015), among other factors. Individuals' interactions with the world are mediated by mental processes and cognitive representations of their surrounding environments (Gold, 1980; Lynch, 1960; Ma & Cao, 2019). This cognitive image of the world is filled with personalized warning signs and green lights, guiding their thoughts, decisions, and actions (Mehrabian & Russell, 1974).

The knowledge of the built environment is shaped through spatial information, which has locational and attributive components (Gold, 1980). The locational component includes declarative, relational, and procedural knowledge (Golledge & Stimson, 1997). This knowledge—of the absolute positions of places, the spatial relations between different places, and how one can move between them—forms the basis for wayfinding and route learning (Golledge et al., 2000). The attributive information includes characteristics of particular spaces themselves and against one another (Gold, 1980). This type of information plays a role in the decision-making process. Research has shown that spatial knowledge is not enhanced through advanced information technologies (Ahmadpoor & Heath, 2018); nevertheless, they play a major role in navigation and give temporary attributive (where to go) and procedural (how to get there) information that would influence behaviour. For example, one can decide to walk instead of taking public transit if they find that walking will not take any longer through using a navigation software.

2.4.3 Perceived accessibility

Combining transport and land-use system configurations and perceptions as a mediator between the physical and the cognitive environment results in the concept of perceived accessibility. The first accounts of this concept are attributed to Morris et al. (1979) when they stated that perceived accessibility is the real determinant of behaviour and that it will be at variance with measured indicators of accessibility. Linking perceived accessibility to behaviour, Ben-Akiva and Lerman (1979) defined accessibility as “some composite measure which describes the characteristics of a group of travel alternatives as they are perceived by a particular individual” (p.654). In the following years, most research focused on the operationalization of measured accessibility in practice with pre-set assumptions on perceptions; therefore, it was more concerned with improving and validating the calculated measures as they provided more concrete results and a basis for comparison between different scenarios and regions.

Decades later, Ferreira and Batey (2007) presented a theoretical approach for accessibility as the perceptions-aware approach. This approach connects accessibility-based behaviour to personal spatial knowledge and experience in addition to time-space restrictions (Miller, 1991). Cascetta et al. (2016) emphasized that the notion of “availability” of opportunities when considering accessibility is based on two components: a spatiotemporal component, based on calculation; and a behavioural component, based on perception. In their definition, an available opportunity is not just one that is included within some assumed spatiotemporal constraint, but one that is also perceived by that individual as a potential alternative that satisfies their needs. In light of recent calls for equitable planning that enables individuals, there has been a recognized necessity for a deeper understanding of how people perceive accessibility from their subjective point of view (Curl et al., 2011; van Wee, 2016; Vecchio & Martens, 2021).

2.5 Methods

There is a consensus in the literature that perceived accessibility remains underexplored on both the local and regional scales (Curl, 2018; De Vos et al., 2023; Pot et al., 2021; van Wee, 2022). As a recent literature review by De Vos et al. (2023) focuses on the local scale of perceived accessibility (i.e., perceived walkability), this review focuses on the studies that examined perceived regional accessibility. To identify these studies, we searched three academic databases — Web of Science, SCOPUS, and TRID. We then screened the titles and abstracts of the resulting articles to identify the ones that mention perceived accessibility and performed a full-text assessment to retain the studies that measure and discuss regional perceived accessibility (**Figure 2.1**).

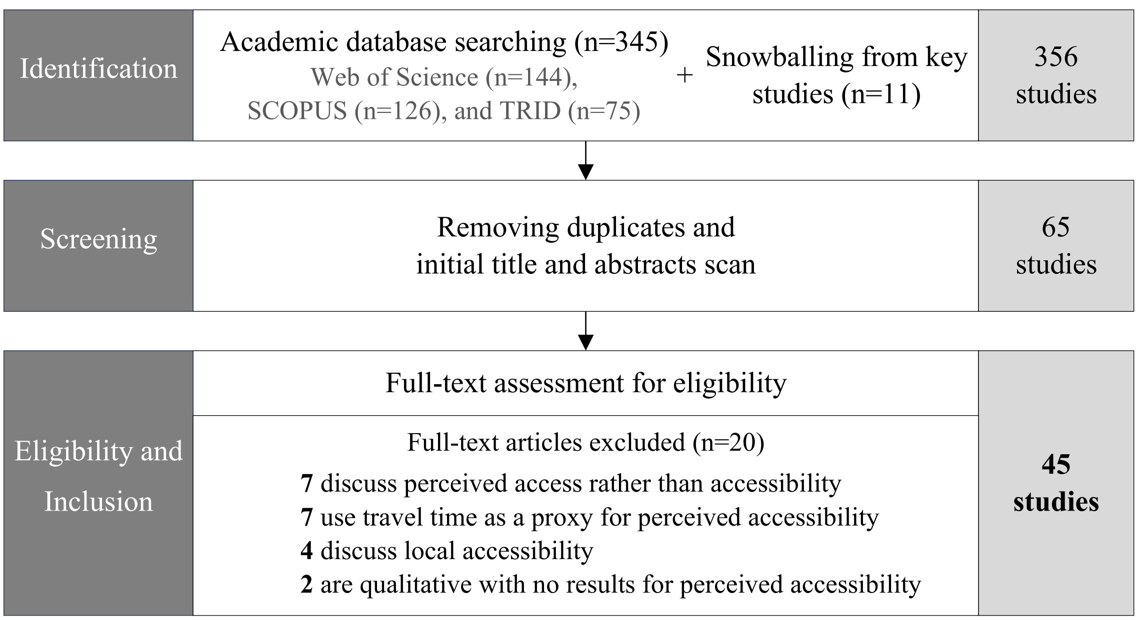

Figure 2.1 PRISMA flow diagram for identifying studies to be included in the analysis

In the identification step, we searched the three databases using the following keywords: ("perceived accessibility" or "perception of accessibility" or “self-reported accessibility”) and (“regional” or “transportation” or “transport” or “transit” or “car” or "private vehicle"). This search displays studies that have both a term from the first pair of parentheses and a term from the second one in their title, abstract, or keywords. We only searched for journal articles written in English. The initial databases search was conducted on August 8th, 2024, resulting a total of 289 papers from the three databases. During the manuscript revision, the database searches were updated to include articles published during the review period. The final inquiry resulted in a total of 345 studies: 144 studies in Web of Science, 126 in SCOPUS, and 75 in TRID, with February 11th, 2025, as the final search date. This approach was supported by snowballing from the key papers that discuss perceived accessibility from a regional perspective to ensure a comprehensive view of the literature. This led to the inclusion of 11 additional papers into the pool of studies for review. From the final database searches and snowballing, 356 articles were identified for review, as illustrated in **Figure 2.1**.

Following the removal of duplicates and an initial scan of the titles and abstracts of the 356 articles, 65 empirical full (peer-reviewed) journal articles were selected for deeper analysis. During the initial scan, it was observed that most studies stemming from the snowballing method—referenced in the context of perceived accessibility in transport—focused on distance-based spatial access, with no connection to the concept of accessibility (Baier et al., 2020; Macintyre et al., 2008; Scott et al., 2007; Wang et al., 2015). These studies focus on the concept of 'access' by measuring the distance to the nearest opportunity (e.g., healthcare facility or park) or the number of opportunities within a certain distance buffer without considering travel time by different transport modes. While distance-based measures can serve as a proxy for travel times at the local level—where a general walking or cycling speed can be reasonably estimated—this approach is insufficient at the regional level, where street networks and transit service significantly impact travel times. Since this review focuses on regional accessibility (mostly measured by the number of opportunities one can reach within a given travel time by car or public transit), these distance-based access studies were excluded as they are out of the scope of this research.

Upon deeper examination, only 45 articles were retained for full analysis of measures and results. Eleven of these papers were published during the reviewing period of the manuscript in late 2024 and early 2025, signifying the rapid development and emerging nature of the topic. The filtering process excluded studies that investigated access, travel time, local accessibility, or employed qualitative methodologies. Seven studies used the term perceived accessibility, but they rather discussed perceived access. These studies were concerned with walking distance, conditions, or route attributes to certain destinations, such as public transport stations (Cheng & Chen, 2015; Márquez et al., 2019; Ryan et al., 2016; Shao et al., 2022; Wong, 2018) or health services (Bihin et al., 2022; Fone et al., 2006), rather than on accessibility as a measure of opportunities reachable within a certain travel time.

Seven studies were disregarded from the final list as they mainly focused on perceived travel time as a proxy for perceived accessibility (Curl, 2018; Curl et al., 2015; Liu et al., 2018; Susilo & Liu, 2017; Tiznado-Aitken et al., 2020; Tiznado-Aitken et al., 2021; Wang et al., 2024). Self-reported travel times (e.g. Curl, 2018; Curl et al., 2015) oversimplifies the concept of accessibility, effectively reflecting only one component of accessibility. In this case, the revealed mismatches between the "objective" and "perceived" measures rather present the individual's perception of mobility (Geurs & van Wee, 2004). Therefore, perceived travel time, even though it considers personal factors, does not reflect an individual's perception of the opportunities provided by the built environment. Likewise, proposing a generalized travel time measure that accounts for the subjective valuation of access, waiting and in-vehicle time, in addition to comfort and transfers (Tiznado-Aitken et al., 2021), does not consider the perception of accessibility to the wide range of desired opportunities (activities).

Four more studies were excluded as they discussed perceived accessibility at the local scale (neighbourhood level) rather than the regional scale which is the focus of this review (Hu & Ettema, 2023; Ma et al., 2025; Richard et al., 2009; Scheepers et al., 2016). Some of these studies disregarded public transport as a means of transport as the authors found that it would be difficult for participants to correctly evaluate destination accessibility for that mode. Finally, two studies were omitted from the analysis because they briefly mention the concept of perceived accessibility in their discussions but do not clearly define the concept, explain its measurement, discuss its implications, or compare it with spatial measurements (Oviedo et al., 2024; Pot et al., 2020).

2.6 Findings

Table 2.1 summarizes the 45 studies we retained for analysis as they address aspects of perceived regional accessibility. Notably, 18 of these studies were published in 2024 and 2025, highlighting the topic's recent relevance. With the scarcity of literature due to its novelty, we retained all possible studies regardless of paper or journal quality. While all journals are peer-reviewed, the peer-review process may considerably vary by journal. We carefully examine the papers chosen and report their results with caution, acknowledging that they can be incomplete or potentially misleading. Based on the aspects discussed in the papers, we extract four topics that we present in this section: definitions, measures, and determinants and impacts of perceived accessibility, as well as the mismatch between calculated and perceived accessibility measures.

Table 2.1 Overview of 45 studies about perceived accessibility in chronological order

Study	Data (N and location)	Perceived Accessibility measure	Main Methods	Main contribution(s)/Result(s)
Lättman, Olsson, et al. (2016)	237 (Study 1), 246 (Study 2, W1), and 259 (Study 2 W2) participants in Karlstad, Sweden	PAC (7-point Likert scale on 4 statements)	Exploratory and Confirmatory factor analysis (EFA & CFA)	Development and validation of the Perceived Accessibility Scale (PAC)
Lättman, Friman, et al. (2016)	750 bus riders in Karlstad, Sweden	PAC (public transport)	Conditional process model and cluster analysis	Perceived public transit service quality, perceived safety, and frequency of use positively influence perceived accessibility.
Lättman et al. (2018)	2,711 residents in Malmö, Sweden	PAC (main mode)	EFA and One sample t-tests	- Modifications to the original PAC - Calculated and perceived measures of accessibility by sustainable transport modes are misaligned.
van der Vlugt et al. (2019)	286 residents in Nottingham, UK (First study case only)	5-point Likert scale on 3 statements	Multivariate regression	- Socio-demographic and attitudinal factors impact perceived accessibility. - Favourable attitude towards public transport positively impacts perception of accessibility.
Thronicker and Klinger (2019)	758 participants in Leipzig, Germany	5-point Likert scale on 6 statements	Logit model	Higher perception of accessibility by sustainable modes increases the chance of being interested in a mobility package.
Lättman et al. (2019)	2,950 older adults in Stockholm, Oslo, Helsinki, Copenhagen, and Bergen	PAC (main mode)	PLS-SEM	Positive perceived accessibility contributes to travel satisfaction and overall life satisfaction.
Lättman et al. (2020)	2,711 participants in Malmö, Sweden	PAC (main mode) and PAC (if car is no longer an option)	T-tests	Perceived accessibility decreases for car users when they are limited to sustainable modes for their daily travel.
Friman et al. (2020a)	122 carpoolers in Sweden	PAC (carpooling)	Multiple linear hierarchical regression	- Simplicity as a motive and commuting as a purpose increase perceived accessibility by carpooling. - Perceived accessibility by carpooling increases in higher density areas.

Study	Data (N and location)	Perceived Accessibility measure	Main Methods	Main contribution(s)/Result(s)
Friman et al. (2020b)	4,944 public transport users in Stockholm, Oslo, Helsinki, Copenhagen, and Bergen	PAC (main mode)	PLS-SEM	- Better service quality has a positive impact on perceived accessibility. - Frequent transit users have lower perception of accessibility than less frequent ones.
Warner et al. (2021)	306 participants in Stockholm, Sweden	PAC (main mode)	One-way ANOVA	For public transport, people in the motivation stage of the transtheoretical model (TTM) have a more positive perception of accessibility than those in the volitional stage.
Aoustin and Levinson (2021)	197 participants in Sydney, Australia	Perception of percentage of accessible jobs in 30 mins	Means comparison	Participants mostly overestimated the walking, cycling, and public transport access.
Ryan and Pereira (2021)	1,149 older adults in Gothenburg, Malmo, and Stockholm	Capability to walk, cycle, use car, or use public transport to carry out all everyday activities (Dichotomous)	Multinomial logit	Conventional accessibility measures tend to overestimate accessibility levels, especially for cycling when compared to public transit.
Al-Rashid et al. (2021)	243 older women in Lahore, Pakistan	PAC (public transport)	PLS-SEM	- Higher levels of perceived accessibility increase social inclusion. - Perceived social norms and perceived neighborhood social environment have a positive effect on perceived accessibility.
Olsson et al. (2021)	1,376 participants in Sweden (major city areas and other areas)	PAC (public transport)	Linear multiple regressions	Travel behaviour, household, and personal characteristics are associated to perceived accessibility.
Liu et al. (2021)	569 participants in Kunming, China	6-point Likert scale on 3 statements	Cross-lagged panel models	The ease of using smartphone-based services influences perceptions of accessibility and transport equity.
Lukina et al. (2021)	2,275 participants in Moscow	PAC (main mode) – 4-point Likert instead of 7-point	One-way ANOVA	Perceived accessibility differs based on travel behaviour, residential area, and sociodemographic factors.

Study	Data (N and location)	Perceived Accessibility measure	Main Methods	Main contribution(s)/Result(s)
Tanimoto and Hanibuchi (2021)	1,474 participants in Sendai, Japan	5-point Likert scale on 4 statements to measure sense of accessibility	Ordered logit	- Good self-rated health is associated with higher sense of accessibility. - Dense, urbanized environments increase the sense of accessibility.
Sheng and Zhang (2022)	341 participants in Hangzhou, China	PAC (public transport)	PLS-SEM	Perceived accessibility by public transport positively affects behavioral intention and actual behaviour in using public transport.
El Murr et al. (2023)	873 participants in Montréal, Canada	5-point Likert scale on one statement	Ordered logit	There is a misalignment between the number of parks accessible and the self-reported accessibility (negative relationship). The quality index for parks and the self-reported accessibility are aligned (positive relationship).
Wolday and Böcker (2023)	858 panel participants in Oslo, Norway	PAC (main mode)	SEM	Residential location mediated the impact of the COVID-19 restrictions on perceived accessibility by public transport.
Pot et al. (2023a)	3,378 participants in the Netherlands	PAC (main mode)	Propensity score matching (PSM)/ average treatment effect (ATE)	Perceived accessibility is spatially more evenly distributed between than the number of opportunities due to diminishing returns and residential self-selection.
Liu et al. (2023)	536 tourists in Mount Yandang Scenic Area, China	6-point Likert scale on 4 statements to measure perceived destination accessibility	PSM/ATE	Perceived destination accessibility and perceived transport equity significantly increased due to the free within-destination tourist bus scheme.
Al-Rashid et al. (2023)	384 older adults in Lahore, Pakistan	PAC (public transport)	PLS-SEM	Perceived accessibility moderates the effect of social and personal norms on social exclusion.
Andersson et al. (2023)	52 employees in Stockholm, Sweden	PAC (main mode)	Mixed ANOVA	- With increased use of public transport, the perceived accessibility decreased, but the self-reported life quality increased. - Free public transport (PT) card intervention had no effect on perceived accessibility.

Study	Data (N and location)	Perceived Accessibility measure	Main Methods	Main contribution(s)/Result(s)
Pot et al. (2023b)	2,227 participants in rural areas in the Netherlands	PAC (main mode)	OLS and Quantile regression	- Perceived accessibility correlates poorly with accessibility calculated from spatial data and rather depends on individual conversion factors. - Lowest levels of perceived accessibility in rural areas are related to a combination of social disadvantages.
Sukhov et al. (2023)	117 older adults in Stockholm, Oslo, Helsinki, Copenhagen, and Bergen	PAC (main mode)	PLS-SEM, NCA, and fsQCA	Comfort is a significant determinant for perceived accessibility for older adults.
Friman and Olsson (2023)	1,041 participants in Sweden	PAC (main mode)	PLS-SEM	- A stronger sense of travel autonomy is related to higher perceived accessibility. - Perceived accessibility positively impacts life satisfaction.
Fu et al. (2024)	1,009 participants in Rotterdam and Utrecht, the Netherlands	5-point Likert scale on 8 statements for perceived transport adequacy and 5 statements for perceived accessibility	Multiple linear regressions	- Multimodality has no significant effect on perceived transport-related achievement (mentioned as perceived accessibility in the other studies). - Bus access, ease of driving, and perception of good quality of public transport have a positive effect on perceived achievement.
Pot et al. (2024)	3,378 participants in the Netherlands	PAC (main mode)	Multinomial logit	Low activity participation is not always indicative of involuntarily social exclusion, as it often nonetheless coincides with high perceived accessibility, particularly in cities.
Vafeiadis and Elldér (2024b)	1,423 participants in Gothenburg, Sweden	5-point Likert scale on at least two statements related to transport mode (maximum four)	Multinomial logit	Mismatch between calculated and perceived accessibility for grocery shopping is more common for car travel, with underestimation of calculated measures.
Watthanaklang et al. (2024)	400 public transport users in Nakhon Ratchasima Province, Thailand.	PAC (public transport)	SEM	- Public transport service quality has a positive effect on perceived accessibility. - Perceived accessibility has a direct positive effect on the intention to use public transport.

Study	Data (N and location)	Perceived Accessibility measure	Main Methods	Main contribution(s)/Result(s)
Blandin et al. (2024)	298 participants in Santiago de Chile	5-point Likert scale on four psychometrics indicators	ICLV and logit (MNL) models	Perceived accessibility is determined by the perceived cost of travelling, perceived quality of the environment and/or availability of different transport modes.
Vafeiadis and Elldér (2024a)	1,534 participants in the Gothenburg Region, Sweden	5-point Likert scale on 16 statements	Ordinal regression models	- Transportation resources, habits and attitudes have the strongest effect on perceived accessibility. - Car access reduces perceived accessibility for all other modes.
Vafeiadis (2024)	1,423 participants in the Gothenburg Region, Sweden	5-scale Likert scale on 20 statements	Bivariate and Semi-partial correlation	There is a significant moderate relationship between accessibility indicators and perceived accessibility. It is positive for transit users, cyclists, and pedestrians, however, negative for car users.
Chau, Gaisie, et al. (2024)	156 participants in the City of Wyndham, Australia	PAC (main mode) and PAC (public transport)	Principal Component Analysis (PCA) and Comparison of means	Perceived accessibility is higher for current travel modes compared to a scenario where only public transport is available.
Kim (2024)	200 older adults in the Republic of Korea	5-point Likert scale on 3 statements	Partial Least Squares (PLS) Bootstrapping	Perceived accessibility by public transport positively influences life satisfaction for older adults.
Chau, Chan, et al. (2024)	156 participants in the City of Wyndham, Australia	PAC (public transport)	PLS-SEM	Perceived safety has a positive influence on perceived accessibility.
Zhu et al. (2024)	664 affordable housing residents and 828 commercial housing residents in Nanjing, China	7-point Likert scale on 6 statements	SEM	- Public transport service levels and transport affordability positively impact perceived accessibility. - Perceived accessibility positively impacts perceived housing equity and transport equity.
Parga et al. (2024)	524 respondents in Scarborough, Toronto, Canada	2 binary statements	Ordinal logistic regressions	Perceived accessibility is positively associated to self-rated health.

Study	Data (N and location)	Perceived Accessibility measure	Main Methods	Main contribution(s)/Result(s)
Hagen (2025)	387, 446, 311, and 522 participants in Arendal, Kongsberg, Lillehammer, and Tønsberg, respectively, in Norway.	5-point Likert scale on one statement	Cross-tabulation	- Perceived accessibility correlates with frequency of city center visits. - Negative perceptions about traffic and parking correlate with lower perceived accessibility.
Mehdizadeh and Kroesen (2025)	4945 panel participants (from two waves) in the Netherlands	3-point Likert scale on 3 statements	Cross-lagged panel model (CLPM)	Travel behaviour has a larger impact on perceived accessibility than the reverse effect.
Nguyen-Phuoc et al. (2025)	535 participants in Hanoi, Vietnam	7-point Likert scale on 3 statements	PLS-SEM	Perceived accessibility by an urban train system positively influences the intention to switch to it from other modes.
Moleman and Kroesen (2025)	20,020 respondents in the Netherlands	5-point Likert scale on 7 statements	Latent class analysis	Only a small portion of society perceives lower accessibility.
De Vos et al. (2025)	2,593 students and staff members at UCL, London, UK	5-point Likert scale on 2 statements	One-way ANOVAs with post-hoc and ordered regressions	Perceived accessibility to campus—both in general and by public transit—is positively influenced by ease-of-travel elements, especially travel skills.
Negm and El-Geneidy (2025)	2,985 participants in Montréal, Canada	4-point Likert scale on 1 statement	Linear regression	Perceived accessibility by public transit positively impacts weekly public transit mode share.

2.6.1 Definitions of perceived accessibility

While the notion of perception in accessibility has been mentioned in the literature since the late 1970s (Ben-Akiva & Lerman, 1979; Morris et al., 1979), the introduction of the Perceived Accessibility Scale (PAC) by Lättman, Olsson, et al. (2016) sets a starting point for the recent empirical research done on perceived regional accessibility. The developers of this tool approach perceived accessibility as an outcome of the transport and land-use system, defining it "how easy it is to live a satisfactory life using the transport system" in a number of their papers (Friman et al., 2020b; Lättman, Friman, et al., 2016; Olsson et al., 2021). Incorporating "transport system" in this definition is crucial as it helps differentiate the level of accessibility in question, whether by local (De Vos et al., 2023; van der Vlugt et al., 2022) or regional modes. Relatedly, Sukhov et al. (2023) defines perceived accessibility as "the degree of ease with which individuals can live their lives using a transportation system." This definition is also focused on the outcome of a transportation system and how it connects to someone's ease of living.

However, incorporating a satisfactory life into definitions of perceived accessibility may expand the concept beyond its intended scope, which is an overall individual evaluation of access to desired opportunities. Approaching perceived accessibility should be limited to the benefits derived from the transport and land-use system, serving as a tool to evaluate the system's performance based on its impact on individuals' evaluation of access to opportunities. Despite transport playing a part in life satisfaction (De Vos & Witlox, 2017), it is not the most important determinant (Pavot & Diener, 1993). Positive perceptions of accessibility do not necessarily relate to a satisfactory life and may not even relate to satisfaction with travel. Such definitions overreaches and disconnects perceived accessibility from the concept of accessibility which focuses on reaching destinations and potentially interacting with different opportunities.

Taking a different perspective, the definition of perceived accessibility formulated by Pot et al. (2021) describes it as the "perceived potential to participate in spatially dispersed opportunities" (p.2). This descriptive definition emphasizes the perception of a quantity of opportunities available through spatial reach on which individuals make decisions, without reference to an eventual social outcome in terms of behaviour, participation or satisfaction. Consequently, this measure is neutral and particularly suited for conceptualizing perceived accessibility but less suited for deriving indicators to empirically evaluate the benefits of transport and land-use systems as experienced by people.

When empirically evaluating the outcomes of the transport system, it is crucial to distinguish the definition of perceived accessibility from the outcomes, such as its influence on life satisfaction. We argue that previous definitions of perceived accessibility tend to overreach and that a more focused definition for evaluating the benefits of transport and land-use system configurations is needed— one that remains grounded in the core concept of accessibility itself, without extending into life satisfaction or other well-being domains.

2.6.2 Measures of perceived accessibility

The Perceived Accessibility Scale (PAC) was the most common measure for perceived accessibility, directly used by 23 out of the 45 studies and adapted to a different phrasing by four. Based on key works on accessibility and travel satisfaction research, this measure was originally developed by Lättman, Olsson, et al. (2016) as four questions that assess the transport system's impact on the ability, ease, and satisfaction of participation in activities, and the ability to live as one wants. This measure was further developed by the same authors two years later (Lättman et al., 2018). While both versions of the PAC are mode-specific, the 2016 version directly represents one specific mode at a time. With "X" being the transport mode in question, the four statements are as follows: (1) "It is easy to do (daily) activities with X", (2) "If X was my only mode of travel, I would be able to continue living the way I want", (3) "It is possible to do the activities I prefer with X", (4) "Access to my preferred activities is satisfying with X" (Lättman, Olsson, et al., 2016). Each of these statements would be assessed on a 7-point Likert scale (ranging from I don't agree = 1 to I completely agree = 7). The modification in the updated version of the scale is the removal of the specific mode (X) part of the questions and replacing it with "Considering how I travel today" and using the present tense for the statements. In both versions, the perceived accessibility score is the mean value from the four assessments.

Using three datasets, Lättman, Olsson, et al. (2016) conduct Cronbach's alpha analysis to confirm the correlation between the 4 scale items, then exploratory and confirmatory factor analyses to check whether the items are unidimensional. These methods, according to the authors aim to validate the scale by proving the matching psychometric properties of the four items which indicate high construct validity. Using three waves of data before and after altered service conditions by a public transport provider (with 259 participants as the largest N), the authors conclude that the PAC is sensitive to changes in service provision and, therefore, a valid instrument to assess accessibility.

This conclusion might be premature because the accessibility measures used do not describe conventionally calculated ones as the alterations mentioned do not include any frequency adjustments, but only an enhanced bus fleet with better amenities and improvement in the announcement function. Therefore, such alterations could affect how one perceives the system, but not change their calculated accessibility level. Another limitation of this study is the small and homogenous sample, with 90% of participants being frequent bus users in all three datasets. Generalizing this scale without further validation could introduce significant bias, as the findings might not apply to different populations or contexts.

More generally, including the notion of satisfaction with life in the definition used to develop PAC could be problematic. Measuring perceptions of one's accessibility should be isolated from life satisfaction to avoid conflation with broader well-being concepts (see Section 4.1). The statements in the PAC tool include life satisfaction but, at the same time, are all specifically related to transport. Consequently, it is yet not clear to what extent the statements reflect general subjective well-being or are they are capturing accessibility-based utility. The PAC tool averages the score from four statements, which assumes equal weights, leading to loses in specificity, and ignores variability. Especially as each of the statements used capture a different aspect and level of an individual's perception, using the mean value for multiple statements could be a biased approach that leads to inaccurate interpretations. Another major limitation of the original study where the PAC tool was developed is the small and homogenous sample used, where 90% of participants being frequent bus users in all three datasets. Generalizing this scale without further validation could introduce significant bias and incomplete results, as the findings might not apply to different populations or contexts.

Tanimoto and Hanibuchi (2021) used the term “sense of accessibility” to describe what is referred to as perceived accessibility in their article. They ask four questions with four possible combinations of reaching wanted and needed destinations with the usual mode of travel and without having the car as an option (e.g., I can do whatever I want even if I cannot use a car). The authors disconnect their measure from the literature with the claim that perceived accessibility in the literature is specific to one destination while “sense of accessibility” is not limited to specific destinations. However, when asking the sense of accessibility questions, they separate destinations by wanted and needed destinations. A problem that could arise from such an approach is that the differentiation between wanted and needed activities is ambiguous, as it is not clear how people differentiate between the two. This complicates judging whether accessibility needs and desires are sufficiently and equitably met.

In some instances, the measure used for perceived accessibility was technical such as asking participants to estimate the percentage of accessible jobs (Aoustin & Levinson, 2021). This approach can be misleading, as most people would not be able to intuitively estimate such a technical variable. Survey questions should be designed to be easily understood and to reflect daily life or expected situations. If questions are too difficult, respondents may drop out, or worse, provide random answers, which would compromise the study's findings. El Murr et al. (2023) used a rating of overall access to parks from home as a proxy for what they refer to as “self-reported accessibility”, which is synonymous with perceived accessibility. In their study, where they compared the matching rate between perceived accessibility and various calculated measures, this approach was appropriate. As this question was not too specific or too broad, it allowed them to capture the role that park quality plays in the perception of accessibility. Ryan and Pereira (2021) relied on the notion of self-reported capability of using different modes to measure perceived accessibility. The question focused on the “possibility” of using different modes for daily activities, regardless of whether the participants choose to use them or not. This question was cross-referenced with another question asking about activities that participants are unable to conduct for some reason, as described in the study design (Ryan et al., 2019). However, this measure does not capture perceived accessibility using a specific mode to a particular destination. As a result, it risks a potential bias of assuming that the possibility of using a mode translates into positive perception of accessibility by that mode to destinations, which is often not the case. For example, just because walking is a possible mode of transport does not mean one considers it suitable for reaching any or all destinations. Blandin et al. (2024) consider perceived accessibility a latent variable and use four psychometric indicators to identify it. However, these indicators are neither destination nor mode specific, and they integrate the notion of satisfaction with movement which we discussed as a potential factor that could mislead results.

Fu et al. (2024) use the PAC to represent 'perceived travel-related achievement', which better suits that scale as it focuses on the outcomes of travel (e.g., life satisfaction) rather than the perception of accessibility. Meanwhile, they use the term perceived accessibility as a representation of whether one can easily reach five main destinations: pharmacy or health center, supermarket or local shopping area, the hospital, friends and family's homes, and gym or hobby. The statements were rated on a five-point Likert scale, ranging from completely agree to completely disagree, allowing for nuances in the perception. While this measure is suitable to quantity perceived accessibility because it is destination-specific, it has a limitation of not-being mode specific. The authors ask whether one can reach the destinations with the transportation options available to them. This could be restricting policy relevance as it makes it harder to understand which areas need improvement, if any.

Many studies have adopted this destination-specific approach to measuring perceived accessibility (De Vos et al., 2025; Fu et al., 2024; Hagen, 2025; Moleman & Kroesen, 2025; Parga et al., 2024; Zhu et al., 2024). Others focused on rating the ease or suitability of reaching daily activities using a specific-mode (Kim, 2024; Negm & El-Geneidy, 2025; Nguyen-Phuoc et al., 2025). However, we argue that perceived accessibility is inherently both mode-specific and destination-specific. It is crucial to select destinations that align with the research question. For example, De Vos et al. (2025) assess perceived accessibility by asking participants about the ease of accessing a university campus in general and by public transit. This approach can help in examining important factors such as travel mode choice to campus. Meanwhile, Mehdizadeh and Kroesen (2025) use statements such as "my neighborhood is easily accessible by [transport mode]" to assess perceived accessibility. This measure is harder to utilize as it focuses on accessibility to the neighborhood rather than from it, making it less compatible with the conventional measures and definitions of accessibility that emphasize access to desired destinations.

Vafeiadis and Elldér (2024a) address these points by asking the participants to rate the ease of performing a specific trip using a specific mode during a specific time period. They rate this aspect for each combination of trip purpose (work, grocery shopping, going to dinner, meeting a friend in the city center) and transportation mode (car, bicycle, public transport, walk). Except for going to the city center, the authors ensured that the participants had performed a trip to the destination in the last month, and the questions were formulated in the past tense. Vafeiadis (2024) uses the same question format and adds another purpose, visiting a cafe/restaurant during the day (lunch). The questions are only asked if a certain mode is available to the participants as cars and bicycles are sometimes unavailable. While this scale is mode- and destination-specific and captures the core aspects of accessibility, we argue that everyone has perceptions to all destinations and by all modes even if they do not perform that trip. And despite past experiences influencing perceived accessibility, restricting the scale to these experiences can hinder the understanding of perceptions.

Studying perceptions is an important tool to understand the differences between people and how they interpret the same physical world differently. To accurately assess perceived accessibility in relation to measures of the built environment and other socio-economic outcomes, it must be clearly defined and not conflated with broader concepts such as well-being. This clarity is essential for designing specific survey instruments that effectively capture the intended information. Current instruments have made progress in validating their questions and ensuring they measure what they are designed for, but uncertainties remain as the next section reviewing empirical findings from these instruments will show.

2.6.3 Determinants and impacts of perceived accessibility

This section explores the determinants and impacts of perceived accessibility as discussed in the reviewed articles. We cluster the findings into three subsections: (1) individual characteristics, including age, gender, household composition, vehicle ownership, and travel attitude; (2) travel behavior; and (3) public transport service quality. We acknowledge that additional determinants and impacts remain unexplored, which will be addressed in section 5.

2.6.3.1 Individual characteristics

Despite some of the uncertainty of some measures' validity, this section reports on the findings of the reviewed articles on socioeconomic impacts on perceived accessibility. The two most explored sociodemographic characteristics were age and gender. Meanwhile, household composition, income, employment status, car ownership, and disability gained less attention.

The impact of age on perceived accessibility is inconsistent. Some studies found no impact (Fu et al., 2024; Lättman et al., 2018; Tanimoto & Hanibuchi, 2021). Others reported positive impact (El Murr et al., 2023; Friman et al., 2020b), negative impact (Liu et al., 2021; Vafeiadis & Elldér, 2024a; van der Vlugt et al., 2019), or non-linear impact (Lättman, Friman, et al., 2016; Pot et al., 2023b). Multiple reasons could cause this discrepancy in findings. In some instances, the methods used do not consider potential confounding effects. For example, some authors use an analysis of variance (Lättman et al., 2018), cluster analysis (Lättman, Friman, et al., 2016), or comparison of means (Lättman et al., 2019) for age and perceived accessibility instead of using regression analysis. These methods do not consider multiple factors and isolate the impact of each variable, which do not provide conclusive or sufficient results for correct interpretation. In other instances, researchers examine access to specific destinations, such as parks (El Murr et al., 2023), rendering such findings ungeneralizable for other destinations.

Some findings were region-specific, where age had no impact in bigger cities and a negative impact in minor cities (Olsson et al., 2021). Others were concerned with only a certain period, such as during the

COVID-19 pandemic where older adults were found to be more likely to suffer from a low level of perceived accessibility and transport equity (Liu et al., 2021). Pot et al. (2023b) explored the possibility of non-linearity, and they found that perceived accessibility increases with age with a peak at 52 and then starts to decrease in rural areas of the Netherlands, which they explained with the notion of willingness and ability to travel. This stresses the importance of considering location, mode of travel, time of study, and travel mode when exploring the impact of age on perceived accessibility.

There is a near consensus on the impact of gender on perceived accessibility. Women were found to experience higher levels of perceived accessibility in most of the studies (Friman et al., 2020b; Lättman et al., 2018; Lättman et al., 2019; Olsson et al., 2021; Pot et al., 2023b). Relatedly, Wolday and Böcker (2023) found that women experienced a greater decline in perceived accessibility during the pandemic. Fu et al. (2024) argues that women have higher perceptions of accessibility to specific destinations, but that gender does not impact general perceived accessibility or perceptions of transport-related disadvantage. Meanwhile, Lättman, Friman, et al. (2016), van der Vlugt et al. (2019), and Sukhov et al. (2023) found that gender does not impact perceived accessibility, with the latter only studying older adults. Similarly, Vafeiadis and Elldér (2024a) found that gender is not statistically significant for perceived accessibility to different destinations by various modes in most cases. However, they found that women have higher perceived accessibility in specific cases such as by bicycle for commuting or by public transport for grocery shopping. Similar to the case of age, studies need to consider all socioeconomic aspects together and use the suitable variables in their models to correctly estimate this impact. Additionally, future studies should explore the reasons for such difference in perception, especially as the reviewed ones could only speculate about differential gender results (e.g. by linking it to cognitive adaptation to more challenging travel patterns).

Only two studies looked at the possible impact of household composition and found no persistent link to perceived accessibility (Tanimoto & Hanibuchi, 2021), except for an overrepresentation of single-parent households in the lowest quantiles in rural areas (Pot et al., 2023b). Income was generally found insignificant to perceived accessibility (Lättman et al., 2018; Pot et al., 2023b; Tanimoto & Hanibuchi, 2021; Vafeiadis & Elldér, 2024a). In some cases, this result was due to income's effect being mediated by car ownership (Pot et al., 2023b). In a specific case of accessibility to parks, El Murr et al. (2023) found that the lower-income population reported a lower level of accessibility to this destination. Categorizing income levels is a crucial step as insignificant results could arise due to binary and/or unclear categorization without proper justification. Car availability/ownership positively impacts perceived accessibility (Pot et al., 2023b; Vafeiadis & Elldér, 2024a; van der Vlugt et al., 2019). Pot et al. (2023b) found that, in addition to car ownership, e-bikes-ownership has a significant positive impact on perceived accessibility in rural areas. While it increases perceived accessibility in general, car ownership negatively relates to perceived accessibility by public transport (Olsson et al., 2021; Vafeiadis & Elldér, 2024a). These results could arise from car users not understanding or considering the potential of public transit to help them reach their destinations.

Retirement, compared to employment, was positively associated with perceived accessibility due to experiencing fewer temporal accessibility barriers (Fu et al., 2024; Olsson et al., 2021). When compared with unemployment, people who are retired, self-employed, or employed tend to have higher perceived accessibility levels (Pot et al., 2023b), which could be due to having better financial abilities to reach desired destinations or constantly accessing and noticing a wider range of destinations that improves spatial knowledge. The only survey that examined physical disability found that it negatively impacts perceived accessibility in both urban and rural areas (Pot et al., 2023b). Related to the notion of expanding temporary spatial knowledge and the role of ICT in perception, digital fluency and having access to the internet was associated with higher levels of perceived accessibility (Pot et al., 2023b) and perceived transport equity (Fu et al., 2024; Liu et al., 2021). This is because it allows individuals to retrieve trip information and adjust plans, or virtually access a wider variety of destinations (e.g. grocery stores that are rather inaccessible by public transport). Finally, for social interaction and bonds, having a social network that can help with transportation was found positively related to perceived accessibility (Pot et al., 2023b), explaining how social cohesion has a positive correlation with perceived accessibility (Tanimoto & Hanibuchi, 2021).

The reviewed articles had minimal discussion on travel attitudes and satisfaction. van der Vlugt et al. (2019) found that a better perception of accessibility is formed by a favourable attitude towards public transport. Conversely, Pot et al. (2023b) argue that this is the case for walking, cycling and car use but not public transit and that the skill of using public transit (e.g., understanding information and knowing how to use online trip planners) is what positively impacts perceived accessibility. Related to intentions of travel by certain modes, people in the motivation stage of using public transit in the transtheoretical model (TTM) were found to have a more positive perception of accessibility than those in the volitional stage (Warner et al., 2021). Similarly, good perceived accessibility by public transit was also related to the behavioural intention to use it (Sheng & Zhang, 2022); however, it was not clear how this intention was calculated in that study. Related to that notion, Nguyen-Phuoc et al. (2025) found that positive perceived accessibility by a newly built urban train system positively impacts the intention to use it once operational, highlighting the potential role of perceived accessibility in shaping future travel behavior

The impact of socioeconomic characteristics on perceived regional accessibility remains inconclusive. Further research should use data from representable samples that adequately reflect diverse population characteristics. Analysis methods should take into account all possible confounding factors. In-depth analysis of specific populations can provide insights into the components that impact their perceived accessibility based on their particular needs. Understanding how populations perceive accessibility based on their different socioeconomic characteristics can help practitioners and policymakers identify their target groups and design appropriate policies for each.

2.6.3.2 Travel behaviour

The link between perceived accessibility and travel behaviour remains underexplored in the literature with some findings that would need further elaboration. Many studies employed a variable reflecting the frequency of use of a certain mode. In many instances, this variable was either ill-defined (e.g., no explanation on how it was calculated), or too general [e.g., using a car more than once a week was considered a frequent user, a 5-point scale with daily/always and never on the two ends (Friman et al., 2020b; Olsson et al., 2021), a 3-point scale with unjustified breaks]. In more recent studies, the measure for travel behaviour is more accurate. Mehdizadeh and Kroesen (2025) use a six-point Likert- scale ranging from never, 1 to 5 days per year, 6 to 11 days per year, 1 to 3 days per month, 1 to 3 days per week, 4 or more days per week. And Negm and El-Geneidy (2025) provide the most detailed measure of travel behavior, using the percentage of weekly public transit trips for five different travel purposes.

Overall, there is little consistency in the results concerning travel behaviour and perceived accessibility. Lättman, Friman, et al. (2016) found that the frequency of use of public transport positively relates to perceived accessibility with that mode. However, their study only includes bus users and does not account for socioeconomic differences. Conversely, two studies found that the frequency of use of public transport is negatively associated with perceived accessibility by that mode (Friman et al., 2020b; Olsson et al., 2021). This result could be considered counterintuitive as users of a specific mode would understand the potential of access by this mode than people who use it less. While all three studies use SEM analysis, they only consider the impact of transit/car uses frequency on public transit and not the opposite direction. Neither consider that perceived accessibility could have an impact on travel behaviour and that decisions of using transit or car frequently could arise from how an individual perceives their accessibility using these modes. Similarly, Andersson et al. (2023) found that the overall perceived accessibility for the sample decreased with the increased number of transit users after a free public transport card intervention. However, this is not a conclusive result on the impact of transit use on perceived accessibility as they do not use panel data that examines perceived accessibility for the same individual.

Some studies simply examined the perceived accessibility for different mode users, or in situations where a certain mode user would be restricted from its use. For example, Lättman et al. (2018) found that bicycle users have the highest levels of perceived accessibility compared to car and public transit users through a comparison of means. By evaluating the PAC for car users if restricted from driving, Lättman et al. (2020) and Tanimoto and Hanibuchi (2021) found that these users' perceived accessibility would significantly decrease if they were restricted from car use. However, both studies did not use panel data from the same individuals to examine such an effect and rather relied on a hypothetical situation, making their results less definitive. Fu et al. (2024) found that multimodal individuals that have limited access to cars have lower perceived accessibility and have higher perception of perceived travel-related disadvantages (spending more money on travel than affordable and more time than desired).

Based on ordinal regression analysis, Vafeiadis and Elldér (2024a) argue that frequent car users have high levels of perceived accessibility by car and low levels by all other modes. For four different destinations, they found the same pattern for other modes where individuals tend to have the highest perceived accessibility by the mode they use most. These preliminary results confirm that car users tend to have higher perceived accessibility in general. Negm and El-Geneidy (2025) used regression analysis to examine the impact of perceived accessibility on travel behaviour while accounting for calculated accessibility, residential selection, travel identity, and individual characteristics. They found that positive perceived accessibility by public transit increases weekly public transit mode share. Both studies acknowledge that their cross-sectional data is limited in terms of inferring causal relationships between perceived accessibility and travel behaviour and recommend the use of panel data in future research.

Using panel data and conducting cross-lagged panel models, Mehdizadeh and Kroesen (2025) find that the relationship between perceived accessibility and travel behaviour is bidirectional. However, they argue that travel behaviour has a stronger influence on perceived accessibility than the reverse effect. It is important to note that this study uses a measure of perceived accessibility that focuses on "accessibility to the neighborhood" (as described in section 4.2), which may overlook how travel behaviour is shaped by the various destinations that people seek to reach by different transport modes.

There is still limited research on perceived accessibility by different modes, whether used or unused. Understanding how travel behaviour impacts and is impacted by perceived accessibility is crucial in developing adequate strategies that encourage sustainable travel.

2.6.3.3 Public transport service quality

Regarding the supply-side of accessibility, the impact of public transport service quality on perceived accessibility was found positive upon examination by five studies using SEM analysis (Friman et al., 2020b; Lättman, Friman, et al., 2016; Sukhov et al., 2023; Watthanaklang et al., 2024; Zhu et al., 2024). Functionality (also described as reliability and convenience) is one of the most important contributors to this positive relationship (Friman et al., 2020b; Lättman, Friman, et al., 2016; Sukhov et al., 2023). This aspect includes reasonable travel times, reliability, frequency, ease of transfers, ease of buying tickets and closeness to the nearest public transport stop. While Sukhov et al. (2023) found functionality not to be a significant determinant for perceived accessibility among older adults, they used necessary condition analysis (NCA) to discover that functionality is a necessary condition for high perceived accessibility for this population group.

Courtesy as a component of responsiveness was also found to be one of the strongest contributors to this relationship, stressing the importance of the staff being ready to assist passengers (Lättman, Friman, et al., 2016; Watthanaklang et al., 2024). Comfort was also found to be a significant factor in the positive relationship between quality service and perceived accessibility (Friman et al., 2020b; Sukhov et al., 2023). While Lättman, Friman, et al. (2016) found perceived safety on public transport to positively impact perceived accessibility, Olsson et al. (2021) and Sukhov et al. (2023) found it to be insignificant; however, necessary for high perceived accessibility (Sukhov et al., 2023). Cost, however, was found either insignificant or the least important factor in formulating positive (or negative) perceived accessibility. This relates to the idea that income was not found significant in other studies (Lättman et al., 2018; Pot et al., 2023b; Tanimoto & Hanibuchi, 2021). An explanation could be the impact of adaptive preference (Baber, 2007), where people with restricted (financial) capabilities adapt their expectations and preferences to align with their circumstances. This adjustment can result in them downplaying the importance of cost when self-reporting their preferences.

2.6.4 (Mis)match between calculated and perceived accessibility measures

A few studies examined the potential (mis)match between calculated an perceived accessibility measures (El Murr et al., 2023; Lättman et al., 2018; Pot et al., 2023a, 2023b; Vafeiadis & Elldér, 2024a, 2024b). Pot et al. (2021) argue that mismatches between calculated accessibility measures based on spatial data and perceived accessibility arise either from inaccuracies in an individual's spatial awareness or from errors in the calculated measures, particularly in how personal evaluations known spatial accessibility components (e.g. transport system characteristics) are incorporated. This means that despite high levels of calculated accessibility, an individual can still perceive a low level of accessibility because they either lack complete spatial knowledge of their surroundings (inaccuracies in awareness), or because the calculated measure does not account for certain components that are essential to their experience (inaccuracies in measure). Similarly, low levels of calculated accessibility can coincide with high levels of perceived accessibility, depending on the measure's match with individual needs and abilities.

Pot et al. (2023a, 2023b) compared gravity-based accessibility measures for a range of services, including supermarkets, education, healthcare, retail, cultural, hospitality and sporting facilities, with self-reported perceived accessibility using PAC. In both studies, they found that perceived accessibility is more evenly distributed than calculated accessibility in both urban and rural settings, meaning that there generally is a discrepancy between the two measures. Similarly, Lättman et al. (2018) compared data from the PAC with calculated accessibility-indices that include eight indicators that consider travel time and distances to certain destinations and public transport. They also found a mismatch between the two measures, with perceived accessibility being more evenly distributed across residential areas. This phenomenon can be attributed to diminishing returns to a higher number of opportunities and spatial heterogeneity in needs and abilities due to residential self-selection (Pot et al., 2023b). This suggests that people living in rural areas (lower spatial accessibility) on average are less sensitive to spatial accessibility, as they choose to life in an area where they know there are fewer opportunities or have adapted their activity and travel preferences over time. Accordingly, they use other methods (e.g. driving) to compensate for the lack of "measured" locally available opportunities. This was also relevant when Lättman et al. (2020) found that there are significant differences in perceived accessibility when restricted to sustainable modes of travel depending on the area of residence.

Some studies limited the comparison between calculated and perceived measures to certain destinations such as parks (El Murr et al., 2023) and grocery stores (Vafeiadis & Elldér, 2024b). While El Murr et al. (2023) found a misalignment between the number of accessible parks using cumulative opportunities measures and the self-reported accessibility (negative relationship), they found the quality index for parks and the self-reported accessibility to be positively related. Vafeiadis and Elldér (2024b) found an overestimation of perceived accessible grocery stores within 15 minutes for cycling and public transport, while an underestimation for car accessibility.

Vafeiadis and Elldér (2024a) use travel time and number of amenities accessible within a certain travel time (cumulative opportunities) as calculated accessibility indicators and examine the relationship between this indicator and perceived accessibility by different modes and to different destinations. While they find that reaching more grocery stores and restaurants as well as shorter travel time to city center by transit is associated with higher likelihoods of perceiving ease in reaching these destinations by transit, they find a mismatch between the car accessibility indicator and perceived accessibility by car. As previously discussed, they argue that residential self-selection could be one of the causes of this mismatch, but they also add that it could be due to the accessibility indicator not correctly capturing the accessibility levels by not accounting for parking and congestion. As Vafeiadis (2024) argues, the calculations for the accessibility indicators could have a major impact on the mismatch between calculated and perceived measures, especially if they are too simple.

These findings stress the importance of considering the modes and destinations in the calculated measures. Ensuring the use of well-established calculated measures rather than ill-described secondary indexes could help pinpoint the inaccuracies of measurement. Additionally, to take the analysis a step further into practice and policy formulation, it is necessary to understand how perceived accessibility relates to certain modes and specific destinations. These understandings not only help direct the needed interventions to address the problems that could be causing transport disadvantages, but they also allow for a deeper investigation of other aspects impacting the mismatches, such as the quality of destinations (El Murr et al., 2023).

2.7 Perceived accessibility conceptual framework

Through the above literature review of perceived regional accessibility, we find that the concept needs a clear definition that captures the core aspects of accessibility and perception at the personal level. As an outcome of the interaction of land-use and transport system with individual characteristics, perceived accessibility can be defined as the ***perception of how easily one can access their desired destinations using a (range of) specific mode(s)***. This definition stems from the original definition of accessibility (Dalvi & Martin, 1976; Handy, 1992; Hansen, 1959; Levinson & Wu, 2020) and recent works that measure perceived accessibility (Vafeiadis & Elldér, 2024a).

To pave the way for future research on perceived accessibility, we summarize its potential empirical relationships to calculated accessibility, residential choice, demographics and personal resources, and travel experience and attitudes based on our new definition and how it connects to travel behaviour in **Figure 2.2**. This framework is designed based on the reviewed studies in addition to conceptual studies (Pot et al., 2021; van Wee, 2022). It also draws inspiration from works that conceptualize and explore perceived walkability (De Vos et al., 2023; van der Vlugt et al., 2022).

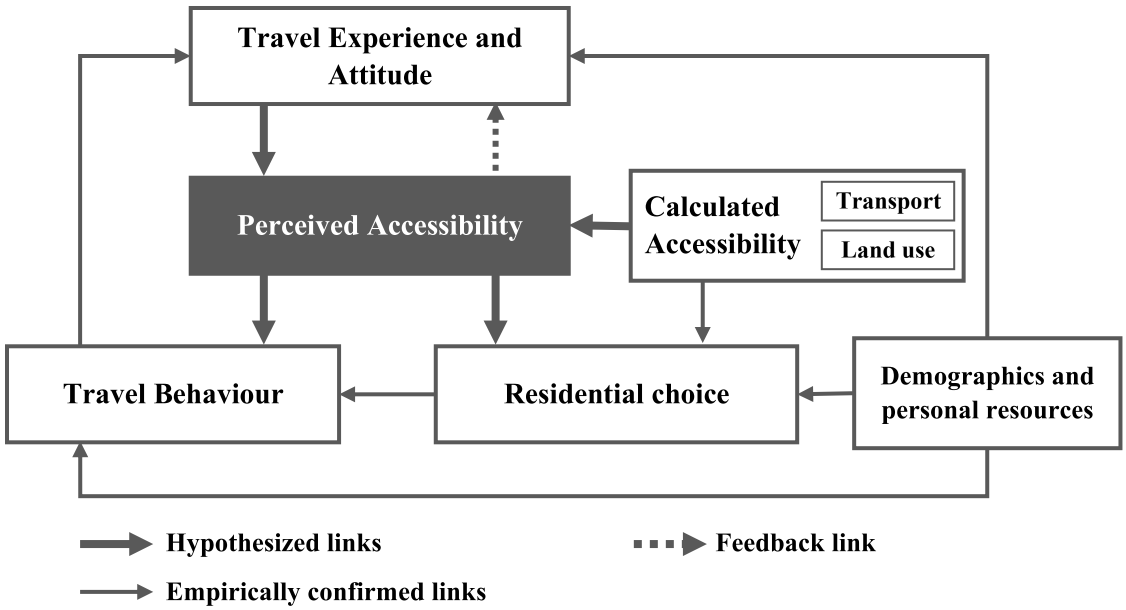

Figure 2.2 Framework for empirical research on perceived accessibility

Calculated accessibility results from the interaction between land-use and transport systems. These spatiotemporal components include the location of opportunities, activity types, the opening hours of destinations, travel mode, transit schedules (if the mode is public transit), road infrastructure, and travel time. Calculated accessibility also considers individual factors, such as basing the calculations on a reasonable travel time threshold, which can be derived from origin-destinations surveys. We argue that these spatiotemporal components in conjunction with individual needs, abilities, travel experiences, and attitudes impact how an individual perceives one's level of accessibility. Previous research has highlighted how calculated accessibility relates to travel behaviour (Moniruzzaman & Páez, 2012; Negm & El-Geneidy, 2024; Owen & Levinson, 2015; Ton et al., 2020). In reality, one's decision relies on how they perceive the built environment. Therefore, as Morris et al. (1979) stated, perceived accessibility is the actual basis of behaviour.

Perceived accessibility, thus, moderates the link between travel needs, experiences, and attitudes and travel behaviour from a certain residential location with a certain spatial accessibility level. An individual's attitude towards a mode may influence the perception of accessibility through this mode, which in turn affects their decision to use it. For example, a person with a positive attitude towards transit and a readiness to use it would likely know the destinations they can reach by transit, unlike someone in the same area with a negative attitude towards transit. An individual weighs their accessibility options based on mode availability, the transport system schedule, the travel time necessary, and the quality of the transport system. Therefore, the availability of the resources themselves, in conjunction with individual needs, desires, experiences, and attitudes, play an important role in the perception of accessibility.

Travel attitudes are related to personal needs and abilities and can be assessed by demographics (e.g., age, gender, household composition, education level, and income level) and personal resources (e.g., vehicle ownership) but may also vary within groups with similar sociodemographic characteristics. Combined, these factors are major determinants of residential location choice (Buehler, 2011; Patterson et al., 2005; Scheiner, 2014). While research shows that people self-select into residences in areas that fit their attitudes (Handy et al., 2006), we hypothesize that this process is rather driven by perceived accessibility (Pot et al., 2023a). An individual with a positive attitude towards transit would not simply reside near a bus or metro stop. They will weigh the ease in which they can access their desired destinations and choose their residence based on this perception of accessibility. As discussed in section 4.3.3, it is important to take the phenomenon of adaptive preference into account when examining the impact of travel attitudes and demographics on perceived accessibility. People may adjust their preferences to their living circumstances, which in turn impacts their perceived accessibility. This phenomenon can best be examined in longitudinal studies where tracking the same individuals' overtime can provide insights into how they adapt their perceptions and behaviours to different circumstances. For example, when a car-dependent individual with low perception of public transit accessibility moves to an area with limited parking and reliable public transit, they may shift their preference overtime to using transit, possibly increasing their perceived accessibility by that mode. Therefore, this adaptation process influences how individuals perceive accessibility, as their preferences and attitudes adjust in response to changes in their lifestyle and surroundings.

As one travels with a certain mode, they develop experiences that can change or reinforce their attitudes or satisfaction towards that mode (De Vos et al., 2016; De Vos et al., 2022; Ye & Titheridge, 2017). A person with a positive transit experience and knowledge of how it works is more likely to see it as an easy way to reach their desired destinations. These experiences and attitudes are impacted by previous travel behaviour (Kroesen et al., 2017). In a broader context, future studies could explore the link between perceived accessibility and both travel and life satisfaction, given that travel satisfaction can have a long-term impact on overall life satisfaction (De Vos & Witlox, 2017). In our literature review, one study that examined this relationship for older adults in five European cities found that perceived accessibility has a positive impact on overall life satisfaction (Lättman et al., 2019). Another study on older adults in the Republic of Korea found similar results (Kim, 2024). As some of the relationships in this model still need investigation and validation in different contexts for various population groups, we recommend areas and methods for future research in the following section.

2.8 Recommendations for future research

Based on examining the current state of research in perceived regional accessibility and the conceptual framework in **Figure 2.2**, this section highlights key areas for future research.

- Utilizing panel data (data that examines the same individuals overtime) is essential to unravel the direction of the relationships in the conceptual model, such as:
  - The impact of perceived accessibility on travel behavior and residential choice.
  - The influence of calculated accessibility on perceived accessibility.
  - The role of travel behavior in shaping perceived accessibility, mediated by travel experience and attitudes.
- Utilizing mediation analysis within the framework of structural equation modelling could prove useful in unravelling the relationships between the different components and impacts of perceived accessibility.

- Based on the findings from the examined research, we recommend deeper examination on the impacts of sociodemographic characteristics on perceived accessibility, understanding how different population groups experience and interpret accessibility.
- Future research could investigate the (mis)match between calculated and perceived accessibility measures across different contexts and populations, with a focus on understanding the reasons behind such mismatches.

Below we provide recommendations on data collection, measures, and methodology.

- Clearly defining perceived accessibility in the context of the research is crucial for properly positioning it within the literature.
- Ensuring the measurement consistency with the definition is important. The measure would ideally be destination- and mode-specific, using a Likert Scale to capture nuances in perception.
- Comprehensive data collection should include all the potential factors related to perceived accessibility, including but not limited to travel behaviour, travel attitude, residential location, self-selection, sociodemographic, and perceived accessibility itself.

2.9 Conclusion

In this article, we review 45 articles that examine perceived regional accessibility. We find that empirical work on the topic is emerging but significant ambiguities surrounding its definition and measurement remain. Definitions of perceived accessibility tend to conflate with broader notions of well-being, which hampers the unambiguous interpretation of empirical findings regarding how perceived accessibility can be explained and connected with travel behaviour and socioeconomic characteristics. Drawing from the conventional definition for accessibility and from the reviewed studies, we define perceived accessibility as ***the perception of how easily one can access their desired destinations using a (range of) specific mode(s).*** Accordingly, we propose a conceptual model that identifies the potential determinants and impacts of perceived accessibility, suggesting pathways for future studies to integrate this concept more effectively.

Accounting for perceptions in accessibility evaluations can appear complex. However, it is important to remember that there is no such thing as 'objective' accessibility, as an individual's decisions are mediated by their needs, desires, and abilities (Pot et al., 2021). Empirical research on perceived accessibility can inform accessibility evaluations in practice through examining how different populations experience their various calculated accessibility levels based on their socioeconomic characteristics. However for this to work, it is crucial to ensure that future measures remain technically feasible, operationally transparent, and yield easily interpretable results (Morris et al., 1979).

As accessibility becomes more integral to transport planning, understanding its meaning to people and how they perceive it is essential for professionals and decision-makers. Exploring how perceived accessibility affects individuals' decisions will help develop strategies that ensure equitable access to opportunities and encourage sustainable behaviour. Rather than focusing solely on expanding infrastructure to improve accessibility and boost public transit use, highlighting areas where there is a mismatch between calculated and perceived accessibility levels can help develop policies ensuring that people are aware of the available transport options to them, increasing their perceived accessibility. Policymakers can aim to promote real-time transit data and digital wayfinding tools around these areas with mismatch, to better communicate the reliability and accessibility of public transit. Additionally, analyzing the relationship between perceived accessibility, well-being, and life satisfaction across different demographic groups can guide policies that better serve underserved communities. Addressing disparities in perceived accessibility can contribute to a more inclusive transport system, ultimately improving social equity and quality of life.

Chapter 3. Exploring the changes in the interrelation between public transit mode share and accessibility across income groups in major Canadian cities in the post-pandemic era

Negm, H., & El-Geneidy, A. (2024). Exploring the changes in the interrelation between public transit mode share and accessibility across income groups in major Canadian cities in the post-pandemic era. *Journal of Transport Geography, 115, 103792.*

Exploring the changes in the interrelation between public transit mode share and accessibility across income groups in major Canadian cities in the post-pandemic era

3.1 Chapter positioning

This chapter corresponds to the second dissertation objective, aiming to confirm the impact of calculated accessibility on travel behaviour in the post-pandemic era. Confirming this relationship establishes the foundation of the conceptual framework introduced in the previous chapter, enabling further investigations in subsequent studies. Due to the COVID-19 pandemic, it can be assumed that the factors influencing public transit behaviour have undergone significant changes, particularly with shifts in travel attitudes (Kroesen et al., 2017; Rahman & Sciara, 2022). This chapter seeks to understand how accessibility impacts public transit usage differently in the post-pandemic era compared to pre-pandemic times. It examines this impact from an equity perspective, focusing on variations among different socioeconomic groups (low-income and other-income groups) in the three largest metropolitan regions in Canada: Toronto, Montréal, and Vancouver. Understanding these variations is an important step in guiding accessibility-focused interventions aiming to promote sustainable mode use and achieve sustainability goals.

3.2 Abstract

The COVID-19 pandemic has impacted the travel behaviour of urban residents in an unprecedented manner, especially public transit (PT) users. PT has experienced a decline in ridership around the world early in the pandemic and has been struggling to rebound again to the pre-pandemic levels, whereas other modes have reached their pre-pandemic levels. PT agencies have been trying to attract users back through service improvements and other policies; nevertheless, the impacts of policies that were effective prior to the pandemic are not guaranteed in the post-pandemic world due to the lasting effects of the pandemic on travel behaviour. This study compares the changes in the impacts of accessibility, the ease of reaching destinations, to jobs by PT on commute mode share pre- and post-pandemic (2016 and 2021) with an equity lens in the three largest metropolitan regions in Canada: Toronto, Montréal, and Vancouver. Results show that planning for accessibility is still an impactful tool to increase PT mode share in the post-pandemic era, yet the magnitude of the impact has declined by almost 50% in Toronto and Montréal and 30% in Vancouver for low-income groups. In the post-pandemic era, the impact of accessibility on PT mode share remains higher for the low-income compared to other-income groups, which is similar to the pre-pandemic times. Understanding the changing effects of accessibility, a major land use and transport planning tool, on travel behaviour is important as PT agencies are developing strategies to restore pre-pandemic levels of ridership and increase it to reach their sustainability goals.

3.3 Introduction

The mitigating strategies imposed by the outbreak of COVID-19 had remarkable impacts on travel behaviour (Javadinasr et al., 2022; Kapatsila, Bahamonde-Birke, et al., 2023; Kolarova et al., 2021; Paul et al., 2022; Shamshiripour et al., 2020) and profoundly influenced public transit (PT) ridership negatively worldwide (Das et al., 2021; Tirachini & Cats, 2020). In Canada, PT ridership levels decreased between 2016 and 2021 by 59% in Toronto, % 46% in Montréal, and 42% in Vancouver (Statistics Canada, 2017, 2023a). As travel and social-distancing restrictions came to an end, the world gradually returned to some of its pre-pandemic state. Nonetheless, this transition was accompanied by shifts in some travel habits and preferences. For example, many employees currently prefer working from home or a hybrid workstyle (Mohammadi et al., 2023) and many institutions have been responding to that through adopting hybrid work policies (City of Toronto, 2023; Public Safety Canada, 2023). Post-pandemic studies reported an increase in the use of private vehicles and a decrease in PT use especially among commuters to work (Abdullah et al., 2021; Javadinasr et al., 2022; Kolarova et al., 2021). These changes challenge many of the known facts when it comes to travel behaviour, such as the magnitude and impact of the built environment on mode choice.

Accessibility, the ease of reaching destinations (Hansen, 1959), has been established as a reliable measure of the built environment, as it incorporates the land use and transport systems in one measure. Previous research has established the impact of accessibility on travel behaviour (Cui et al., 2020; Legrain, Buliung, et al., 2015), especially PT mode choice. The pandemic had a clear impact on travel behaviour which has been shown to influence travel attitude (Kroesen et al., 2017; Rahman & Sciara, 2022). Based on the idea of changing travel behaviours and attitudes, we can assume that the factors impacting PT mode choice could have witnessed significant changes post-pandemic. To our knowledge, the changes in the effects of accessibility on PT mode share have not yet been studied. Our study aims to understand the variations in the impact of accessibility on PT mode share in the post-pandemic era and compare it to the pre-pandemic times from an equity perspective. We investigate these impacts for low and other-income groups in the three largest metropolitan regions in Canada: Toronto, Montréal, and Vancouver. As many PT agencies around the world are struggling with the decline in ridership, an understanding of the changing effects of accessibility, a major planning tool, on travel behaviour will help inform their decisions on services additions or cuts to achieve their sustainability goals.

3.4 Literature review

Transport is a cornerstone of sustainable development (UN High-level Advisory Group on Sustainable Transport, 2016). In their transport plans, many cities aspire to achieve higher sustainable mode share. For example, the City of Vancouver's 2040 plan, which was developed in 2016, aims for two-thirds of all trips to be made by foot, bike, or transit (City of Vancouver, 2012). Most of the transport plans' mode share targets, however, were set before the COVID-19 pandemic, which deeply impacted transit ridership and perception. Most North American agencies reduced service levels in the pandemic's early months when COVID-19 restrictions were highest (DeWeese et al., 2020). By mid-2021, many had returned to pre-pandemic service levels in the hopes of bringing ridership back (González-Hermoso & Freemark, 2021). However, today many agencies started to understand that the impacts of service provisions are no longer the same as they were in pre-pandemic times. Many agencies are exploring several options for service cuts and changes to address their financial deficit (Levitz, 2023), yet to what extent these changes will impact ridership is still unknown.

As much as COVID-19 had an impact on the decisions of transit agencies, it also had a major influence on travelers' behaviors and attitudes. A longitudinal study in Toronto and Vancouver by Palm et al. (2022) found that post-pandemic, public transit has seen a decline in choice riders, the ones who have access to multiple transport options and deliberately opt to use public transit for specific trips (Guerra, 2022). They also revealed a surge in car ownership amongst previous transit riders who found that having a car is necessary and helpful during the pandemic. In another study, Palm et al. (2023) revealed that people who depended on transit before the pandemic tended to keep using it for essential needs such as grocery shopping, while those who used transit less replaced these trips by online grocery delivery. Shopping trips were not the only ones impacted by COVID-19. Javadinasr et al. (2022) and Anik and Habib (2023) display the potential replacement of work trips by telecommuting even in the post-pandemic era. Building on the research investigating travel behavior changes after the pandemic, our study aims to examine the shifts, if any, in the impacts of the built environment on mode shares before and after the pandemic in various regions across Canada.

One major built environment factor that has been found to impact transit use is accessibility by public transit. Accessibility is considered one of the most comprehensive measures that link land use and transport systems to assess how they benefit the population in reaching opportunities (El-Geneidy & Levinson, 2022; Geurs & van Wee, 2004; Handy, 2020). It is often used as a tool to explain the equity impacts of land use and transport policies and projects (Allen et al., 2021; Deboosere & El-Geneidy, 2018; Ermagun & Tilahun, 2020; Geurs et al., 2016; Martens, 2012). Understanding the impacts of service changes through accessibility on mode choice is essential as many agencies include them in their planning goals as effectiveness measures (Boisjoly & El-Geneidy, 2017a). The relationship between accessibility by PT and its use has been well established as a positively correlated one (Moniruzzaman & Páez, 2012; Owen & Levinson, 2015). People who tend to use public transit more are the ones experiencing higher levels of accessibility by public transit. A recent study by Cui et al. (2020) confirmed the impact of accessibility on mode share for low- and other-income groups in eleven Canadian cities through a series of linear regressions using 2016 census data. They found that accessibility is a predictor of PT mode share and that the positive impact of increasing accessibility is much higher for the low-income groups' mode share. We hypothesise that this impact of accessibility on PT mode share has changed after the pandemic due to the service cuts, changes in job distributions, and telecommuting rates, which could have a major impact on travel behaviours and attitudes.

When it comes to measures of accessibility, cumulative opportunities measure is one of the most commonly used, due to its ease of interpretation, and communication to the public and policymakers (El-Geneidy & Levinson, 2022). In this measure of accessibility, all the opportunities (destinations) available within a predefined travel time threshold are weighted equally (Geurs & van Eck, 2001). Several other methods are used to measure place-based accessibility including gravity-based accessibility which weighs opportunities based on the travel time necessary to reach them. This method allows for the inclusion of opportunities that could be discarded in the cumulative measures if they are not within the set time threshold. While this measure improves the approximation to reality, it also requires an extensive amount of additional data and is more challenging to compute, interpret, and communicate to the policymakers and the public. Comparison between cumulative opportunities and gravity-based measures found high correlation between the two measures in the North American context (El-Geneidy & Levinson, 2006; Giannotti et al., 2021; Kapatsila, Palacios, et al., 2023; Palacios & El-Geneidy, 2022). This suggests that using cumulative opportunities is sufficient to present the built environment adequately when examining a variable such as public transit mode share and allow for the ease of communication of the results. Our research seeks to build upon prior studies concerning accessibility and mode choice by investigating the effect of its recent effects on PT mode share in the post-pandemic era and compares that to the pre-pandemic time while focusing on the aspect of equity of these impacts

3.5 Data

3.5.1 Census data

The main data sources for this study are the 2016 and 2021 Canadian population census and commuting flows (CCF) (Statistics Canada, 2017, 2023a). The CCF tables provide the number of workers commuting between their home and work census tracts (CTs) by income groups and mode of transport. These tables were used to define the threshold for the low and other-income workers in each region and year. Low-income workers were defined as the lowest paid 30% in each region following Deboosere and El-Geneidy (2018). As the census income groups are defined in 5k to 20k CAD increments, the threshold was set as close as possible to the 30th percentile. This resulted in 30k CAD being the low-income cut-off threshold for Toronto, Montréal, and Vancouver in 2016, and 40k CAD being the threshold in 2021 for the three regions. The same thresholds were used to calculate the number of low and other-income jobs in each region's CTs, which were used to calculate accessibility to jobs. For the other-income workers and jobs, we used the income groups above the set threshold for 2016 and 2021. In other words, the other-income workers are defined as the ones who earned more than 30k in 2016 and more than 40k in 2021. This logic was applied to all three Census Metropolitan Areas (CMAs).

Public-transit mode shares were calculated from the CCF as the share of low- and other-income commuters living in each CT who use public transit to commute. Low-income workers commuting via transit were divided by the total number of low-income commuters, and a similar calculation was performed for other-income commuters. A limitation faced in this part was data suppression which is the deletion/zeroing of certain values, such as the number of commuters within an income bracket. This is applied when the values are below a certain threshold set by the data provider (Statistics Canada, 2016). In some instances, data suppression within CCF income brackets caused discrepancies between the sum of the income groups' number of trips and the total number of trips reported per CT. In cases where both low and other-income number of trips equalled zero, due to the suppression of data within income brackets, and the total commuters provided by the CFF was non-zero, the CT was excluded from the dataset. If the two income groups did not add up to the total and one group had a non-zero value, the missing portion was assumed to be represented by the other group to complete the total. CTs with a transit mode share higher than 80% for any income group were excluded from the analysis as they were found to be the result of census data suppression, resulting in mode-share overestimation.

Although Statistics Canada offers data at a more detailed spatial resolution known as Dissemination Area (DA) level, the information at this level is subject to even stricter data suppression compared to the Census Tract (CT) level. This heightened suppression is a result of the smaller population residing in and commuting from these DAs, leading to numerous values being suppressed to safeguard the privacy of individual population members. Despite the theoretical potential for more accurate insights through analysis at the DA level, the prevalence of missing data poses a significant risk of distortion. Consequently, we have chosen to utilize the higher-level CT data for our analysis to mitigate the impact of data suppression.

3.5.2 Spatial data

The regional accessibility by PT to jobs was calculated using the number of jobs per CT (commuters arriving in the CT), General Transit Feed Specification (GTFS) data, and OpenStreetMap networks. GTFS data was obtained from Transitland using an API for October 2016 and June 2021, as these dates guaranteed the availability of the schedules for all transit systems in the three regions. The OpenStreetMap street network was obtained for each region through BBBike extracts. We used the r5r package in R with GTFS data and the OSM network for each region as inputs to calculate a travel time matrix (TTM) between CT centroids (Pereira et al., 2021). This TTM presents the shortest travel time by public transit between each origin and destination (CTs) for a regular Wednesday traveling between 8 AM and 9 am then averaged to account for schedule variability. The calculated travel times include access, egress, waiting, in-vehicle, and transfer times if applicable.

Cumulative opportunities measures were calculated for the three studied regions. The travel-time threshold was set to 45 minutes as it is closest to the median travel times by public transit for the three metropolitan areas (Statistics Canada, 2017, 2023b) in both time periods, as suggested by Kapatsila, Palacios, et al. (2023). Accessibility to low- and other-income jobs was calculated separately by adding the number of these jobs accessible from each CT centroid within 45 minutes of travel by PT. To allow for comparisons between different income groups, regions, and time periods, we divided the resulting accessibility values per CT by the total number of jobs available in each CMA, resulting in a proportional accessibility measure. This represents the percentage of low and other-income jobs in the CMA accessible from each CT.

As an indicator of the availability of high-quality PT service in a CT, we calculated the shortest distances on the road network between CT centroids and the closest rapid transit station using the dodgr package in R (Padgham, 2023) for each region. Rapid transit comprises metro, commuter trains, and bus rapid transit (BRT). We retrieved the coordinates of the stations from Transitland based on the data provided by the regions' respective agencies. The same method was applied to calculate the closest highway ramp for each CT centroid.

3.6 Methods

The study aims to understand the relationship between public transit mode share and accessibility to jobs by PT for different income groups and how it has changed throughout the pandemic for three different Canadian regions. We analyze the mode share of low-income workers to low-income jobs and the same for other-income workers and jobs. We first conduct an exploratory analysis through scatterplots to represent the relationship between accessibility and PT mode share by income group for all regions. We then investigate this relationship by estimating multiple linear regression models with PT mode share in each CT as the dependent variable. For each CMA, we estimate four models to inspect the differences between 2016 and 2021 for the low- and other-income groups. The dependent variable in each model represents the share of PT users within an income group relative to the total number of workers in that income group (e.g., low-income transit users/ total low-income workers) commuting to work. PT accessibility to jobs divided by the total number of jobs in the region is our key independent variable and, in each model, it corresponds to the income group that is being modeled. Based on the exploratory analysis, a squared term of this accessibility percentage is included as an independent variable to capture the non-linear relationship between accessibility and PT mode share that was revealed in the scatter plots (Cui et al., 2020).

We incorporated other socio-demographic variables, such as average age and household size into our models enabling the consideration of the CTs population characteristics. Additionally, we take into account the effects of COVID-19 on travel behaviour and telecommuting by including the percentage of employees working from home as an independent variable (Javadinasr et al., 2022). Other built-environment characteristics were included in the models as controls, such as population density and the distance to the closest rapid transit station (Ewing & Cervero, 2001). The distance to the closest highway ramps were tested and was revealed to be statistically insignificant; therefore, it was excluded from the models.

3.7 Results and discussion

3.7.1 Context maps

The bivariate maps in **Figure 3.1** display the changes in accessibility to jobs by public transit between 2016 and 2021 for the three studied regions. The maps display the distribution of proportional accessibility to low- and other-income jobs in relation to each other. Proportional accessibility is the number of accessible jobs (low or other-income ones) divided by the total numbers of jobs in the CMA. It is important to emphasize that although certain areas have high accessibility for both low- and other-income jobs in 2016 and 2021, that does not imply that the number of accessible jobs remained similar between the two years as the map display relative values (high and low accessible jobs). Overall, in the central areas characterized by significant intersection of rapid transit networks, accessibility is highest for both low- and other-income jobs in the two time periods.

Moving outwards of city centers, the distribution of accessible jobs for both groups exhibits some changes in all three CMAs. These changes are attributed to variation in the types of jobs available (low- or other-income jobs) and changes in infrastructure. The changes in infrastructure include the addition of new transit lines such as the Line 1 Yonge–University western extension that opened in late 2017 (Toronto Transit Commission, n.d.) and the Millennium Line Evergreen Extension in Vancouver that started operating in late 2016 (Infrastructure BC, n.d.). On the opposite side, in Montréal, the transit network was impacted by some closures and rerouting due to the construction of the new light-rail network, including the complete closure of the Exo Deux-Montagnes line by the end of 2020 (Gouvernement du Québec, n.d.).

To illustrate an example for the changes in accessibility to different types of jobs, in the Eastern side of Toronto; there was a higher accessibility for low-income jobs compared to other-income ones in 2016. However, for many CTs, this ratio changed in 2021 and proportional accessibility became intermediate for both jobs' groups. These changes are seen in the three regions in different ways as higher or lower accessibility to low-income jobs, or other-income ones in relation to each other. To account for these dynamic changes in accessibility to low- and other- income jobs, we estimate our regression models for each income group individually.

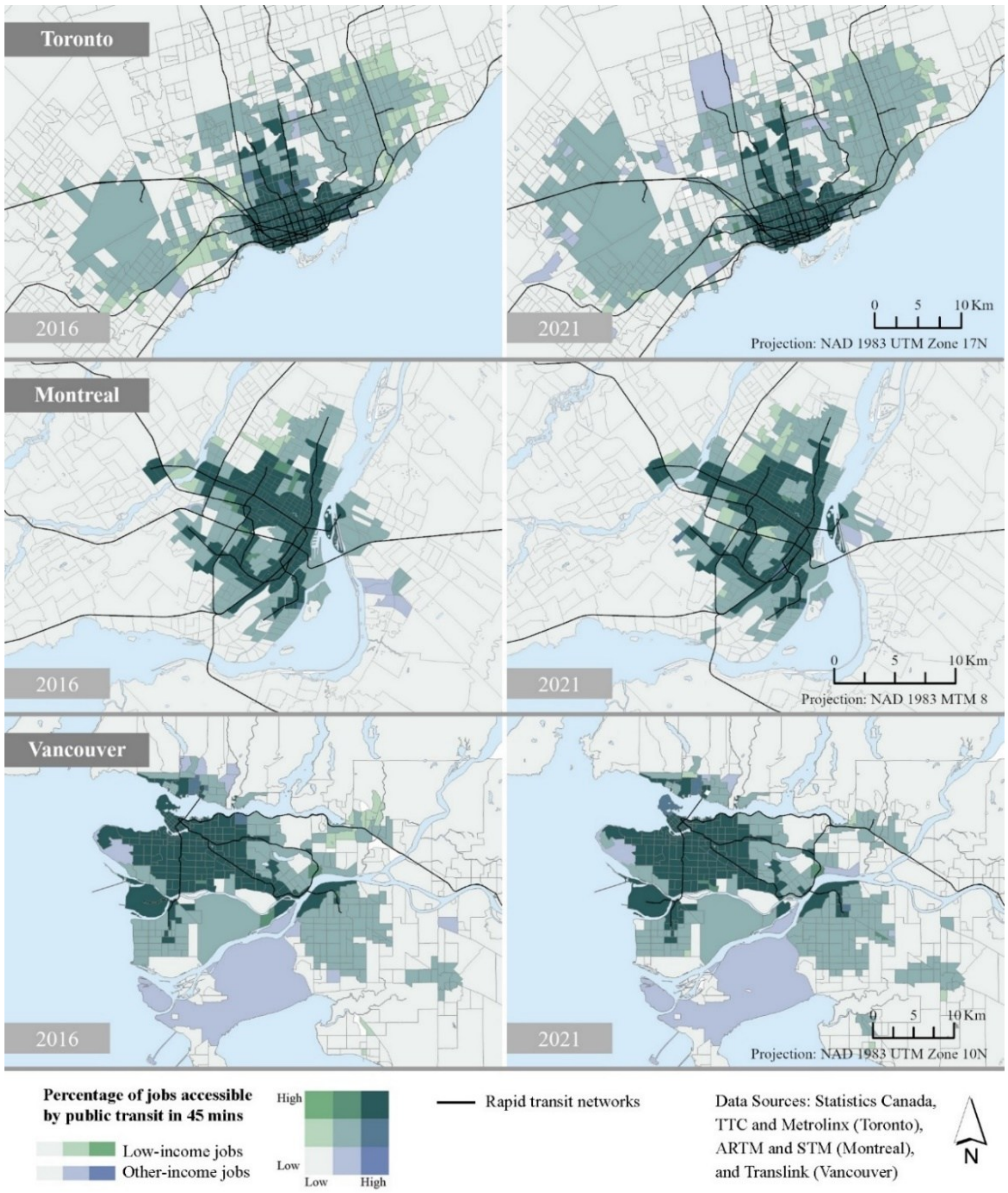

Figure 3.1 Proportional accessibility to low- and other-income jobs by public transit in 45 minutes for Toronto, Montréal, and Vancouver in 2016 and 2021

3.7.2 Descriptive statistics

Table 3.1 includes descriptive statistics of the data used in the models by year and region. It is observed that the mean PT mode share is always higher for low-income groups compared to other-income ones across all regions and in the two time periods. Comparing between years, we find that the mean PT mode share decreased in 2021 for both income groups in all CMAs, with a contrasting increase in the mean car mode share. This could mainly be attributed to the COVID-19 social distancing interventions executed by transit agencies that significantly reduced the levels of PT ridership (Kamga & Eickemeyer, 2021; Palm et al., 2021) and the working-from-home policies.

In 2021, the mean percentage of accessible jobs for low-income groups slightly increased compared to 2016, while it decreased for other-income groups. The increase in the low-income accessibility percentage can be attributed to two things: the decrease in the total number of jobs, and the increase in telecommuting which is considered a more plausible option for other-income jobs than low-income ones (Anik & Habib, 2023). Therefore, the increase in accessibility percentages between the two years does not mean that accessibility to jobs was enhanced for the lower-income group as the decrease in the number of jobs was disproportionate for low- and other-income jobs that people commute to in 2021. As census population data is not disaggregated by income groups, other variables are presented for the CT as a whole. The increase in the percentage of employees working from home (WFH) is noteworthy, as WFH employees in 2021 account for more than a quarter of the population in each CMA. Average age and household size remain similar in 2021 compared to 2016 for each CMA.

Table 3.1 Descriptive Statistics for the CTs in the three studied CMAs by mean (SD)

	Toronto				Montréal				Vancouver			
	2016		2021		2016		2021		2016		2021	
Region Population	5,928,040		6,202,225		4,104,074		4,291,732		2,463,431		2,642,825	
Number of CTs	N= 1139		N= 982		N= 944		N= 817		N= 463		N= 465	
Income Level	Low	Other	Low	Other	Low	Other	Low	Other	Low	Other	Low	Other
PT Mode Share (%)	32.14 (17.54)	23.68 (13.66)	21.62 (13.95)	13.1 (10.42)	31.43 (18.48)	23.31 (14.06)	23.94 (15.36)	14.36 (11.48)	28.75 (13.87)	16.87 (10.14)	21.44 (12.48)	9.8 (7.12)
Car Mode Share (%)	55.8 (22.19)	70.24 (19.44)	60.76 (23.07)	73.01 (18.68)	53.83 (24.64)	67.84 (21.44)	54.49 (25.35)	68.05 (24.06)	56.98 (19.08)	74.35 (17.03)	59.38 (19.21)	76.32 (16)
Accessibility by PT in 45 mins (%)	1.52 (1.9)	4.16 (6.17)	1.7 (1.72)	3.59 (4.26)	3.32 (3.87)	8.85 (10.49)	3.86 (4.13)	7.17 (7.79)	3.66 (3.88)	8.59 (9.72)	4.5 (4.15)	8.37 (8.16)
Total Jobs (10,000)	0.24 (0.71)		0.13 (0.33)		0.19 (0.49)		0.14 (0.26)		0.23 (0.46)		0.15 (0.23)	
Employed Population (%)	60.81 (7.09)		55.29 (6.94)		61.07 (8.23)		60.56 (7.15)		61.28 (7.56)		59.66 (7.22)	
WFH Employees (%)	7.42 (3.96)		33.69 (12.9)		6.9 (3.1)		27.57 (11.24)		8.56 (4.4)		25.93 (10.01)	
Age	40.27 (3.95)		40.98 (3.72)		40.65 (4.25)		41.02 (3.98)		41.38 (4.01)		41.85 (3.9)	
Household structure	2.84 (0.6)		2.82 (0.62)		2.31 (0.41)		2.28 (0.39)		2.65 (0.56)		2.62 (0.57)	
Median Income	8.56 (3.08)		10.09 (2.98)		6.6 (2.67)		7.69 (2.52)		7.84 (2.16)		9.43 (2.2)	
Population density (1,000/km2)	5.59 (6.44)		6.66 (7.88)		5.67 (5.19)		6.44 (5.54)		4.69 (4.95)		5.55 (5.66)	
Distance to Station (km)	3.7 (4.98)		3.64 (5.09)		4.59 (6.03)		4.3 (5.54)		6.05 (6.07)		5.15 (5.06)	

3.7.3 Public transit mode share and accessibility

To investigate the relationship between PT mode share and accessibility for both income groups, **Figure 3.2** presents scatter plots of these two variables per region, income group, and year. To allow for comparison between the income groups, we use normalized accessibility (z-scores). We fitted a polynomial model as the best-fit curve, as it was found to be the most accurate in previous research (Cui & El-Geneidy, 2019). The plots reveal a non-linear relationship that applies to both income groups, where the mode share increases with the improvement of accessibility until a certain point and then starts to decrease for higher accessibility. These results are consistent with those presented by Cui and El-Geneidy (2019) for 2016.

In both years and across the regions, we find low-income groups use public transit more than other-income ones at any accessibility level. In 2016, when accessibility improved significantly (within z-scores of -1 and 1), there was a surge in PT usage, particularly in Montréal and Toronto. For all regions in 2021, we find that PT mode share is much lower than in 2016 at all accessibility levels. Factors influencing such change could be the increasing rates of WFH, the decrease in the number of on-site jobs and the decreased activity around denser city centers. There was a notable decline in PT usage at very high levels of accessibility in 2016 which is not as evident in 2021.

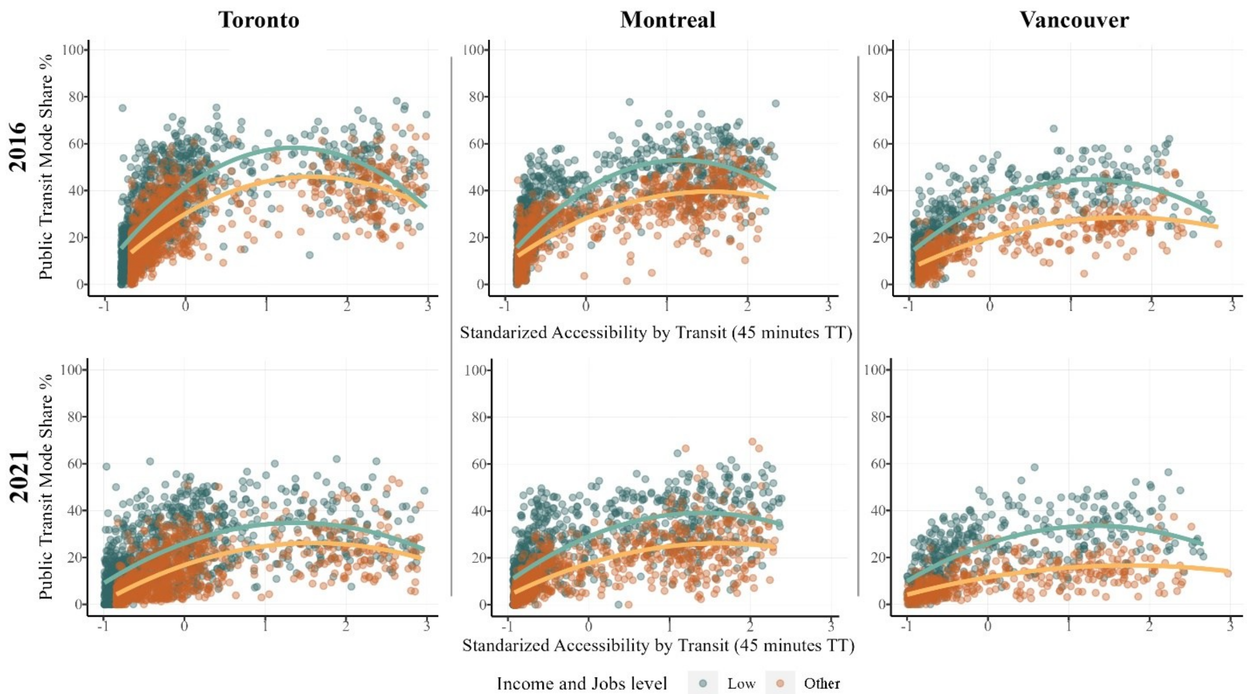

Figure 3.2 Scatter plots for PT mode share and standardized accessibility for low and other-income groups in Toronto, Montréal, and Vancouver in 2016 and 2021.

3.7.4 Statistical model and discussion

Regression results for the three CMAs, Toronto, Montréal, and Vancouver, are presented in **Table 3.2**, **Table 3.3**, and **Table 3.4**, respectively. For every region, there are four distinct models for each year and income group with the census tract (CT) serving as the unit of analysis. The dependent variable for these regressions is the percentage of PT mode share. The R-squared values range from 0.61 to 0.72 in 2016 and from 0.50 to 0.61 in 2021. External influences and control variables related to COVID-19 that were less significant in 2016 could be impacting the goodness-of-fit of the models in 2021.

The values we used for accessibility were the percentages of accessible jobs for each income group rather than the absolute number of accessible jobs to enable comparisons across regions, income groups, and years. For example, accessing 100,000 jobs could mean a high level of accessibility in a region with a small total number of jobs, it could also mean a low level of accessibility in a region with a much higher total number of jobs. Dividing this absolute value of 100,000 by the total number of jobs in the region provides a more meaningful scale for assessment and comparison between regions. Proportional measures are also important for comparison between years. In the case of our research, improving accessibility by 1% in 2016 would mean increasing the absolute number of accessible jobs by a larger value compared to 2021, as the denominator (total number of jobs) is larger in 2016 than in 2021 due to the working from home policies implemented at the time of the data collection. In all the models, there is a statistically significant positive association between accessibility and PT mode share, but at different levels. The accessibility squared term in the models shows a negative impact on PT mode share, keeping all else constant. This finding aligns with the observations from **Figure 3.2**, where the mode share increases with accessibility up to a certain threshold, after which the relationship becomes reversed. The decline in PT mode share at higher accessibility areas could be explained by a greater prevalence of active modes of travel in these areas around the regions' city centers.

Considering the quadratic relationship between the percentage of accessibility and PT mode share, it is important to note that the starting point from which accessibility is increased would have different effects on PT mode share. Increasing accessibility from 1 to 2% would not have the same impact as increasing it from 7 to 8% although both are an increase of 1%. For example, we take the low-income group in Toronto in 2021 and solve the quadratic equation by inserting the mean values for the constants. We find that the maximum value of accessibility that would give out the highest mode share is when 4.46% of the total number of jobs in the region is accessible by PT. This translates to access to 62,000 low-income jobs in Toronto, provided that the total number of jobs remains unchanged. At this point, the PT mode share would become 31.5%. In other words, the accessibility target that needs to be set to achieve the maximum possible ridership among low-income individuals in Toronto in the post-pandemic time is 62,000 jobs reachable by PT in 45 minutes in travel time. While this value can be specific for a point in time (2021) when working from home was generally on the high end, it can be used as a directive for later periods when including the knowledge about the changes in WFH. Such numbers can help PT authorities in understanding the consequences of service cuts or changes on ridership.

A comparison between 2016 to 2021 across all regions indicates that the coefficients for accessibility have decreased for both income groups, with a larger drop for low-income groups. This decline signifies that the role of accessibility in promoting PT use has become less impactful in 2021. For example, concerning the low-income group in Toronto, a 1% increase in accessibility around the mean (from 1.6% to 2.6%) would increase the PT mode share by 16.4% in 2016 but only 8.2% in 2021, keeping all else constant. This represents an 8.2% decrease in the impact of improving accessibility by 1% on PT mode share for the low-income. A similar trend is observed in Montréal and Vancouver, with decreases of approximately 3.6% and 1.8%, respectively, for the low-income group. It is important to stress that to increase the percentage of accessibility, increasing the number of accessible jobs would not be sufficient if it is evened out by the increase in the total jobs in the region. In other words, planning for accessibility needs to be more ambitious in terms of targets to achieve the targeted rebound in ridership and increase it as outlined in transport plans especially for low-income groups.

For the other-income groups, the change in accessibility impact on PT mode share between 2016 and 2021 is not as remarkable as for the lower-income groups. To start with, accessibility already had a much smaller impact on PT mode share for this group in 2016. For example, in Montréal, increasing accessibility to low-income jobs by 1% would result in a 7.42% increase in PT mode share while the same increase for other-income jobs would lead to only 1.56%, ceteris paribus. Comparing this figure to 2021, we find that increasing accessibility to other-income jobs would increase PT mode share by 1.52%, only 0.04% less than in 2016. A similar pattern is observed in Toronto and Vancouver, with 0.48 and 0.29 differences, respectively, between the coefficients of accessibility for the other-income jobs in 2016 and 2021. This analysis indicates that the influence of accessibility on PT mode share for other-income groups has remained relatively stable or has experienced only marginal changes between 2016 to 2021, while the impact on lower-income groups is more pronounced. In other words, planning to increase accessibility in other income areas will not return as many ridership as it will in low-income areas in 2021. Nevertheless, low-income areas became less receptive to accessibility changes and require higher accessibility targets to achieve the same levels of ridership increase that they could have achieved with lower accessibility changes in 2016.

Another spatial factor that was considered in the analysis is the distance to the closest rapid transit station which was used as a proxy for the availability of high-quality transit in CTs. As discussed by Cui et al. (2020) in 2021 and aligning with the findings of Cervero et al. (2010), the distances remained negatively associated with the PT mode share for all three regions and the two income groups in 2021. There were only marginal changes in the coefficients between 2016 and 2021. However, in both 2016 and 2021, the low-income groups' PT mode share is more negatively impacted by the increase in the distance to stations. In other words, CTs far away from rapid transit use PT less in general in both time periods at the same rates.

The control variables used in the models include the average age and household size of the CT population. In Toronto, a one-year increase in average age would decrease PT mode share by about 0.3% for the low-income in 2016, and by 0.66% and 0.31% for the low- and other-income workers respectively in 2021, all else equal. This aligns with previous findings that public transit use tends to decline with increasing age (Brown et al., 2016; Newbold & Scott, 2018). Vancouver has a similar pattern of decreased PT ridership with the advancement of age and more so for low-income workers. While this pattern is similar for Montréal in 2021, the results suggest a reversed effect in 2016 where a one-year advancement in age for the lower-income group increases their PT usage by 0.32%. This result requires further investigation as previous research in Montréal suggests that aging has a negative impact on PT usage; however, it had not considered the impact of income (Fordham et al., 2017).

The effect of average household size is different for each region, income group, and year. The general notion is that the larger the household size average in a CT, the less PT ridership, except for the low income in 2016 Montréal. In Toronto, the negative impact of a growing household on PT mode share has increased in 2021 for both income groups. In Vancouver, this impact has decreased for the other income in 2021. The impact remained negative in the way that the growth of household size average by one person would decrease PT mode share by 3.19 %, while it would have decreased the mode share by 4.93% in 2016, ceteris paribus. In Montréal, the PT mode share increases with a growing low-income household size in 2016 but this effect is reversed in 2021. This phenomenon can be explained by many factors including the different travel needs for children and older adults in a household and would require further investigations for Montréal in 2021. The WFH coefficients suggest that the increase in the percentage of WFH employees in the CT decreases the percentage of employees commuting by transit across all income groups and over time. This impact is stronger for low-income groups than other-income ones in both 2016 and 2021, which suggests that telecommuting replaces more PT trips for low-income groups than other-income ones. Due to the limitation imposed by the lack of census data that describe the number of workers from home in each income group, it is difficult to fully examine the impact of telecommuting on mode share using the available dataset.

Table 3.2 Toronto PT mode share percentage regression model

	2016				2021			
	Low-income		Other-income		Low-income		Other-income	
Predictors	*Coef.*	*95% CI*	*Coef.*	*95% CI*	*Coef.*	*95% CI*	*Coef.*	*95% CI*
(Intercept)	**55.07** ***	43.39 – 66.75	**36.16** ***	27.02 – 45.30	**79.36** ***	67.32 – 91.39	**42.08** ***	33.57 – 50.60
Accessibility measures								
Access. to below 30k jobs (%)	**16.46** ***	15.07 – 17.85						
Accessibility^2 (%^{2})	**-1.99** ***	-2.19 – -1.78						
Access. to above 30k jobs (%)			**3.40** ***	3.00 – 3.80				
Accessibility^2 (%^{2})			**-0.13** ***	-0.15 – -0.11				
Access.to below 40k jobs (%)					**8.22** ***	6.97 – 9.46		
Accessibility^2 (%^{2})					**-0.92** ***	-1.11 – -0.72		
Access.to above 40k jobs (%)							**2.92** ***	2.52 – 3.32
Accessibility^2 (%^{2})							**-0.14** ***	-0.17 – -0.11
Built environment								
Population density (1000/km^2)	0.08	-0.05 – 0.21	**0.34** ***	0.24 – 0.44	0.07	-0.03 – 0.18	**0.23** ***	0.16 – 0.30
Distance to Station (km)	**-0.48** ***	-0.63 – -0.34	**-0.52** ***	-0.63 – -0.42	**-0.50** ***	-0.63 – -0.36	**-0.27** ***	-0.36 – -0.18
CT Population characteristics								
Work from home %	**-0.97** ***	-1.15 – -0.80	**-0.34** ***	-0.48 – -0.20	**-0.43** ***	-0.49 – -0.37	**-0.24** ***	-0.28 – -0.20
Age (avg.)	**-0.30** **	-0.50 – -0.10	-0.11	-0.27 – 0.04	**-0.66** ***	-0.86 – -0.46	**-0.31** ***	-0.45 – -0.17
Household size (avg.)	**-5.52** ***	-7.13 – -3.92	**-4.34** ***	-5.59 – -3.09	**-8.30** ***	-9.87 – -6.74	**-5.23** ***	-6.34 – -4.13
Observations	1139		1139		982		982	
R^2 / R^2 adjusted	0.614 / 0.612		0.613 / 0.611		0.501 / 0.498		0.557 / 0.554	

* p<0.05   ** p<0.01   *** p<0.001

Table 3.3 Montréal PT mode share percentage regression model

	2016				2021			
	Low-income		Other-income		Low-income		Other-income	
Predictors	*Coef.*	*95% CI*	*Coef.*	*95% CI*	*Coef.*	*95% CI*	*Coef.*	*95% CI*
(Intercept)	6.31	-5.25 – 17.86	**22.16** ***	13.68 – 30.65	**59.62** ***	47.32 – 71.92	**36.61** ***	27.10 – 46.11
Accessibility measures								
Access. to below 30k jobs (%)	**7.42** ***	6.65 – 8.20						
Accessibility^2 (%^{2})	**-0.44** ***	-0.50 – -0.37						
Access. to above 30k jobs (%)			**1.56** ***	1.34 – 1.77				
Accessibility^2 (%^{2})			**-0.03** ***	-0.04 – -0.02				
Access.to below 40k jobs (%)					**3.74** ***	2.99 – 4.50		
Accessibility^2 (%^{2})					**-0.17** ***	-0.22 – -0.11		
Access.to above 40k jobs (%)							**1.52** ***	1.21 – 1.83
Accessibility^2 (%^{2})							**-0.03** ***	-0.05 – -0.02
Built environment								
Population density (1000/km^2)	**0.44** ***	0.26 – 0.63	**0.47** ***	0.34 – 0.61	**0.39** ***	0.22 – 0.57	**0.21** **	0.08 – 0.34
Distance to Rapid Transit Station (km)	**-0.66** ***	-0.78 – -0.53	**-0.44** ***	-0.53 – -0.35	**-0.67** ***	-0.82 – -0.52	**-0.31** ***	-0.43 – -0.20
Population characteristics								
Work from home %	**-1.11** ***	-1.33 – -0.89	**-0.76** ***	-0.92 – -0.59	**-0.40** ***	-0.48 – -0.33	**-0.23** ***	-0.29 – -0.17
Age (avg.)	**0.32** ***	0.14 – 0.49	-0.02	-0.15 – 0.11	**-0.49** ***	-0.68 – -0.30	**-0.30** ***	-0.45 – -0.15
Household size (avg.)	**3.09** *	0.74 – 5.43	-0.83	-2.56 – 0.90	**-5.75** ***	-8.12 – -3.39	**-4.76** ***	-6.60 – -2.92
Observations	944		944		817		817	
R^2 / R^2 adjusted	0.724 / 0.722		0.745 / 0.743		0.618 / 0.614		0.597 / 0.593	

* p<0.05   ** p<0.01   *** p<0.001

Table 3.4 Vancouver PT mode share percentage regression model

	2016				2021			
	Low-income		Other-income		Low-income		Other-income	
Predictors	*Coef.*	*95% CI*	*Coef.*	*95% CI*	*Coef.*	*95% CI*	*Coef.*	*95% CI*
(Intercept)	**40.55** ***	27.66 – 53.43	**37.57** ***	28.55 – 46.58	**44.09** ***	29.94 – 58.24	**26.99** ***	18.50 – 35.48
Accessibility measures								
Access. to below 30k jobs (%)	**5.91** ***	5.12 – 6.70						
Accessibility^2 (%^{2})	**-0.34** ***	-0.41 – -0.28						
Access. to above 30k jobs (%)			**1.17** ***	0.94 – 1.41				
Accessibility^2 (%^{2})			**-0.03** ***	-0.03 – -0.02				
Access.to below 40k jobs (%)					**4.11** ***	3.37 – 4.84		
Accessibility^2 (%^{2})					**-0.19** ***	-0.24 – -0.14		
Access.to above 40k jobs (%)							**0.88** ***	0.65 – 1.12
Accessibility^2 (%^{2})							**-0.02** ***	-0.03 – -0.01
Built environment								
Population density (1000/km^2)	**-0.31** **	-0.52 – -0.09	0.02	-0.13 – 0.16	0.02	-0.17 – 0.20	0.08	-0.03 – 0.19
Distance to Rapid Transit Station (km)	**-0.54** ***	-0.71 – -0.36	**-0.38** ***	-0.50 – -0.27	**-0.51** ***	-0.70 – -0.32	**-0.28** ***	-0.39 – -0.16
CT Population characteristics								
Work from home %	**-0.24** *	-0.43 – -0.05	**-0.36** ***	-0.49 – -0.23	**-0.37** ***	-0.47 – -0.27	**-0.20** ***	-0.26 – -0.14
Age (avg.)	**-0.29** *	-0.52 – -0.06	**-0.19** *	-0.36 – -0.03	**-0.37** **	-0.60 – -0.15	**-0.18** *	-0.32 – -0.04
Household size (avg.)	-1.86	-3.75 – 0.02	**-4.93** ***	-6.25 – -3.61	**-2.45** *	-4.56 – -0.33	**-3.19** ***	-4.47 – -1.92
Observations	463		463		465		465	
R^2 / R^2 adjusted	0.665 / 0.660		0.694 / 0.689		0.565 / 0.559		0.517 / 0.510	

* p<0.05 ** p<0.01 *** p<0.001

3.8 Conclusion

Our research investigated the changing impacts of accessibility on PT mode share at the CT level of analysis for low- and other-income workers in the three largest metropolitan regions in Canada: Toronto, Montréal, and Vancouver. Using 2016 and 2021 census data, we find that there are major differences in the effect of accessibility on PT mode share pre- and post-pandemic. Our findings indicate that in 2021, low-income groups still use PT at a higher rate than other-income groups, as found in previous research (Cui et al., 2020; Giuliano, 2005). Increasing accessibility to jobs by PT remains to have a positive influence on PT mode share (Moniruzzaman & Páez, 2012; Owen & Levinson, 2015). However, the strong impact that was observed in 2016 has significantly decreased in 2021. For the low-income groups, that impact has declined by approximately 50% in Toronto and Montréal and by 30% in Vancouver. As the relationship between accessibility and PT mode share is quadratic (Cui & El-Geneidy, 2019), increasing accessibility is only useful until a certain threshold that needs to be carefully calculated before it starts becoming ineffective.

As PT agencies around the world try to attract the users back and balance their budgets through changes in service, service cuts (decrease in accessibility) would have a statistically significant negative impact on PT ridership. Service additions in 2021 will need to be more assertive, as the change in accessibility that was targeted in 2016 will not lead to the same increase in 2021 especially among low-income users, who are the core riders. Other income groups are still impacted by accessibility in 2021 like 2016, yet the impact is much lower when compared to the impacts of the same change in accessibility on low-income groups. We found that telecommuting is more likely to be replacing transit trips for low-income groups than other groups. It is important to note that while the magnitude of the impact of telecommuting has decreased, the average percentage of telecommuting has increased in all regions. Such coefficients need to be interpreted with the changes in the mean values in mind due to the magnitude of the output on PT mode share. Similar to 2016, the general trend is that the increase in average age and household size has a negative impact on the PT mode share. However, the extent of this impact varies among different income groups.

Achieving higher ridership through accessibility-focused planning has become more challenging due to the pandemic's repercussions. Increased efforts are needed in transport planning, land-use zoning, and jobs distribution to achieve the mode share targets of each region that were set prior to the pandemic. As the recovery process continues, it becomes essential to develop adaptive transport strategies that address the evolving needs of various communities to promote equity and provide services to those in need the most. This paper has shown that targeting low-income areas with accessibility increase in the post pandemic era will lead to higher return on such investments compared to investing these services in other-income areas. Yet, it is important to note that planning for accessibility in 2021 requires to be more assertive to achieve the planned PT mode shares as the accessibility impacts in 2021 are lower than the ones from 2016. Future research can follow a different modeling approach to control for spatial and temporal effects through utilizing more detailed datasets for each region, including comprehensive information about travel behavior of the inhabitants and not limited to commute only.

Chapter 4. Subjectivity matters: Investigating the relationship between perceived accessibility and travel behaviour

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Chapter 4

Subjectivity matters: Investigating the relationship between perceived accessibility and travel behaviour

4.1 Chapter positioning

This chapter addresses the third dissertation objective by examining how perceived accessibility influences travel behaviour in the post-pandemic era. While the previous chapter confirms the impact of calculated accessibility on travel behaviour, calculated measures of accessibility do not account for individuals' experiences and perceptions, which play a pivotal role in travel behaviour (Morris et al., 1979). The relationship between perceived accessibility and travel behaviour is a key component of the conceptual framework in **Figure 2.2**, representing a novel and rarely examined connection (Mehdizadeh & Kroesen, 2025; Pot et al., 2021). This chapter investigates this relationship while accounting for calculated accessibility, residential selection, travel identity, and individual characteristics. It focuses on the impact of perceived accessibility at local and regional levels on weekly mode shares for walking and public transit, respectively. By investigating both perceived and calculated accessibility, this chapter provides valuable insights for promoting sustainable travel modes.

4.2 Abstract

Accessibility, the ease of reaching destinations, encompass local and regional metrics used to evaluate the performance of the land use and transport systems in a region. These measures are known to impact individuals' travel behaviour, which led to their adoption in practice as performance indicators to evaluate transport projects and plans, monitor progress towards equity goals, and evaluate changes induced by various policies. However, calculated measures of accessibility do not account for individuals' experiences and perceptions, which play a pivotal role in travel behaviour. This research examines the relationship between travel behaviour and perceived accessibility, while accounting for calculated accessibility, residential selection, travel identity, and individual characteristics. Using data from a large-scale bilingual online survey administered in Montréal, Canada in Fall 2023 (N=5,277), we perform statistical analyses at both local and regional levels to model weekly mode shares for walking and public transit, respectively. Calculated accessibility is accounted for locally using Walk Score® and regionally using cumulative opportunities accessibility measures by public transit. Our findings reveal that perceived accessibility by walking and public transit positively impact the weekly walking and transit mode share, respectively, for all purposes. Accounting for calculated accessibility and travel identity is important to avoid overestimating the influence of perceived accessibility on travel behaviour. This research provides transport professionals a nuanced understanding of the link between accessibility (perceived and calculated) and travel behaviour, offering insights for promoting the use of sustainable travel modes.

4.3 Introduction

In recent years, there has been a significant shift in the transport planning field, transitioning its focus from emphasizing the mere movement of people (mobility) to prioritizing the ease of reaching destinations (accessibility) as a key performance measure (Handy, 2023). Accessibility is the most comprehensive measure that links land use and transport systems, offering a multi-dimensional evaluation of their performance (El-Geneidy & Levinson, 2022; Levinson & Wu, 2020; Wachs & Kumagai, 1973). It is often used to explain the equity impacts of urban policies and projects (Deboosere & El-Geneidy, 2018; Foth et al., 2013; Geurs et al., 2016). Calculated measures of accessibility can be generated at the regional or local scales. Regional scales usually concentrate on accessibility by public transit or car, while local accessibility concentrates on accessibility by walking or cycling. Calculated measures of accessibility are one of the important determinants of mode choice. For example, areas with higher levels of regional accessibility by public transit were found to have higher public transit mode share (Cui et al., 2020; Moniruzzaman & Páez, 2012; Negm & El-Geneidy, 2024; Owen & Levinson, 2015), while areas with higher levels of local accessibility by walking (walkability) experience higher pedestrian activities (Cervero, 2002; Lin et al., 2017; Manaugh & El-Geneidy, 2011; Zuniga-Teran et al., 2017).

Despite accessibility's increasing prominence as a planning tool, we still do not fully understand how it is perceived and experienced by individuals and how these perceptions can affect their choices and subjective well-being (Lionjanga & Venter, 2018; Reardon et al., 2019; van Wee & Geurs, 2011). Discrepancies between the effects of calculated and perceived accessibility may hinder the anticipated outcomes of efforts aimed at improving accessibility levels to influence travel behaviour. For instance, people living in areas with high levels of measured accessibility might still perceive challenges in reaching their desired destinations with a certain mode due to social differences (Curl, 2018) and travel attitudes. Recent research has been calling for more nuanced studies linking perceived accessibility to travel behaviour (De Vos et al., 2023; Pot et al., 2021), as the relationship between these concepts remains understudied with only few studies briefly exploring the topic (Andersson et al., 2023; Lättman et al., 2020; Mehdizadeh & Kroesen, 2025; Tanimoto & Hanibuchi, 2021; Vafeiadis & Elldér, 2024a).

This study contributes to the literature by investigating the relationship between perceived accessibility and weekly travel behaviour, while accounting for calculated accessibility, residential selection, travel identity, and individual characteristics. We use data from Wave 4 (Fall 2023) of the Montréal Mobility Survey (MMS), a bilingual longitudinal travel survey conducted yearly by the Transportation Research at McGill group in Montréal, Canada (Negm et al., 2023). This survey wave collected data on participants' self-reported perceived accessibility, weekly travel behaviour, travel identity, residential selection, and socioeconomic characteristics. Retrieved Walk Score® and calculated regional accessibility measures for public transit were linked to the survey data to represent calculated accessibility measures. We conduct a series of weighted linear regression models using a stepwise approach with weekly walking and public transit mode shares as the determinants of travel behaviour on the local (N=4,679) and regional (N=2,985) levels, respectively, controlling for confounding factors to reveal the impact of perceived accessibility on travel behaviour. As accessibility gains more prominence in transport planning, understanding how its perception impacts travel behaviour is vital. This insight enables transport professionals to effectively allocate resources, whether by increasing calculated accessibility through built environment improvements or by enhancing perceived accessibility through campaigns that help individuals recognize the actual quality of the transport system within their reach.

4.4 Theoretical background

4.4.1 Calculated and perceived accessibility

Local accessibility presents the amount and variety of amenities accessible in a neighborhood through active travel modes (i.e., walking and cycling) (Forsyth & Krizek, 2010). In recent years, local accessibility has been gaining more interest in research and practice, especially in the ideas of the x-minute city (Logan et al., 2022; Lu & Diab, 2023). Local accessibility sometimes referred to as walkability is known to impact travel behaviour (Ewing & Handy, 2009; Lo, 2009; Maghelal & Capp, 2011). For instance, Manaugh and El-Geneidy (2011) found that walkability indices are highly correlated with walking trips for non-work trip purposes. They found that each of the different indices have strength explaining the variation in walking trips to specific destinations with Walk Score® (walkscore.com) being a reliable measure for walkability. Elldér et al. (2020) argue that while the increase in active travel is associated with increased local access, this relationship is not necessarily linear and it depends on the geographical context, which is similar to other studies finding that the built environment-travel behaviour relationship is often non-linear (Cui et al., 2020; Ding et al., 2021; Hatami et al., 2023). Research on perceived walkability showed prominent links to well-being and walking behaviour (De Vos et al., 2023; van der Vlugt et al., 2022; Van Dyck et al., 2013).

Regional accessibility is one of the most inclusive measures linking land use to transport systems to assess how they benefit the population in reaching opportunities around them (El-Geneidy & Levinson, 2022; Levinson & Wu, 2020). Regional measures of accessibility can be generated for a specific mode of transport at a specific time of day (Geurs & van Wee, 2004). Several methods are used to measure regional accessibility, among which two are the most used in practice: cumulative opportunities and gravity-based measures (Boisjoly & El-Geneidy, 2017a, 2017b). The cumulative opportunities measure is one of the most commonly used, due to its ease of interpretation and communication to the public and policymakers (El-Geneidy & Levinson, 2022). In this measure of accessibility, all the opportunities (destinations) available within a predefined travel time (TT) threshold are weighted equally (Geurs & van Eck, 2001). Meanwhile, gravity-based accessibility weighs opportunities based on the TT necessary to reach them. This method allows for the inclusion of opportunities that could be discarded in the cumulative measures if they are not within the set time threshold. While this measure improves the approximation to reality, it requires an extensive amount of additional data and is more challenging to compute, interpret, and communicate to policymakers and the public. Comparison between cumulative opportunities and gravity-based measures found a high correlation between the two measures in the North American context (Giannotti et al., 2021;

Kapatsila, Palacios, et al., 2023; Palacios & El-Geneidy, 2022), suggesting that using cumulative opportunities is sufficient to represent the built environment adequately.

While many studies focused on the calculated side of local and regional accessibility, only a few have studied the notion of perceived accessibility, especially at the regional scale (Pot et al., 2021; Ryan & Pereira, 2021; van Wee, 2016). The Perceived Accessibility Scale (PAC), developed by Lättman, Olsson, et al. (2016), has been lately used as one of the tools to study perceived accessibility by public transport (Al-Rashid et al., 2021; Al-Rashid et al., 2023; Sheng & Zhang, 2022; Watthanaklang et al., 2024) and by the main mode of travel in general (Lättman et al., 2020; Lättman et al., 2018; Pot et al., 2024; Pot et al., 2023a, 2023b; Sukhov et al., 2023; Warner et al., 2021; Wolday & Böcker, 2023). This scale consists of four self-reported questions that attempt to capture key aspects of subjective accessibility based on previous literature; however, it includes overarching notions such as life satisfaction and assumes equal weights between the four statements which can render some interpretations to be inaccurate. Other studies utilized a more focused approach to measuring perceived accessibility depending on statements about ease of performing specific trips with specific modes rated on a Likert-scale (Vafeiadis, 2024; Vafeiadis & Elldér, 2024a).

While the existing literature examined the connection between perceived accessibility and several factors such as public transit service quality (Sukhov et al., 2023; Watthanaklang et al., 2024), social exclusion and life quality (Al-Rashid et al., 2023; Andersson et al., 2023), activity participation (Al-Rashid et al., 2021; Pot et al., 2024), and behavioural intentions (Sheng & Zhang, 2022); few studies explored the possible connection between perceived accessibility and travel behaviour (Andersson et al., 2023; Lättman et al., 2020; Mehdizadeh & Kroesen, 2025; Tanimoto & Hanibuchi, 2021; Vafeiadis & Elldér, 2024a).

Lättman et al. (2020) and Tanimoto and Hanibuchi (2021) evaluated the perceived accessibility (PAC) of car users under hypothetical driving restrictions, finding that their perceived accessibility would significantly decrease. However, the results from these studies are inconclusive as they relied on hypothetical scenarios rather than using panel data from the same users. Vafeiadis and Elldér (2024a) found that frequent car users have high levels of perceived accessibility by car and low levels by all other modes. While Mehdizadeh and Kroesen (2025) suggest that travel behaviour has a larger impact on perceived accessibility than the reverse effect, they use a measure for perceived accessibility that focuses on accessibility to the participants' neighborhoods rather than from the neighborhoods to the participants' desired destinations. This measure does not align with the conventional definition of accessibility that focuses on the ease of reaching destinations (Levinson & Wu, 2020; Wachs & Kumagai, 1973). This approach could overlook aspects of how travel behaviour is influenced by the range of destinations that individuals seek to access by certain travel modes.

Some studies investigated the (mis)match between calculated and perceived accessibility. Pot et al. (2023a, 2023b) found that perceived accessibility by the main mode of travel tends to be more evenly distributed than calculated accessibility at rural, urban, and national levels, highlighting a general discrepancy between the two measures. Pot et al. (2021) and Vafeiadis (2024) stress the importance of measurement as inaccuracies can be a potential cause of the differences between perceived and calculated measures of accessibility. At the local scale, more studies explored perceived accessibility and found that it mainly in line with the calculated one (Arvidsson et al., 2012; Gebel et al., 2009; Van Dyck et al., 2013) and that it has a positive impact on walking behaviour (Hinckson et al., 2017; Solbraa et al., 2018).

Recently, studies by Pot et al. (2021) and De Vos et al. (2023) produced generalized conceptual frameworks that link perceived and calculated accessibility. However, these frameworks were not practically validated. While calculated accessibility has been continuously discussed and measured in the transport literature (Handy, 2023; Hansen, 1959), perceived accessibility is a newer term that researchers are still trying to understand (Pot et al., 2021; Vafeiadis, 2024), measure (Lättman et al., 2018; Vafeiadis & Elldér, 2024a), and link to behaviour (Pot et al., 2023a, 2023b; Vafeiadis & Elldér, 2024a).

4.4.2 Mode choice determinants

To make a specific trip, an individual usually weighs their options through a matrix of objective and subjective determinants to select the mode they would use based on their personal characteristics (Panter & Jones, 2010; Scheiner & Holz-Rau, 2007). On the personal characteristics side, determinants of mode choice encompass age, gender, income, and household attributes (Patterson et al., 2005; Scheiner, 2014). The literature has consistently shown that gender and age are among the determinants of mode choice (Ha et al., 2020; Legrain, Eluru, et al., 2015). Income and car ownership are among the household characteristics that influence travel behaviour the most (Buehler, 2011). Lower-income individuals are also shown to react differently to varying levels of objective measures compared to those with higher incomes (Cui et al., 2020).

Among the objective determinants are spatial and temporal considerations. Spatial factors such as density, land use distribution, and the availability of a certain mode play a significant role in favouring one mode over the other (Cervero, 2002; Lin et al., 2017). Temporal factors include the flexibility in the time of departure and the travel time, which are major determinants of mode choices (Scheiner & Holz-Rau, 2007). Limited transport options at the time of travel often lead travelers to use certain modes despite their higher level of inconvenience because alternatives do not exist (Manaugh & El-Geneidy, 2011). These spatial and temporal considerations can be combined in one calculated measure, accessibility, which is one of the major determinants of mode choice (Moniruzzaman & Páez, 2012; Negm & El-Geneidy, 2024; Owen & Levinson, 2015; Ton et al., 2020).

Subjective measures encompass travel attitudes and preferences, including residential self-selection (Cao et al., 2009; Handy et al., 2005; Kamruzzaman et al., 2015; Parkany et al., 2004). Attitudes and preferences mainly stem from personal beliefs (Mann & Abraham, 2012) and habits (Verplanken & Orbell, 2003). They represent the degree to which a person would favour a mode over another because they link it to some positive aspect in their life (De Vos et al., 2022). There is a constant debate in the literature on whether travel attitude influences behaviour or vice-versa. Kroesen et al. (2017) argue that they both mutually influence each other over time but that behaviour influences attitudes more. Based on the theory of cognitive dissonance (Festinger, 1957), people are likely to change their attitudes or behaviours to align with each other (McCarthy et al., 2023). Among the factors that can be classified under travel attitudes is the perception of the possible benefits and challenges of using a specific mode. Studies showed that the perception of challenges negatively impacts a certain mode choice (Ball et al., 2007; Titze et al., 2008). Many studies focused on the perception of public transit quality (Gilbert & Foerster, 1977; Habib et al., 2011; Zhao et al., 2013) and how positive perception increases transit use. The link between perceived accessibility by different modes and travel behaviour remains underexplored. This research will expand on the studies that address the perception of accessibility in their attempt to fill the gap in the literature by developing a better understanding of this notion and applying it in transport planning to encourage the use of sustainable modes.

4.5 Data and methods

This research focuses on investigating perceived accessibility and its impacts on travel behaviour in Montréal, Canada at the local and regional scales. Spatial census data from Statistics Canada is utilized with the MMS survey data to achieve this goal. Spatial data is mainly used to generate regional calculated accessibility measures while survey data is used to gather perceived accessibility measures and travel behaviour. Local accessibility is concerned with the neighborhood-scale level where individuals can reach their destinations using non-motorized modes. For this scale, we focus on walking as it is a generally more accessible mode to travel than bicycles. Meanwhile, regional accessibility is considered at the city-scale level, allowing the comparison between the number of potential opportunities for interaction between different areas of the city. We define these areas as the Census Tracts (CT). To be able to move between the CTs in a reasonable amount of time, individuals would need to use travel modes that cover long distances quickly (i.e., car and public transit).

4.5.1 Spatial data

Local accessibility was accounted for using Walk Score®, an indicator that uses a decay function to evaluate access to various amenities (dining and drink, groceries, parks, schools, shopping, culture and entertainment, and errands) within a 30-minutes walk of a certain location (Walk Score, 2024). The index is linearly expressed on a range from 0 (car dependent) to 100 (walker's paradise). It is often used in the transport literature as an indicator of the density of the built environment and the utilitarian walking potential (Hall & Ram, 2018) and has been validated in the past (Manaugh & El-Geneidy, 2011). Using an API, we retrieved Walk Score® for each participant based on their home location in December 2023.

For regional accessibility, Canadian population census and commuting flows (CCF) (Statistics Canada, 2017, 2023a) is used to identify the number of jobs present in each CT in the Montréal metropolitan region. The number of jobs in an area is often used in the accessibility literature as a proxy for the quantity and diversity of services and products that the area offers (El-Geneidy & Levinson, 2022); thus, representing the different opportunities that individuals seek to reach. The latest polygon shapefiles for Montréal's CTs were retrieved from the 2021 Canadian population census. The centroid for each polygon was then calculated to be used as a reference point for the CT. In some instances, the centroids would fall into inaccessible areas, such as water, mountains, or agricultural land. These centroids were then manually moved to the closest dense area in their corresponding CTs. The CCF tables provide the number of workers commuting between their home and work CTs. In 2021, numerous jobs relied entirely on telecommuting due to the COVID-19 pandemic, which may not accurately reflect the most recent circumstances. We determined that utilizing the 2016 CCF tables would provide a more representative depiction of the current situation, as many areas restored pre-pandemic activity even though telecommuting has become more ubiquitous (Anik & Habib, 2023; Javadinasr et al., 2022). The 2016 jobs (commuters arriving in the CT) were then proportionally fitted to the 2021 CT since some 2016 CTs were subdivided into multiple CTs in 2021.

The regional accessibility by public transit to jobs at the CT level was calculated using the number of jobs per CT, General Transit Feed Specification (GTFS) data, and OpenStreetMap networks. GTFS data was obtained from Transitland using an application programming interface (API) for October 2023, to match the public transit services at the time of collecting the MMS. The OpenStreetMap street network was obtained for the Montréal Census Metropolitan Region (CMA) through BBBike extracts. We used the r5r package in R with GTFS data and the OSM network for the Montréal CMA as inputs to calculate a travel time matrix (TTM) between CT centroids for every minute in a predefined period of the day (Pereira et al., 2021). This TTM represents the shortest travel time (TT) by public transit between each origin and destination (CTs) for a regular Wednesday travelling at any minute between 8 AM and 9 am, which is then averaged to account for schedule variability. The calculated TT includes access, egress, waiting, in-vehicle, and transfer times if applicable. To calculate the cumulative opportunities measure, the travel-time threshold was set to 45 minutes as it is closest to the mean TT by public transit in Montréal (Statistics Canada, 2023b) as suggested by Kapatsila, Palacios, et al. (2023).

4.5.2 Survey data

MMS is a bilingual longitudinal online survey that collects travel behaviour data as well as opinions on major transport projects in the region (Negm et al., 2023). Across four waves, the MMS has collected data about sociodemographic characteristics, attitudes towards transit, current and past travel behaviour, and residential self-selection. In this study, we use the fourth wave of the survey, which was conducted in October 2023. Any incomplete responses were dropped, and a thorough validation process enforced a set of exclusion criteria to eliminate unreliable responses. This process used participants' e-mail and IP addresses, the time they took to fill out the survey, the location pins or addresses they indicated for home, work and/or school, household structure, and age and height data for participants who filled out previous waves of the MMS. The fourth wave's recruitment resulted in a total of 5,277 complete and valid responses.

To link spatial data with survey data, calculated local accessibility (Walk Score®) was linked to each participant based on their postal code. Calculated regional accessibility by public transit was linked to the survey for each participant through the CT of their home location. Among the travel behaviour variables, the MMS asked the participants the number of trips they performed per week for work, school, shopping, healthcare, and leisure and which travel mode they used for these trips. There were four main travel mode categories: car, transit, walking, and cycling. To account for travel identity, participants were asked to identify the travel mode they associate themselves with. They were provided with the option to choose multiple modes (e.g., I consider myself as both a driver and a pedestrian). Finally, for perceived accessibility, participants were asked to evaluate the statement "(Travel Mode) is a suitable mode of travel for me to reach my desired destinations" on a 4-point Likert scale from strongly agree to strongly disagree. Walking is used as the travel mode for the local scale analysis, while public transit is the mode used for the regional scale analysis.

For both local and regional analysis, we only maintained participants whose weekly trip count fell within the range of four to thirty trips as we consider them mobile individuals for whom we can reliably calculate mode share percentages. For the regional scale analysis, we performed two additional inclusion criteria. Firstly, we included only participants who performed at least 50% of their trips by car and/or transit. Secondly, we excluded those who identified only as pedestrians or cyclists as they are more concerned with local accessibility. In other words, participants can identify as pedestrians, but they must also identify as car and/or transit users to be considered in the analysis as those interested in regional accessibility. This filtering resulted in a final sample of 4,679 participants for the local level analysis and 2,985 participants for the regional level analysis.

4.5.3 Methods

The analysis in our study aims to examine the relationship between perceived accessibility and travel behaviour at the local and regional scale. We first conduct an exploratory analysis through scatterplots to visualize the relationship between calculated accessibility, perceived accessibility, and travel behaviour. We then investigate this relationship by estimating multiple linear weighted regressions at the local and regional scales to predict travel behaviour. To represent travel behaviour, we use the percentage of walking trips for weekly activities for the analysis at the local scale, whereas we use the percentage of public transit use for the analysis at the regional scale. The use of weighted regressions accounts for any sampling bias in the survey. The weighting is calculated for all valid responses using the anesrake R package (Pasek, 2018), which follows an iterative ranking process (DeBell & Krosnick, 2009). The weights were calculated to match the census-tract information of age, income, and gender obtained from Statistics Canada 2021 census (Statistics Canada, 2023a), which was retrieved through the cancensus R package (von Bergmann et al., 2021). We use a stepwise approach for the statistical modelling. In the initial regression models, we incorporate three sets of independent variables: sociodemographic factors, residential self-selection, and calculated accessibility. The second model introduces perceived accessibility as an additional variable. Finally, the third model builds on the second and controls for travel identity. We follow the same procedure for constructing the models at the local and regional scales using respective variables.

4.6 Results and discussion

4.6.1 Descriptive statistics

Table 4.1 includes descriptive statistics of the data used in the models. For both local and regional groups, people perform less trips by walking or public transit than by car on average per week. For the regional group, as we have removed any participants whose weekly percentage of walking plus cycling trips constitute more than 50% of their weekly trips, the mean for the weekly trips done through walking or cycling is significantly lower compared to transit or car. Despite the lower mode share of transit compared to car in that group, more participants stated that they chose to live in a neighborhood near transit rather than one where it is practical to move around by car. For both the local and regional group, on average, it is most important to live in a walkable neighborhood. Most of the local sample (82%) identified themselves as pedestrians, while most of the regional sample (79%) identified themselves as car users. For the statistical analysis, we converted the 4-point Likert scale used to measure perceived accessibility into a binary one. About 63% of the local sample consider walking as a suitable mode for reaching their desired destination, while half of the regional sample perceive public transit as a suitable mode for the same purpose.

Table 4.1 Descriptive statistics by mean (standard deviation)

			Local (N= 4,679)	Regional (N= 2,985)
Travel Behaviour [Weekly mode share]	Public Transit	[%]	21.04 (25.97)	24.51 (29.55)
	Private car		43.32 (37.87)	60.83 (35.24)
	Walking		27.59 (27.37)	12.96 (14.81)
	Cycling		8.05 (18.81)	1.69 (6)
Sociodemographic	Gender	[1=female]	0.51 (0.5)	0.54 (0.5)
	Age	[Years]	47.21 (16.61)	46.96 (16.73)
	Household income	[1k CAD]	99.74 (57.41)	103.75 (56.72)
	Household size	[Persons]	2.42 (1.28)	2.58 (1.32)
	Employment	[1=Full time]	0.57 (0.49)	0.6 (0.49)
Residential selection	Near transit	[1= Imp, 0= Unimp.]	0.72 (0.45)	0.65 (0.48)
	Move by car and park		0.48 (0.5)	0.59 (0.49)
	Walkable neighborhood		0.73 (0.45)	0.68 (0.47)
Calculated Accessibility	Accessibility by public transit within 45 mins	[10,000 jobs]	26.32 (24.5)	17.76 (21.74)
	Walk Score®	[0 to 100]	76.75 (22.13)	70.13 (22.76)
Perceived Accessibility [...is suitable to reach desired destinations]	Public transit	[1=Agree, 0=Disagree]	0.65 (0.48)	0.52 (0.5)
	Walking		0.63 (0.48)	0.53 (0.5)
Travel Identity [I consider myself a...]	Transit user	[1=Yes]	0.69 (0.46)	0.61 (0.49)
	Car user		0.65 (0.48)	0.79 (0.41)
	Both transit and car user		0.37 (0.48)	0.4 (0.49)
	Pedestrian		0.82 (0.38)	0.74 (0.44)
	Cyclist		0.39 (0.49)	0.28 (0.45)

4.6.2 Contextual maps

The distribution of the home locations of the local and regional participants is displayed in **Figure 4.1** and **Figure 4.2**, respectively. The figures show the level of calculated accessibility in Montréal and the perceived accessibility of the survey respondents. In **Figure 4.1**, calculated local accessibility is represented by Walk Score® for each postal code. In **Figure 4.2**, calculated regional accessibility is represented by cumulative accessibility by public transit within 45 minutes of travel time for each CT. In both figures we observe little spatial correlation between perceived accessibility by walking (for the local group) or public transit (for the regional group) and their respective calculated accessibility. Some people living in high calculated accessibility areas perceive their accessibility levels to be low, and vice versa. We further examine this relationship through plots and statistical regressions.

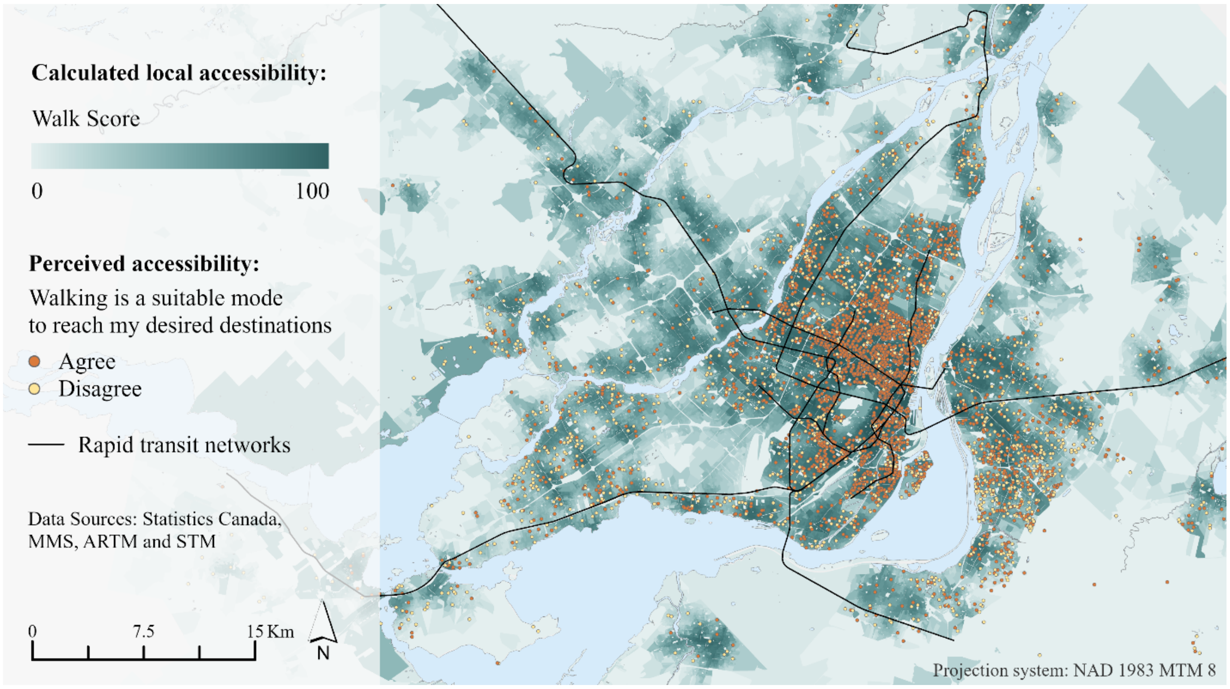

Figure 4.1 Walk Score® and perceived accessibility by walking for 4,679 survey respondents

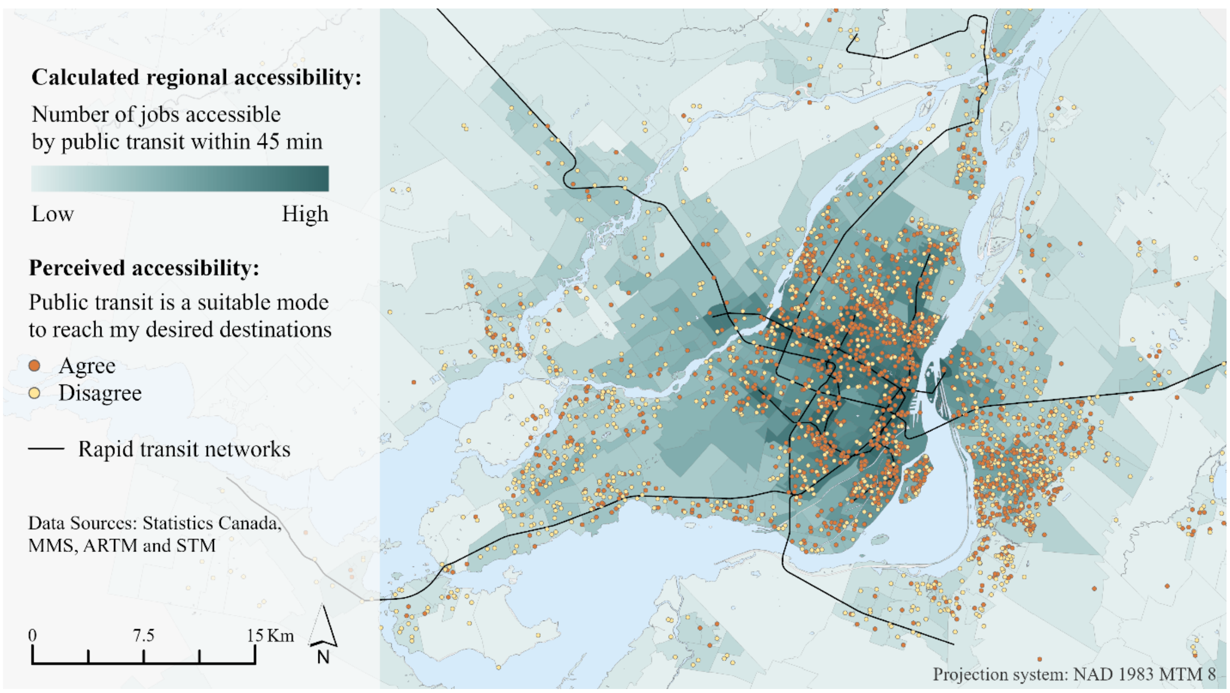

Figure 4.2 Accessibility by public transit in 45 minutes at the CT level and perceived accessibility by public transit for 2,985 survey respondents

4.6.3 Accessibility and travel behaviour

Exploratory plots at the local level are presented in **Figure 4.3** and regional level in **Figure 4.4** providing an overview of the relationship between calculated accessibility (x-axis), travel behaviour (y-axis), and perceived accessibility (color). Each dot in the figure represents a survey respondent. According to the figures, there seems to be no direct relation between perceived and calculated measures of accessibility, which aligns with the mismatch found in previous studies (Pot et al., 2023a, 2023b; Vafeiadis, 2024; Vafeiadis & Elldér, 2024b). We observed no clear correlation between transit or walking mode share and calculated measures of accessibility as in many instances people who walk or use public transit frequently resided in areas with low levels of accessibility. Meanwhile, we noted that pedestrians and frequent transit users hold a positive perception of accessibility, regardless of their calculated accessibility levels. On the contrary, individuals with a negative perception of accessibility tended to walk or take public transit less, even in areas characterized by very high accessibility levels, revealing a potential relationship between perceived accessibility and travel behaviour, which we further investigate through statistical analyses.

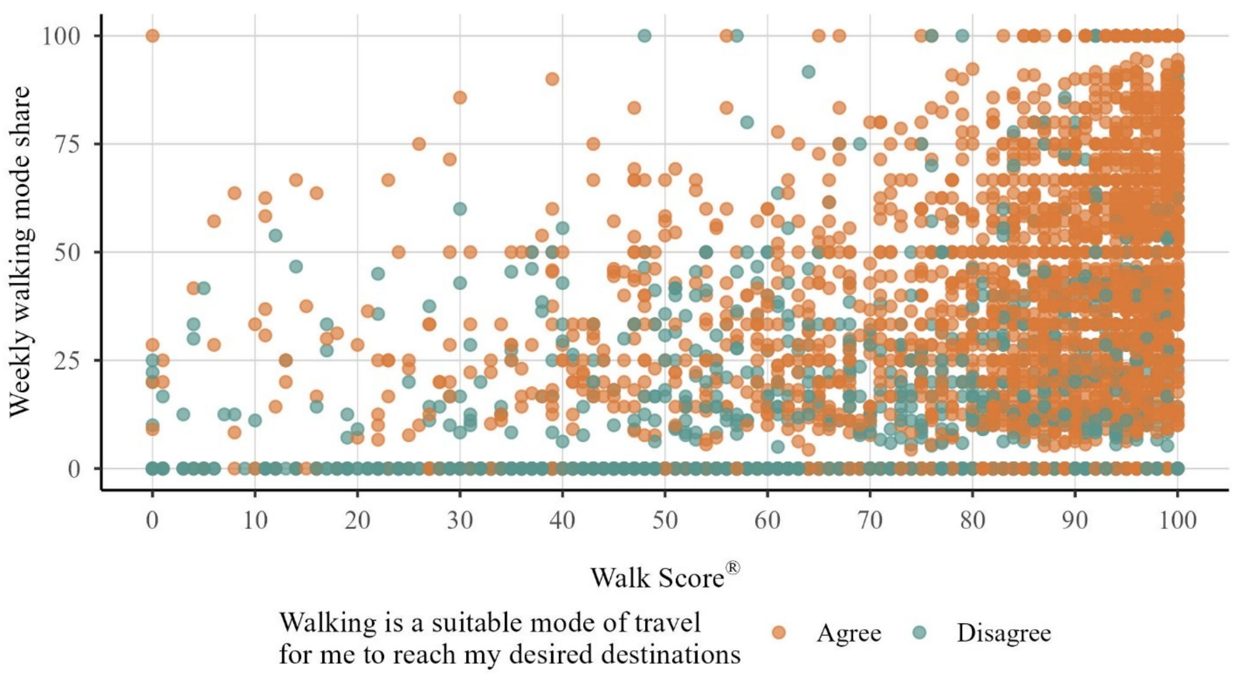

Figure 4.3 Walk Score® and weekly walking mode share colored by perceived accessibility

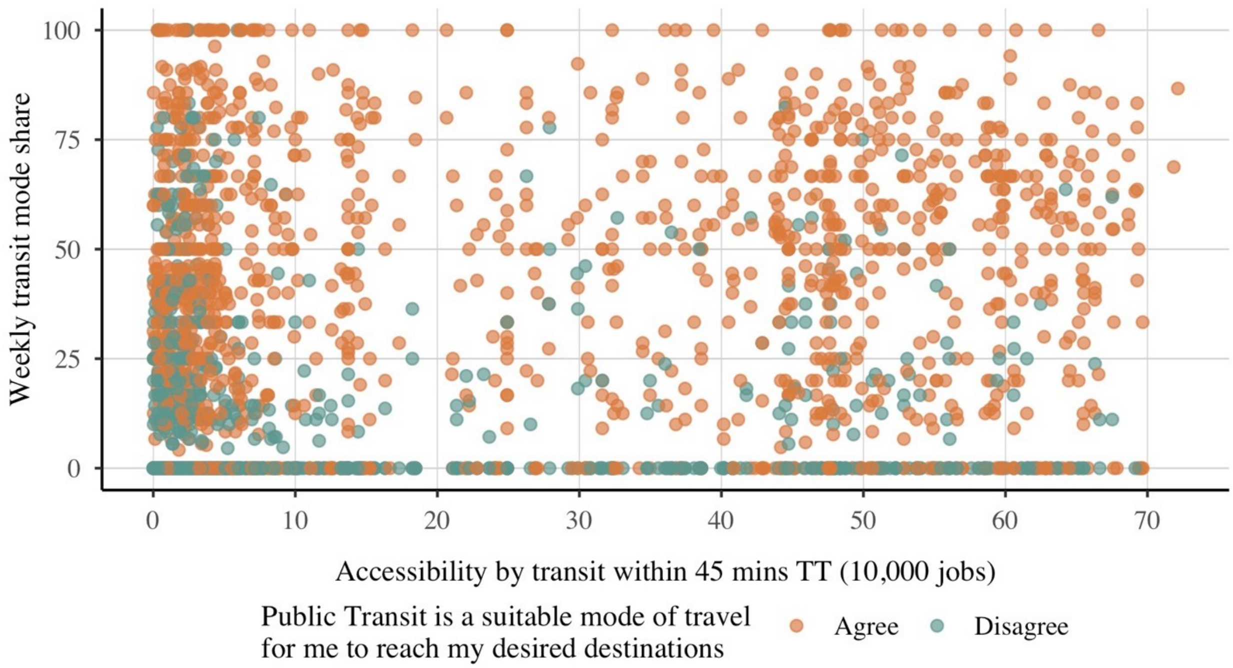

Figure 4.4 Calculated regional accessibility and weekly transit mode share colored by perceived accessibility

4.6.4 Statistical model and discussion

We further explore the relationship between calculated and perceived accessibility and travel behaviour using a stepwise regression approach. This approach allows for the systematic comparison between models by incrementally adding variables to evaluate their contributions to the model fit. It helps identify the most significant predictors of travel behaviour while controlling for potential confounding factors. The weighted linear regression models are reported in **Table 4.2** for the local (L) analysis and **Table 4.3** for the regional (R) analysis. The dependent variable in the local analysis is the weekly walking mode share per individual, while for the regional analysis, it is the public transit mode share.

For each analysis level, we run three statistical models. Models L1 and R1 include only sociodemographic, residential self-selection, and calculated accessibility variables. Models L2 and R2 include the perceived accessibility variable. Finally, Models L3 and R3 include a travel identity variable to account for the possible indirect relationship between perceived accessibility and travel behaviour.

Comparing the model fit (R^2) in the three models for each analysis level, Models L3 and R3 explain the highest variation in the dependent variable. We find that for each analysis level, these models are the one with the smallest ranges in the confidence intervals, particularly for the regional analysis. This shows that some of the variance caused by perceived accessibility and travel identity was captured by other variables in the other models. For these reasons, we will focus our discussion on these models. The findings of Models L3 and R3 validate our hypothesized relationship between perceived accessibility and travel behaviour.

In our models of interest, income, age, household size and residential self-selection followed the expected direction and statistical significance, which is similar to previous research (Buehler, 2011; Ha et al., 2020; Legrain, Eluru, et al., 2015). In the regional analysis, age has a negative and statistically significant impact on public transit mode share, keeping everything else equal. Every additional year decreases weekly transit use by 0.4%, all else kept constant. This can be attributed to the progression in life stages that makes driving a more affordable and comfortable option, which is consistent with previous research (Grimsrud & El-Geneidy, 2014). Meanwhile, it has a positive but slight impact on walking mode share in the local level analysis. This suggests that as people grow older, they tend to make more of their daily trips by walking.

For every 10,000 CAD increase in income, the weekly walking mode share decreases by 0.3% and public transit mode share decreases by 0.5% ceteris paribus, according to L3 and R3, respectively. This aligns with previous research suggesting that higher-income households tend to depend more on driving than other transport modes (Buehler, 2011). Full-time employees make 5.74% less walking trips and 4.25% fewer trips using public transit compared to retirees, students, or homemakers, ceteris paribus. An increase in household size has a statistically significant negative impact on weekly walking and public transit mode shares, where it decreases by 1.47% and 0.95% for every additional person, respectively, keeping all other variables constant at their mean.

Table 4.2 Local level analysis: weekly walking mode share weighted linear regression model

	Model L1		Model L2		Model L3	
Variables	Coef.	95% CI	Coef.	95% CI	Coef.	95% CI
(Intercept)	0.46	-4.21, 5.13	-2.51	-6.91, 1.90	**-8.61** ***	-13.13, -4.08
Gender [1= woman]	-0.11	-1.55, 1.32	-0.08	-1.44, 1.27	-0.02	-1.36, 1.32
Age	0.02	-0.02, 0.06	0.02	-0.02, 0.06	**0.04** *	0.00, 0.09
Income [1k CAD]	**-0.03** ***	-0.04, -0.01	**-0.03** ***	-0.04, -0.02	**-0.03** ***	-0.04, -0.02
Household size	**-1.97** ***	-2.60, -1.35	**-1.52** ***	-2.11, -0.93	**-1.47** ***	-2.05, -0.88
Full time empl.	**-6.09** ***	-7.66, -4.53	**-6.04** ***	-7.51, -4.57	**-5.74** ***	-7.20, -4.29
RS walkable	**3.58** ***	2.86, 4.30	**2.14** ***	1.45, 2.83	**1.78** ***	1.10, 2.47
Walk Score®	**0.44** ***	0.41, 0.48	**0.33** ***	0.29, 0.36	**0.31** ***	0.27, 0.34
Walking is suitable			**18.72** ***	17.20, 20.24	**15.53** ***	13.91, 17.16
Ident: Pedestrian					**10.35** ***	8.32, 12.39
Observations	4,679		4,679		4,679	
R^2 / R^2 adjusted	0.207/ 0.206		0.296/ 0.295		0.310/ 0.309	

* p<0.05   ** p<0.01   *** p<0.001

Table 4.3 Regional level analysis: weekly transit mode share weighted linear regression model

	Model R1		Model R2		Model R3	
Variables	Coef.	95% CI	Coef.	95% CI	Coef.	95% CI
(Intercept)	**68.25** ***	63.68, 72.82	**52.56** ***	47.96, 57.16	**36.65** ***	32.23, 41.07
Gender [1= female]	-0.32	-2.14, 1.49	0.07	-1.64, 1.79	0.53	-1.04, 2.11
Age	**-0.66** ***	-0.72, -0.60	**-0.55** ***	-0.60, -0.49	**-0.41** ***	-0.46, -0.36
Income [1k CAD]	**-0.06** ***	-0.07, -0.04	**-0.05** ***	-0.06, -0.03	**-0.05** ***	-0.06, -0.03
Household size	**-0.84** *	-1.59, -0.09	**-0.90** *	-1.61, -0.19	**-0.95** **	-1.60, -0.30
Full time empl.	**-8.16** ***	-10.11, -6.22	**-5.79** ***	-7.64, -3.94	**-4.25** ***	-5.95, -2.54
RS near transit	**12.25** ***	10.25, 14.25	**7.14** ***	5.18, 9.10	**1.92** *	0.08, 3.77
RS move by car	**-17.45** ***	-19.41, -15.49	**-13.73** ***	-15.62, -11.85	**-9.85** ***	-11.61, -8.09
Accessibility by transit in 45 mins	**0.15** ***	0.11, 0.20	**0.08** ***	0.04, 0.13	**0.07** ***	0.03, 0.11
PT is suitable			**18.78** ***	16.85, 20.70	**10.57** ***	8.68, 12.46
Ident: Transit user					**23.91** ***	21.94, 25.88
Observations	2,985		2,985		2,985	
R^2 / R^2 adjusted	0.343 / 0.341		0.415 / 0.413		0.508/0.506	

* p<0.05   ** p<0.01   *** p<0.001

We account for residential self-selection to avoid overestimating the influence of the built environment on travel behaviour (Cao et al., 2009). The relationships between the relevant residential self-selection variables and travel behaviour were statistically significant. Based on the local model (L3), respondents who value residing in a walkable neighborhood tend to make 1.78% more walking trips, holding all other variables constant. According to the regional model (R3), individuals who prioritize residing near public transit tend to use it for 1.92% more of their trips compared to those who do not, keeping other variables unchanged. Meanwhile, respondents who find it important to be in a neighborhood where it is practical to drive and park make 9.85% fewer trips using transit, keeping all else constant.

The impact of calculated accessibility on weekly walking and public transit mode shares decreases when we include the perceived accessibility and travel identity variables. However, it remains positive and statistically significant, similar to previous studies on local accessibility (Elldér et al., 2020; Manaugh & El-Geneidy, 2011) and regional accessibility (Cui et al., 2020; Moniruzzaman & Páez, 2012; Negm & El-Geneidy, 2024; Owen & Levinson, 2015). For every one-point increase in the Walk Score® index, the weekly walking mode share increases by 0.31%, keeping all else constant. And for every 10,000 jobs accessible by public transit, the weekly public transit mode share increases by 0.07%, keeping other variables at their mean value. This translates to 12.6% weekly transit mode share for a person who can access 180,000 jobs in Montréal, which is the mean number of accessible jobs by public transit within 45 minutes for our regional sample.

Perceived accessibility has a positive and statistically significant impact on travel behaviour in L3 and R3, confirming the hypothesized relationship shown in the exploratory plot (**Figure 4.3** and **Figure 4.4**). People who perceive walking to be a suitable mode to reach their desired destinations make 15.53% more of their trips by walking compared to those who do not consider it as a viable mode of transport, keeping all else constant. Similarly, people who have positive perceived accessibility by public transit make 10.57% more of their trips by public transit compared to those with negative perceptions, keeping all else constant.

The relationship between perceived accessibility and travel behaviour can be indirect. In these statistical models, we incorporate a binary variable based on the self-reported question "I consider myself a pedestrian" in the local model and "I consider myself a transit user" in the regional model to represent travel identity. This variable serves to address this indirect relationship concern and isolate the effect of perceived accessibility on travel behaviour. This approach is similar to accounting for residential self-selection when exploring how contextual factors tied to location (e.g., calculated accessibility) influence travel behaviour, as suggested in previous studies (Cao et al., 2009; van Wee, 2009). Including the travel identity variable allows us to account for individuals' subjective preferences and better isolate the impact of perceived accessibility. Accounting for travel identity and attitudes is essential to avoid overestimating the effect of perceived accessibility on travel behaviour.

Previous frameworks hypothesize that travel behaviour is impacted by perceived accessibility (De Vos et al., 2023; Morris et al., 1979; Pot et al., 2021). Consistent with this theoretical background, our empirical findings confirm a positive and statistically significant relationship between the two variables. By drawing on strong theoretical foundations, accounting for confounding travel behaviour variables, and assuming temporal anchoring—where perceived accessibility precedes travel behaviour—we infer a causal relationship. However, we acknowledge that this relationship could also be bidirectional, with travel behaviour influencing perceived accessibility. Due to the limitations of our cross-sectional data, addressing this bidirectionality remains a challenge. Future studies employing panel data could better explore this possibility.

4.7 Conclusion

In this study, we examined the impact of perceived accessibility on travel behaviour, building upon previous research by Pot et al. (2021) and De Vos et al. (2023). We hypothesize that travel mode choice is impacted by multiple factors including individual characteristics, travel identity and attitudes, residential selection, calculated accessibility, and perceived accessibility. To validate this hypothesized relationship, we use a series of weighted linear regression models at the local and regional level to analyze the weekly walking and transit mode share, respectively, as the dependent variables.

The findings from the models confirm our hypothesis about the positive impact of perceived accessibility on weekly public transit mode share for all purposes, namely work, school, leisure, healthcare, and shopping. We find that individuals who agree that walking is a suitable mode to reach their desired destinations perform about 15% more of their trips on foot. Similarly, those who find public transit suitable for their needs make about 10% more of their trips by public transit compared to those who do not have the same positive perception of their accessibility levels. We control for travel identity in our final statistical models, which is crucial to avoid overestimating the influence of perceived accessibility on travel behaviour.

This research provides valuable insights for transport professionals aiming to promote the use of sustainable modes by highlighting the role of perceived accessibility in shaping travel behaviour. Our findings emphasize the importance of enhancing perceptions of walkability and public transit accessibility, particularly in regions with high accessibility levels. Planners and policy makers should aim to address how infrastructure improvements are communicated and perceived by the public. Enhancing the perception can be achieved through conducting advertising campaigns introducing the existing services to those residing in areas characterized by high levels of accessibility. Campaigns like car-free day, which include free public transit use, can be used as a tool to change the perceived accessibility as non-users will be encouraged to use public transit for that day for societal and environmental purposes. Similarly, this can be applied during large events to reduce the pressure on the transport network and introduce walking and public transit as viable alternatives. Improving first- and last-mile connectivity, through investments in the microscale-built environment around transit stops, can encourage residents to explore their areas and improve their perceived accessibility; thus, encouraging active travel and public transit use. Leveraging technology and real-time data to provide intuitive, user-friendly public transit interfaces can further improve perceptions of accessibility and attract more users to sustainable travel modes (Pot et al., 2023b). Future research can delve deeper into the demographic construct of perceived accessibility as understanding how it varies across different groups can help develop equitable policies that prioritize underserved communities.

While our findings provide evidence of the positive and statistically significant impact of perceived accessibility on travel behaviour, the cross-sectional nature of our data limits the ability to confidently establish time precedence, thereby hindering the examination of bidirectional relationships between the two constructs. Future research can explore the constructs of perceived accessibility and the possible bidirectional relationship with travel behaviour in more detail through advanced statistical methods such as structural equation modelling (SEM). However, it is important to note that while SEM can offer insights into complex relationships, it has certain limitations, including the need for a large sample size and detailed measures for latent constructs. Additionally, the complexity of SEM models can present challenges in interpretation and communication with broader audiences. Future studies can also utilize panel data that collects travel behaviour, perceived accessibility, travel attitude, and sociodemographic information from the same participants overtime allows for longitudinal analysis that reveals details about the changes in these constructs, facilitating the confirmation and validation of causal relationships and helps explain discrepancies between calculated and perceived accessibility. Although we focus on the local and regional scale in Montréal, our study can be replicated in other contexts to confirm our evidence and at different scales such as national and international levels. The national and international scale of perceived accessibility can be collected to measure its impacts on mode choices between rail and car when traveling between cities and countries where the travel time is short and such modes are competitive.

Chapter 5. Operationalizing accessibility thresholds: Identifying perceived minimum and sufficient accessibility in Canada

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Negm, H., & El-Geneidy, A. (Under review). Operationalizing accessibility thresholds: Identifying perceived minimum and sufficient accessibility in Canada.

Chapter 5

Operationalizing accessibility thresholds: Identifying perceived minimum and sufficient accessibility in Canada

5.1 Chapter positioning

This chapter addresses the fourth and final objective of the dissertation by examining how calculated and perceived accessibility can be integrated to identify operational accessibility thresholds that inform transport planning practice. As the concluding empirical component of the dissertation, it represents the final piece of the puzzle in answering the overarching research question: how can calculated and perceived accessibility be operationalized in transport planning practice? Motivated by the operationalization gap between theory and planning practice, it develops minimal and sufficient levels of accessibility that allow basic and convenient access to essential destinations, respectively. The chapter is structured around two key objectives. First, it develops a rigorous methodological framework to identify perception-based accessibility thresholds. Second, these thresholds are positioned within a travel behaviour framework to evaluate their practical implications. The use of nationwide Canadian Mobility Survey data allows for the identification of region-specific thresholds across diverse urban contexts, strengthening the methodological robustness and policy relevance of the findings. By explicitly connecting calculated and perceived accessibility, distinguishing between minimum and sufficient access, and grounding threshold identification in distributive justice, this chapter provides a coherent and operational framework for translating accessibility theory into equitable and sustainable planning practice.

5.2 Abstract

As accessibility becomes integral to transport planning, it is important to identify operational thresholds for evaluating access to essential destinations. Motivated by the operationalization gap between theory and planning practice, we develop a methodology to identify two levels of accessibility thresholds: Perceived Minimum Accessibility (PMA), representing basic access to essential destinations, and Perceived Sufficient Accessibility (PSA), representing convenient access. Using data from the nationwide Canadian Mobility Survey (N = 15,960), we analyze the relationship between perceived accessibility to grocery stores, healthcare, and leisure destinations by walking and public transit and the participants' corresponding calculated accessibility by public transit. We apply binned log-linear regressions combined with a quartile-based approach to identify region-specific PMA and PSA thresholds. We then assess threshold coverage for the general and low-income populations and map their spatial distribution across income groups. Finally, we examine how these thresholds relate to travel behaviour by estimating weekly walking and public transit mode share using region-specific weighted linear regressions and marginal effects analysis. Our findings reveal substantial regional variation. Large regions achieve broad coverage at the PMA level but require significant improvements to reach PSA levels. Mid-sized and smaller regions often struggle to meet PMA for most of their population, and PSA levels remain largely unattainable under current conditions. PMA levels yield only modest gains in sustainable mode share, whereas PSA levels are associated with considerably higher levels of walking and public transit use. By developing perception-based accessibility thresholds, this study provides a practical framework to support more equitable and sustainable transport and land-use planning.

5.3 Introduction

Integrating accessibility, the ability of individuals to reach destinations, in transport planning has become a central concern in recent years (El-Geneidy & Levinson, 2022; Ryan & Martens, 2023; Siddiq & Taylor, 2021), with the aim of avoiding social exclusion and promoting wellbeing (Lucas, 2012). In the transport planning literature, frameworks such as *sufficientarianism* and the *capability approach* have been proposed to evaluate levels of accessibility provision (Karner et al., 2024; Lucas et al., 2016; Martens, 2016; Miller, 2018). *Sufficientarianism* holds that planning should prioritize raising accessibility above a certain threshold for all residents beyond which it does not matter how much more others can have (Golub & Martens, 2014; Grengs, 2010; Karner et al., 2024), while the *capability approach* evaluates accessibility in terms of whether individuals have freedom to reach the destinations necessary for social participation (Beyazit, 2011; Nahmias-Biran & Shiftan, 2020; Pereira et al., 2017; Vecchio & Martens, 2021). These frameworks establish a normative case for accessibility standards: that some level of access constitutes a floor below which planning has a responsibility to intervene. However, neither framework specifies how such thresholds should be empirically identified in planning practice. While some studies attempted setting participation-based thresholds (Martens, 2016; Pot et al., 2024), car-accessibility-based benchmark standards (van der Veen et al., 2020), or examining transit-desert spatial distribution (Aman & Smith-Colin, 2020; Guo & Brakewood, 2024; Jiao & Dillivan, 2013), they offer limited empirical guidance for determining what constitutes "enough" accessibility in practice.

Motivated by this operationalization gap, we propose an empirical approach to identifying accessibility planning descriptive benchmarks grounded in perceived experience. While much of the transport equity literature calls for accessibility standards (Karner et al., 2024; Pereira et al., 2017), it does not distinguish between minimum and sufficient accessibility. We argue that they should not be treated synonymously. A minimum threshold may prevent some transport disadvantage, yet it may remain too low to support wellbeing (Hananel & Berechman, 2016; Lucas, 2012). Planning practice should distinguish between a minimum accessibility threshold that allows basic access to essential destinations and a sufficient accessibility threshold that ensures convenient access to these destinations.

Identifying these thresholds requires both a calculated measure of accessibility and a perception-based one. Calculated accessibility quantifies individuals' ability to reach destinations given land use and transport system configurations (Dalvi & Martin, 1976; Handy, 1992, 2023; Hansen, 1959; Levinson & Wu, 2020) and has been extensively used to study travel behaviour, economic development, transport equity, and transport policies and plans (Foth et al., 2013; Golub & Martens, 2014; He, 2020; Luo et al., 2023; Manaugh et al., 2015; Moniruzzaman & Páez, 2012; Owen & Levinson, 2015; Ton et al., 2020). Calculated accessibility alone may not reflect how individuals experience their opportunities to reach essential destinations given their personal characteristics, needs, and constraints; and ignoring perceptions of accessibility could misrepresent the lived experience (Negm, De Vos, et al., 2025; Pot, 2025). Therefore, we argue that perceptions of accessibility should play a central role in defining these thresholds. In this paper, we use the perceived accessibility definition by Negm, De Vos, et al. (2025) as "*the perception of how easily one can access their desired destinations using a (range of) specific mode(s).*" We combine perceived accessibility by walking and PT as we mainly focus on sustainable access; therefore, this approach reflects the role of destination proximity in shaping sustainable mode viability: where destinations are nearby, walking may substitute for PT, and lower perceived transit accessibility does not necessarily indicate limited sustainable access.

In that light, we define Perceived Minimum Accessibility (PMA) and Perceived Sufficient Accessibility (PSA) as the calculated accessibility levels at which more than 50% and at least 75% of residents, respectively, perceive that they can easily reach their desired essential destinations by walking or public transit (PT). For PMA, we adopt the median threshold as a majority criterion, representing the accessibility level at which at least half of residents perceive basic access to essential destinations. For PSA, we adopt the third quartile threshold to represent a strong majority of participants, reflecting broad consensus without requiring unanimity. This quartile-based approach provides a transparent and distribution-sensitive method for identifying empirically grounded planning thresholds.

This research provides a new methodology for identifying PMA and PSA thresholds in Canadian regions based on calculated and perceived accessibility levels and examine their influence on travel behaviour. To achieve this goal, we use data from a nationwide Canadian transport survey (N= 15,960), which includes measures of perceived accessibility, travel behaviour, travel identity and attitudes, and socioeconomic characteristics. These data are paired with region-specific cumulative opportunities accessibility measures. We use binned log-linear regression analysis to identify region-based PMA and PSA. We then examine their impact on weekly travel behaviour using weighted linear regression models followed by a marginal effects analysis. This paper is structured as follows: Section 2 presents the literature review, covering efforts to set accessibility standards, the role of calculated and perceived accessibility, and the operationalization gap that motivates this study. Section 3 presents the data used in the analysis. Given the methodological focus of this paper, Section 4 presents the analytical framework and empirical results jointly. Finally, Section 5 presents the conclusion of the study.

5.4 Literature Review

5.4.1 Setting standards of accessibility

In recent years, there have been efforts to position transport provision within the framework for equitable transport planning such as *sufficientarianism* and the *capability approach* (Karner et al., 2024; Martens, 2016; Nahmias-Biran et al., 2017; Pereira et al., 2017; van Wee & Mouter, 2021). While these frameworks offer guidance on what could constitute a just transport system, their application in empirical research often relies on simplified quantitative tools and their implementation in planning practice is still challenging (Ryan & Martens, 2023).

5.4.1.1 Sufficient accessibility

Sufficientarianism provides a useful conceptual starting point to defining what constitutes a sufficient level of accessibility in the transport literature. It suggests that each individual should have access to at a baseline level of transport resources, beyond which, it does not matter how much more others can have (Meyer & Roser, 2006). In transport, this concept guides the research on transport/accessibility poverty and disadvantage, where one would not be able to access essential activities because of the lack of a baseline level of transport resources, services, safety, and accessibility. This poverty can stem from various factors, including the absence of private vehicles, inadequate PT services, financial constraints, physical barriers in vehicles and spaces, belonging to specific socioeconomic or marginalized groups, or a combination of these elements (Golub & Martens, 2014; Grengs, 2010; Karner et al., 2024). However, translating this concept into a concrete and operational threshold has proven difficult.

Martens (2016) proposed setting the threshold at the point where activity participation benefits reach a meaningful level, to be determined through democratic deliberation, but empirical attempts to link sufficient accessibility to activity participation benefits have found little to no association between the two, revealing difficulties in quantifying sufficient accessibility (Pot et al., 2024). van der Veen et al. (2020) used average calculated accessibility by car in Rotterdam to define sufficiency thresholds and applied these thresholds to assess accessibility levels across other transport modes, highlighting spatial differences in the fairness of transport provision. This approach uses car accessibility as a reference benchmark for evaluating accessibility sufficiency across the city, constraining other modes to the spatial reach of driving. However, accessibility is inherently mode-specific and should be evaluated based on the ease and extent of destinations reachable by each mode, rather than in comparison to car accessibility.

5.4.1.2 Gaps in transport provision

Other methods focus on identifying the gaps and needs in demand (Currie, 2004; Karner et al., 2024). Areas characterized by accessibility poverty by PT are often referred to as transit or service "deserts" (Aman & Smith-Colin, 2020; Guo & Brakewood, 2024; Jiao & Dillivan, 2013). Identifying these areas is based on the definition of the potentially disadvantaged populations that would rely on transit, referred to as transit-dependents, whose accessibility needs to essential services are unmet (Jiao & Dillivan, 2013). Social indicators are typically used to identify such disadvantaged groups, concentrating on specific socioeconomic variables such as unemployment rates, household income, the proportion of ethnic minorities, or particular age demographics such as the elderly (Church et al., 2000; Currie et al., 2010; Dodson et al., 2006; Foth et al., 2013). These indicators are used to identify socially disadvantaged areas examined in relation to accessibility outcomes of different transport systems.

5.4.1.3 Accessibility as a capability

The Capability Approach (Nussbaum, 2009; Sen, 2008), has been recently given attention as a framework that accounts for heterogeneity in individuals' experiences with transport, useful for integrating social equity into transport policy-making and evaluation (Beyazit, 2011; Nahmias-Biran & Shiftan, 2020; Pereira et al., 2017; Vecchio & Martens, 2021). From this perspective, Pereira et al. (2017) argue that accessibility can be understood as a capability that allows for the freedom to reach valued destinations and that transport policy should guarantee minimum standards of accessibility to essential destinations, prioritise disadvantaged groups, and avoid sacrificing individuals' basic rights in the pursuit of aggregate accessibility gains. While this framework introduces complexity, it provides a useful lens for understanding why individuals with different backgrounds may experience and use the transport system differently, a consideration that motivates the need for both calculated and perceived dimensions when setting accessibility thresholds.

5.4.2 Calculated and perceived accessibility

Both calculated and perceived measures of accessibility should be considered when setting standards for accessibility, as they complement each other. Place-based calculated measures quantify the potential of a location to provide access to spatially distributed opportunities as a function of travel time, departure time, travel mode, and destination quantity (Dalvi & Martin, 1976; Geurs & van Wee, 2004; Handy, 1992; Hansen, 1959; Levinson & Wu, 2020). While valuable as scalable planning tools, their aggregate nature treats all persons within a spatial unit as equally positioned to take advantage of available opportunities. Perceived accessibility addresses this gap by foregrounding the individual, capturing how people subjectively assess their ability to reach desired destinations, conditioned by personal characteristics, prior experiences, attitudes, and psychological factors (Negm, De Vos, et al., 2025; Pot et al., 2021). From the perspective of the Capability Approach, calculated accessibility aligns with the top-down aggregate perspective, approximating what the transport and land-use system makes available, while perceived accessibility aligns with the bottom-up disaggregate perspective, reflecting whether individuals can actually convert those resources into meaningful access given their particular conversion factors (Vecchio & Martens, 2021).

Individual characteristics and personal resources, including sociodemographic characteristics, mobility means, attitudes and preferences, and previous experience, have been shown to shape perceived accessibility (El Murr et al., 2023; Fu et al., 2024; Pot et al., 2023b; Tanimoto & Hanibuchi, 2021; Vafeiadis & Elldér, 2024a; van der Vlugt et al., 2019). This means that two individuals with similar calculated accessibility levels may perceive their access differently depending on who they are and how they travel. Socially disadvantaged groups may face unmet accessibility needs due to financial constraints, inadequate service, or physical barriers, despite seemingly adequate calculated accessibility (Karner et al., 2024). These differences could be difficult to capture at the aggregate level, requiring the nuances of perceptions at the individual level, underscoring that a group-differentiated analysis attending to both calculated and perceived dimensions is necessary if accessibility standards are to reflect the diversity of circumstances through which people engage with transport systems.

5.4.3 Towards minimum and sufficient accessibility thresholds

The debate is yet to settle on what is considered a sufficient level of accessibility. In this article, we argue two main points. The first is that sufficiency should not be synonyms with the minimality concept. These should be set as two different thresholds, this has been argued by Hananel and Berechman (2016) where they explained the notion that the thresholds aiming at minimum can be too low, preventing many from living a full and free life. The second point is that in addition to calculated accessibility, perceptions of accessibility should play a major role in determining these thresholds (Pot, 2025). To our knowledge, no study has incorporated the notion of perceived accessibility in combination with calculated accessibility to set thresholds for minimum and sufficient accessibility. Our study aims to fill the gap by providing a methodology to set these thresholds as descriptive benchmarks.

5.5 Data

This research focuses on identifying the PMA and PSA thresholds in Canadian regions based on calculated and perceived accessibility levels and examines their influence on travel behaviour. To achieve this goal, we use survey data from the Canadian Mobility Survey (CMS) to account for perceived accessibility and travel behaviour, and we pair it with calculated accessibility by PT for each participant's home location measured at the period of survey data collection.

5.5.1 Survey data

We use data from the CMS, a bilingual online travel survey conducted in Fall 2024 across 12 Census Metropolitan Areas (CMAs) of varying sizes in Canada. The survey covers three large regions with populations over two million: Toronto, Montréal, and Vancouver; three mid-size regions with populations over one million: Ottawa–Gatineau, Calgary, and Edmonton; and six smaller regions with populations under one million: Québec, Winnipeg, Hamilton, Halifax, Victoria, and Saskatoon (**Figure 5.1**). For the CMS, recruitment was performed using a variety of strategies including online social media advertisement, the distribution of flyers, radio interviews, and a public opinion company, as recommended by Dillman et al. (2014).

Figure 5.1 Surveyed regions in the CMS

A thorough multi-step data-cleaning procedure was applied to the survey data. The cleaning process used exclusion criteria based on participants' IP and e-mail addresses, location pins of home, work and/or school, the time it took to complete the survey, reported frequency of weekly travel, and other quality checks. Full details of the cleaning and validation procedure are outlined in Negm, Neufeld, et al. (2025).

For this study, we use variables for participants' perceived accessibility, weekly travel behaviour, residential self-selection, travel identity and attitude, socioeconomic characteristics, and home location. The perceived accessibility questions were designed based on the definition of perceived accessibility by Negm, De Vos, et al. (2025) and previous studies by Vafeiadis and Elldér (2024a) and Vafeiadis (2024). Participants were asked to rate their agreement with the mode- and destination-specific statement: "By [mode], I can easily access my desired destination for [purpose]" on a 4-point Likert scale from strongly disagree to strongly agree. For the purpose of this paper, the scale was converted into a binary variable with positive and negative responses. This statement was presented a total of six times, corresponding to two travel modes, walking and PT, and three destination types: grocery shopping, healthcare, and leisure.

Perceived accessibility was combined for walking and PT for each purpose. It was considered positive if participants reported a positive response for walking and/or PT. This approach accounts for participants who reported lower perceived accessibility by PT due to the proximity of their destinations, which can make transit unrealistic, while still reporting positive perceived accessibility by walking.

For weekly travel behaviour, we asked the participants the number of trips they performed in the last week for shopping, healthcare, and leisure by each of the four travel modes: car, transit, walking, and cycling. In this study, we excluded participants who made less than four trips as they were considered insufficiently mobile and their perceptions of accessibility could be strongly influenced by their limited mobility. To account for travel identity, participants rated their agreement with the statement: "I consider myself a [mode user]" for driving, transit user, walking, and cycling. Participants could select multiple modes (e.g., "I consider myself a transit user and a pedestrian").

To classify participants into income groups, we first use the most recent Canadian census (Statistics Canada, 2023a) to identify the household income corresponding to the 30th percentile of the income distribution in each region, which was considered the low-income threshold. This threshold ranged from CAD 64,000 to CAD 90,000 across regions and was rounded to the nearest CAD 30,000 to align with the survey's income categories (reported in CAD 30,000 intervals). A binary variable was then created to distinguish low-income and other-income households: participants whose income category upper bound was less than or equal to the rounded regional threshold were classified as low-income, and all others as other-income.

The cleaning and validation process resulted in a total of 15,960 participants across the 12 regions, with regional samples ranging from 711 to 2,036 participants.

5.5.2 Calculated accessibility metrics

Accessibility has been extensively used to link land use to transport systems, assessing how they benefit the population in reaching various opportunities via different transport modes (El-Geneidy & Levinson, 2022; Geurs & van Wee, 2004; Levinson & Wu, 2020). Cumulative opportunities and gravity-based measures are among the most widely used accessibility metrics in research and practice (Boisjoly & El-Geneidy, 2017a). The cumulative opportunities measure, in particular, is favored due to its ease of interpretation and communication to the public and policymakers (El-Geneidy & Levinson, 2022). It also shows high-correlation with the more complex gravity-based measures, at least in the North American context (Giannotti et al., 2021; Kapatsila, Palacios, et al., 2023; Palacios & El-Geneidy, 2022), suggesting that cumulative opportunities is sufficient to represent the built environment adequately.

In this study, we use cumulative opportunities measures of employment accessible by PT to represent calculated accessibility. While perceived accessibility in this study focuses on specific destination types, employment accessibility is widely used as a proxy for the overall diversity and quantity of opportunities accessible in a given area (Alousi-Jones & El-Geneidy, 2025; Deboosere & El-Geneidy, 2018; El-Geneidy & Levinson, 2022; Rodrigue et al., 2023). This is because employment centres tend to co-locate with essential destinations such as grocery stores, healthcare facilities, and leisure amenities, meaning that areas with high job accessibility also tend to offer broad access to the services captured by our perceived accessibility measures. This decision was further motivated by our aim to develop holistic accessibility thresholds that reflect the overall range of opportunities accessible by PT, rather than thresholds tied to specific destination types.

Calculated accessibility to jobs by PT at the Dissemination Area (DA) level was computed using the number of available jobs, DA-level spatial points, General Transit Feed Specification (GTFS) data, and

OpenStreetMap networks. We first identify the number of jobs in each Census Tract (CT) across the 12 regions using the Canadian Commuting Flows (CCF) data, which track commutes from CT of residence to CT of work (Statistics Canada, 2017). Although the most recent CCF was collected in 2021, we used the 2016 data because it provides a more representative depiction of typical post-pandemic commuting patterns. The 2021 flows are heavily influenced by the rise in telecommuting and the overall decline in commuting during the pandemic. To provide finer spatial granularity, the jobs at the CT level were proportionally allocated to the DAs based on land area. This approach was preferred instead of using commuting flows at the DA level because, although Statistics Canada provides data at this finer resolution, it is subject to stricter data suppression due to smaller population sizes in DAs.

DA-level spatial centroids were first extracted for each region using census data shapefiles. Some of these centroids were then manually adjusted to better reflect the spatial distribution of the population, as in many instances, the original centroids fell in unpopulated areas or over water. GTFS data for each region's PT agencies were obtained from Transitland using an application programming interface (API) for October 2024, to match the PT services at the time of collecting the CMS. The OpenStreetMap street network was obtained for each region's CMA through BBBike extracts.

To calculate a travel time matrix (TTM) between the DA-level points, we used the r5r package in R with GTFS data and OSM networks as inputs (Pereira et al., 2021). The TTM represents the shortest travel time (TT) between each pair of DA points and was generated for a typical Wednesday at one-minute intervals during the morning peak period (7:30 a.m. to 8:30 a.m.). To account for schedule variability, we retrieved the median TT across all departure times. The calculated TT includes access and egress times by walking, as well as waiting, in-vehicle, and transfer times, where applicable.

To best represent accessibility within each region, the TT threshold for the cumulative opportunities measure was set based on the mean TT by PT in the region (Statistics Canada, 2022), rounded to the nearest 5-minute interval, following Kapatsila, Palacios, et al. (2023). Specifically, thresholds of 30 minutes were used for Victoria; 35 minutes for Québec, Halifax, Saskatoon, and Winnipeg; 40 minutes for Hamilton and

Ottawa–Gatineau; 45 minutes for Montréal, Calgary, Vancouver, and Edmonton; and 50 minutes for Toronto. Proportional accessibility was then calculated by dividing accessibility values by the total number of jobs in the region to enable comparisons across regions. For each participant in the CMS, calculated proportional accessibility was linked to the DA of their home location.

5.5.3 Descriptive statistics

Table 5.1 and **Table 5.2** present descriptive statistics for the 15,960 participants, classified by region. In the three large regions, the majority of participants report positive perceived accessibility by PT and/or walking to grocery stores, healthcare, and leisure destinations individually, with positive responses ranging from 71% to 85%. However, when combining perceptions across all three purposes, the share reporting positive accessibility drops to 59%-71%. This decline is also observed in mid-size and small regions, reaching as low as 42% for the purpose-combined perceived accessibility, indicating that some participants have positive perceived accessibility to certain basic destinations but not all of them. On average, participants can access between 9% and 20% of jobs in their respective regions; however, this proportional range corresponds to a much wider absolute range of 16,400 to 392,100 jobs, highlighting the importance of using proportional accessibility to account for differences in regional size and labour market scale. Across all regions, driving is the predominant travel mode, followed by walking, and then PT for the three purposes combined during a typical week. The following section delves deeper into the relationship between these three variables.

Table 5.1 Descriptive statistics for large and mid-size regions by mean (standard deviation)

	Toronto	**Montréal**	**Vancouver**	**Ottawa – Gatineau**	**Calgary**	**Edmonton**
N	1950	2036	1612	1764	1052	1254
Perceived Accessibility by PT and/or Walking [1= Positive]						
Grocery stores	0.83 (0.38)	0.75 (0.44)	0.84 (0.37)	0.65 (0.48)	0.72 (0.45)	0.7 (0.46)
Healthcare	0.85 (0.36)	0.78 (0.41)	0.85 (0.36)	0.64 (0.48)	0.69 (0.46)	0.7 (0.46)
Leisure	0.82 (0.38)	0.71 (0.46)	0.81 (0.39)	0.59 (0.49)	0.67 (0.47)	0.66 (0.47)
All three destinations	0.71 (0.45)	0.59 (0.49)	0.69 (0.46)	0.42 (0.49)	0.5 (0.5)	0.52 (0.5)
Calculated Accessibility by PT						
Mean commute time in the region	50	45	45	40	45	45
N of accessible jobs (x10,000)	39.21 (28.82)	24.63 (26.13)	20.04 (14.46)	6.69 (7.64)	9.13 (8.94)	8.0 (7.07)
% of accessible jobs	15.3% (11.2%)	14.0% (14.9%)	19.9% (14.4%)	11.2% (12.8%)	15.5% (15.2%)	14.4% (12.8%)
Travel Behaviour (Weekly to grocery, leisure, and healthcare)						
% of PT trips	18% (24)	13% (13)	18% (25)	7.2% (18)	9.2% (22)	10% (23)
% of walking trips	37% (30)	27% (27)	35% (30)	23% (29)	24% (27)	21% (26)
% of driving trips	36% (38)	54% (54)	40% (38)	62% (39)	61% (38)	63% (38)
Socioeconomic characteristics						
Gender [1=Woman]	0.52 (0.5)	0.5 (0.5)	0.54 (0.5)	0.58 (0.49)	0.6 (0.49)	0.58 (0.49)
Age	44 (16)	47 (16)	45 (17)	44 (15)	43 (16)	44 (16)
Low-income household [1= Yes]	0.37 (0.48)	0.24 (0.42)	0.48 (0.5)	0.27 (0.45)	0.47 (0.5)	0.5 (0.5)
Household size	2.47 (1.26)	2.56 (1.31)	2.33 (1.22)	2.56 (1.26)	2.61 (1.33)	2.5 (1.28)
Full time employment [1=Yes]	0.59 (0.49)	0.59 (0.49)	0.58 (0.49)	0.68 (0.47)	0.6 (0.49)	0.57 (0.49)
Travel and residential variables						
Residing near transit [1= Important]	0.69 (0.46)	0.6 (0.49)	0.65 (0.48)	0.52 (0.5)	0.46 (0.5)	0.44 (0.5)
Identify as transit and/or pedestrian [1=Agree]	0.90 (0.3)	0.82 (0.39)	0.90 (0.3)	0.77 (0.42)	0.79 (0.41)	0.76 (0.42)
Know how PT system works [1=Agree]	0.93 (0.26)	0.89 (0.32)	0.95 (0.22)	0.85 (0.36)	0.86 (0.35)	0.85 (0.35)

Table 5.2 Descriptive statistics for small regions by mean (standard deviation)

	Québec	Winnipeg	Hamilton	Halifax	Victoria	Saskatoon
N	1301	1183	993	1100	1004	711
Perceived Accessibility by PT and/or Walking [1= Positive]						
Grocery stores	0.64 (0.48)	0.72 (0.45)	0.74 (0.44)	0.67 (0.47)	0.8 (0.4)	0.66 (0.47)
Healthcare	0.72 (0.45)	0.72 (0.45)	0.81 (0.39)	0.7 (0.46)	0.76 (0.43)	0.65 (0.48)
Leisure	0.54 (0.5)	0.69 (0.46)	0.77 (0.42)	0.64 (0.48)	0.72 (0.45)	0.61 (0.49)
All three destinations	0.43 (0.49)	0.51 (0.5)	0.6 (0.49)	0.48 (0.5)	0.6 (0.49)	0.44 (0.5)
Calculated Accessibility by PT						
Mean commute time in the region	35	35	40	35	30	35
N of accessible jobs (x10,000)	3.36 (3.56)	4.82 (4.39)	4.4 (2.88)	3.06 (3.06)	2.83 (2.25)	1.64 (1.67)
% of accessible jobs	9.0% (9.5%)	14.0% (12.8%)	16.1% (10.5%)	16.9% (16.9%)	18.8% (14.9%)	12.9% (13.1%)
Travel Behaviour (Weekly shopping, leisure, and healthcare)						
% of PT trips	6.2% (17)	10% (23)	11% (20)	8.9% (21)	8.3% (19)	8.2% (22)
% of walking trips	22% (30)	24% (28)	28% (27)	28% (31)	33% (31)	20% (26)
% of driving trips	65% (39)	59% (38)	56% (38)	58% (40)	48% (38)	68% (36)
Socioeconomic characteristics						
Gender [1=Woman]	0.49 (0.5)	0.59 (0.49)	0.59 (0.49)	0.58 (0.49)	0.54 (0.5)	0.62 (0.49)
Age	48 (15)	44 (16)	43 (16)	46 (16)	50 (18)	43 (17)
Low-income household [1= Yes]	0.18 (0.39)	0.3 (0.46)	0.5 (0.5)	0.3 (0.46)	0.51 (0.5)	0.58 (0.49)
Household size	2.36 (1.16)	2.58 (1.33)	2.66 (1.36)	2.39 (1.18)	2.25 (1.19)	2.53 (1.3)
Full time employment [1=Yes]	0.65 (0.48)	0.58 (0.49)	0.58 (0.49)	0.59 (0.49)	0.48 (0.5)	0.5 (0.5)
Travel and residential variables						
Residing near transit [1= Important]	0.48 (0.5)	0.49 (0.5)	0.48 (0.5)	0.46 (0.5)	0.49 (0.5)	0.35 (0.48)
Identify as transit and/or pedestrian [1=Agree]	0.70 (0.46)	0.81 (0.39)	0.83 (0.38)	0.79 (0.41)	0.86 (0.35)	0.78 (0.41)
Know how PT system works [1=Agree]	0.87 (0.33)	0.88 (0.32)	0.84 (0.37)	0.85 (0.36)	0.88 (0.32)	0.77 (0.42)

5.6 Analysis and results

Our research consists of multiple steps, all stratified by region. First, we identify the PMA and PSA thresholds by examining the relationship between calculated and perceived accessibility levels using binned log-linear regressions (**Figure 5.2**). We then assess the shares of the general and low-income populations that meet these thresholds and visualise the spatial distribution of the two thresholds across lower- and other-income areas. Finally, we examine walking and PT mode shares at the PMA and PSA thresholds using weighted linear regression models that control for socioeconomic factors, residential selection, travel identity, and travel attitudes.

5.6.1 Defining PMA and PSA thresholds

Within each region, participants were first ordered sequentially by the calculated accessibility values of their home locations. Based on this order, they were grouped into bins of 50 participants to ensure the reliability of and stability of information obtained from the selected groups (occasionally up to 53 to accommodate the full sample), resulting in a minimum of 14 bins in Saskatoon, a maximum of 40 bins in Montréal, and an average of 28 bins per region. The mean calculated proportional accessibility of participants in each bin was then computed and assigned to each bin.

For each bin, a perceived accessibility score (PA-score) was calculated as the percentage of participants who agreed that they could easily access their desired destinations for grocery, healthcare, and leisure separately, as well as for all three purposes combined, by walking and/or PT. Since the PA-score is computed as a percentage of agreement within a group, it converts individual binary responses into a continuous group-level measure.

Calculated accessibility by PT was used as a proxy for both PT and walking accessibility. This is because walking is explicitly incorporated into the travel time (TT) calculations (see Section 3.2); when walking is faster than PT, the TT in the accessibility calculations is the walking TT. Additionally, there is a strong positive correlation ($r = 0.73$) in our sample between PT accessibility and Walk Score®, a validated measure of neighbourhood walkability and amenity density (Carr et al., 2011). This association suggests that PT-based calculated accessibility reasonably captures both PT and walking accessibility in this study. Based on these groupings, binned log-linear regression analyses were conducted.

Each group's PA-score was plotted against its calculated proportional accessibility and log-linear models were fitted for each travel purpose as well as for all purposes combined, as displayed in **Figure 5.3**. The lines in shades of green correspond to the fitted log-linear models for each travel purpose, while the orange line represents the model estimated using all three purposes combined. The goodness of fit (R^2) of the combined-purposes models ranges from 0.46 to 0.86, with an average of 0.69. These goodness-of-fit values indicate that the log-linear models provide a sufficiently good fit to reliably identify the intended minimum and sufficient thresholds.

We identified the PMA and PSA at the intersection of the combined model's fitted line with the 50% and 75% PA-score (representing the percentage of participants with positive perceived accessibility), respectively. As the combined model line only surpasses the 75% score in the large regions; we only identified PSA for these regions.

To assess the sensitivity of the PMA and PSA estimates to the choice of threshold, we tested alternative PA-score cutoffs ranging from 40% to 60% for the PMA and from 65% to 85% for the PSA in 5 percentage point increments, computing the shift in estimated accessibility values per step for each region. Results confirm that estimated accessibility values remain stable at or below the chosen cutoffs but diverge rapidly above them, identifying PMA at 50% and PSA at 75% as natural breakpoints that converge with their grounding in majority and supermajority consensus conventions, respectively.

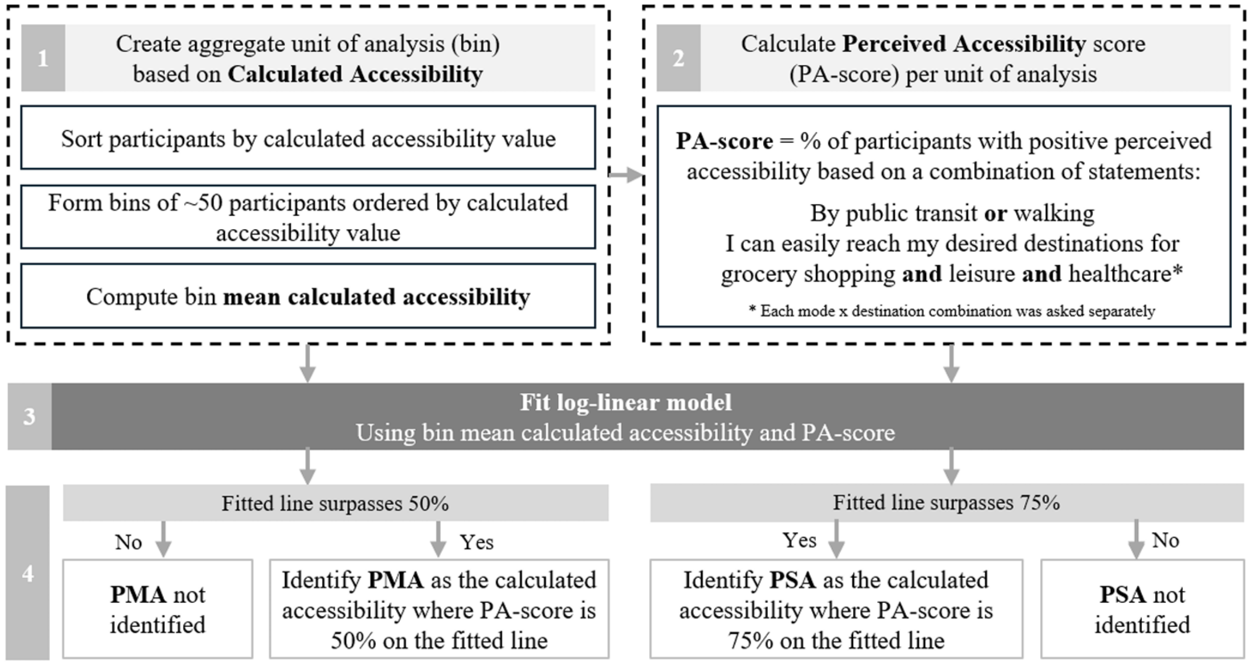

Figure 5.2 Methodological framework for identifying PMA and PSA using calculated and perceived accessibility

Table 5.3 shows the PMA diagnostics as a percentage and as a number of jobs accessible within the region's average travel time, as well as the percentage of the general and low-income population meeting that threshold. Low-income population statistics were calculated using the thresholds described in Section 3.1, without rounding to the nearest CAD 30,000, because this analysis was performed at the dissemination area (DA) level, which provides detailed median income for each DA. This approach allowed for identification of low- and other-income DAs and their corresponding populations. In the large regions (Toronto, Montréal, and Vancouver), the PMA threshold ranges between 1.02-1.32% of accessible jobs within average travel time by PT in the region, translating to 10,000-31,800 jobs. This threshold slightly increases in Hamilton and Victoria to range between 2.5-2.8% (4,200-6,700 jobs). For Edmonton, Calgary, Québec, Winnipeg, and Halifax, the PMA ranges between 5-7% (12,700-36,600 jobs). Ottawa-Gatineau and Saskatoon have the highest PMA reaching 11.3% and 19.7%, respectively. Ottawa-Gatineau's PMA translates to the highest job count requirement among all regions (67,400 jobs).

In terms of population coverage, Vancouver has the best performance with the lowest PMA among all regions (1.0%) covering 86.1% of its population and 97.7% of its low-income population. It is followed by Toronto, Montréal, Hamilton, and Victoria where the PMA serves at least 50% of their population and 82% of their low-income population. Meanwhile, all other regions' PMA serves less than 40% of the population. Regardless, most of these regions still serve a majority of the low-income population, except for Ottawa-Gatineau and Saskatoon. Despite their high PMA values, these two regions' PMA only meet about 14-17% of their total population and 36% of their low-income population.

Table 5.4 presents the same diagnostics as **Table 5.3**, however for PSA in large regions, as they are the only ones where the 75% PA-score was attainable. The PSA threshold is exponentially higher than the PMA for these regions, reaching 12.3%, 21.8%, and 23.1% in Toronto, Montréal, and Vancouver, respectively. These thresholds are represented by a range of 232,000-315,000 jobs. These thresholds are available for less than 25% of the population in each of the regions, and a much lower range of only 29-43% of the low-income population, compared to the PMA.

Figure 5.4 and **Figure 5.5** display the spatial distribution of perceived minimum and sufficient accessibility through classifying the DAs based on whether their calculated proportional accessibility values meet the PMA and PSA thresholds in their respective regions, stratified by income group. As portrayed in the tabulated diagnostics, large regions achieve widespread coverage of minimum accessibility for both low- and other-income groups across most parts of their CMAs, with gaps primarily at the urban periphery. However, perceived sufficient accessibility is largely concentrated in central areas, predominantly along rapid transit corridors with high destination density. As for the mid-size and small regions, PMA coverage is largely confined to central areas, leaving many low- and other-income census tracts without even basic access to essential destinations.

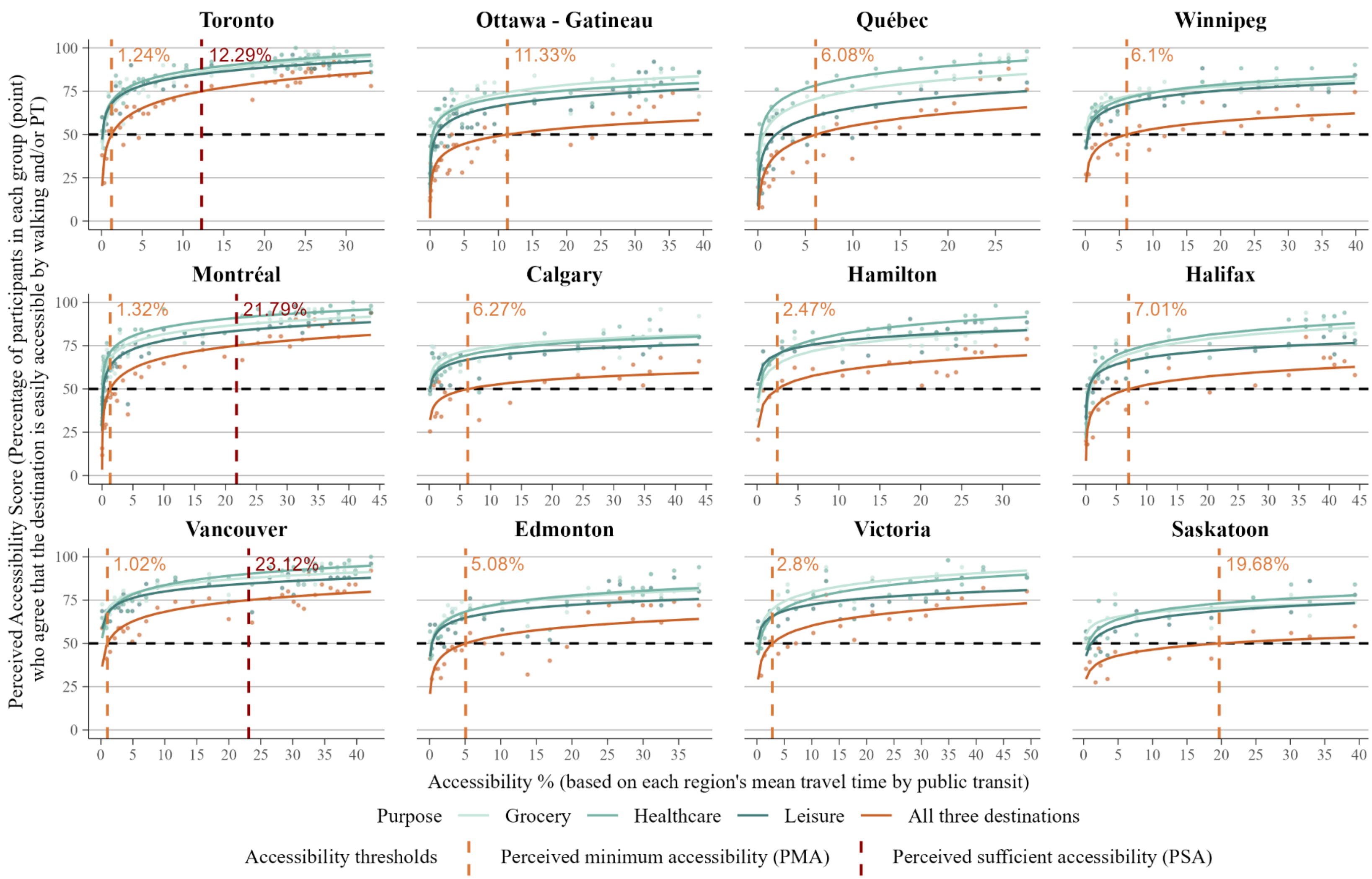

Figure 5.3 Perceived minimum accessibility (PMA) and Perceived sufficient accessibility (PSA) by region based on perceived accessibility score (PA-score) and calculated accessibility

Table 5.3 Perceived Minimum Accessibility (PMA) diagnostics

	Total jobs [x1,000]	**Total pop.** [x1,000]	**Low-income pop.** [x1,000]	**PMA** [% (Nx1,000 of jobs in region]	**Total pop. with PMA** [% (Nx1,000)]	**LI pop. with PMA** [% (Nx1,000)]
Large regions						
Toronto	2,566	6,202	1,910	**1.2%** (31.8)	**65.5%** (4,064)	**92.7%** (1,770)
Montréal	1,753	4,292	1,291	**1.3%** (23.2)	**59.4%** (2,549)	**85.3%** (1,102)
Vancouver	1,003	2,643	814	**1.0%** (10.2)	**86.1%** (2,276)	**97.7%** (795)
Mid-size regions						
Ottawa - Gatineau	595	1,488	456	**11.3%** (67.4)	**16.7%** (248)	**35.8%** (163)
Calgary	584	1,482	452	**6.3%** (36.6)	**29.4%** (436)	**55.5%** (251)
Edmonton	552	1,418	426	**5.1%** (28.0)	**34.3%** (486)	**70.1%** (299)
Small regions						
Québec	375	839	253	**6.1%** (22.8)	**27.2%** (228)	**64.0%** (162)
Winnipeg	343	835	258	**6.1%** (20.9)	**38.2%** (319)	**72.2%** (186)
Hamilton	273	785	241	**2.5%** (6.7)	**57.1%** (449)	**89.8%** (217)
Halifax	181	466	143	**7.0%** (12.7)	**23.9%** (111)	**48.2%** (69)
Victoria	151	397	121	**2.8%** (4.2)	**51.1%** (203)	**82.4%** (100)
Saskatoon	127	317	97	**19.7%** (25.0)	**14.6%** (47)	**36.3%** (35)

Table 5.4 Perceived sufficient accessibility PSA diagnostics (for large regions only)

	Total jobs [x1,000]	**Total pop.** [x1,000]	**Low-income pop.** [x1,000]	**PSA** [% (Nx1,000 of jobs in region]	**Total pop. with PSA** [% (Nx1,000)]	**LI pop. with PSA** [% (Nx1,000)]
Large regions						
Toronto	2,566	6,202	1,910	**12.3%** (315)	**17.4%** (1,082)	**29.0%** (553)
Montréal	1,753	4,292	1,291	**21.8%** (382)	**23.3%** (999)	**43.0%** (555)
Vancouver	1,003	2,643	814	**23.1%** (232)	**23.4%** (620)	**38.6%** (314)

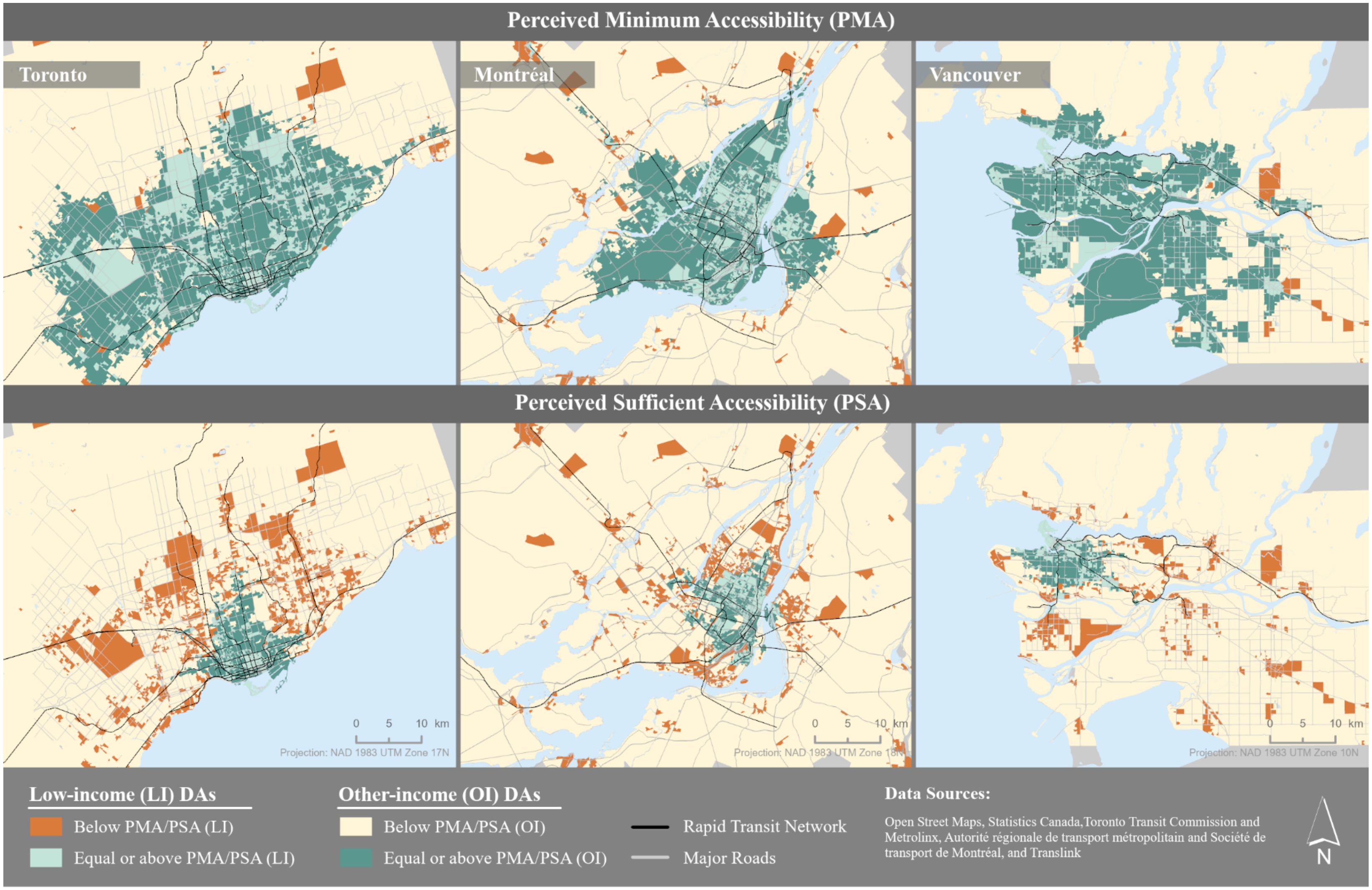

Figure 5.4 DAs in large regions classified by whether their proportional calculated accessibility meets the PMA and PSA thresholds, by income group.

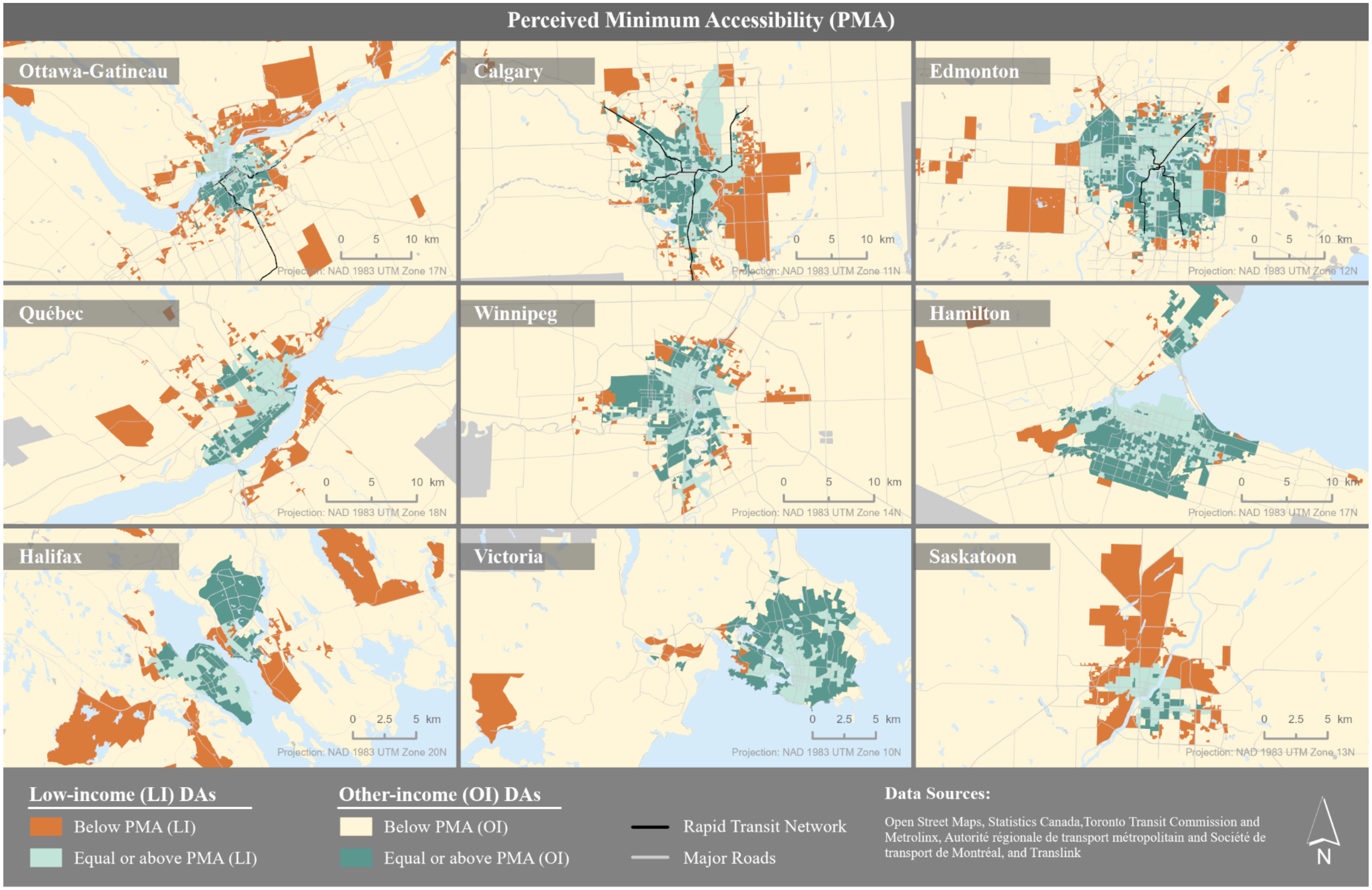

Figure 5.5 DAs in mid-size and small regions classified by whether their proportional calculated accessibility meets the PMA thresholds, by income group

5.6.2 PMA, PSA, and travel behaviour

To assess the connection between the identified thresholds and travel behaviour, we ran weighted linear regressions for each region, with the dependent variable being the percentage of weekly trips performed by walking and PT combined to grocery stores, healthcare, and leisure destinations. Weighted regression models accounted for potential sampling bias in the cleaned survey data. We calculated the weights using the anesrake R package (Pasek, 2018), following an iterative ranking process (DeBell & Krosnick, 2009). The weights were calculated to match the census-tract information of age, income, gender, and commute mode obtained from the 2021 Canadian census (Statistics Canada, 2023a), as well as the most recent commute mode share data retrieved from Statistics Canada (2024). These models account for socioeconomic characteristics, travel-attitude and identity factors, residential selection, and most importantly for this research, calculated accessibility.

For brevity, **Table 5.5** presents a subset of results for three representative regional groups: Toronto (large region), Ottawa–Gatineau (mid-size region), and Halifax (small region). The complete set of regression results is provided in Appendix 5.A. The model fit (R^2) in the three displayed models ranged from 0.35 to 0.37, indicating moderate explanatory power, which is typical for models of travel behaviour. In all models, four factors are consistently statistically significant: employment statuses, travel identity, perceived accessibility, and calculated accessibility by PT. Other variables are statistically significant in most, but not all, regions, highlighting regional heterogeneity and justifying the estimation of separate models to improve accuracy.

Consistent with previous literature, older participants tend to have a lower walking and PT mode share, ceteris paribus (Brown et al., 2016; Ghani et al., 2016; Newbold & Scott, 2018; Ozbilen et al., 2024; Ravensbergen et al., 2023). Full-time employment is associated with a decrease of 7.8 to 9.2 percentage points in walking and PT mode share, all else held constant. Accounting for residential self-selection is essential to avoid overestimating the influence of the built environment on travel behaviour (Cao et al., 2009). In our models, the importance of residing near PT is positively associated with walking and PT use.

Knowing how the PT system operates in one's region is associated with an increase of approximately 5 percentage points in walking and PT mode share ceteris paribus. Travel identity is a crucial control variable in our models, as previously discussed by Negm and El-Geneidy (2025). Identifying as a pedestrian and/or transit user is associated with an increase of approximately 13.7 to 19.9 percentage points in weekly walking and PT mode share, holding other variables at their mean values. Consistent with prior research (Negm & El-Geneidy, 2025), having positive perceived accessibility by walking and/or PT is associated with a statistically significant increase of 10.3 to 13.6 percentage points in mode share, ceteris paribus.

The key variable of interest is calculated accessibility. Prior research has established calculated accessibility as a predictor of walking mode share at the local scale (Elldér et al., 2020; Manaugh & El-Geneidy, 2011) and PT mode share on the regional scale (Cui et al., 2020; Moniruzzaman & Páez, 2012; Negm & El-Geneidy, 2024; Owen & Levinson, 2015). Across all regions, proportional calculated accessibility by PT is statistically significant and positively associated with walking and PT mode share to essential destinations, although the magnitude varies regionally. A one-percentage-point increase in jobs accessible by PT is associated with a 0.6 to 1.1 percentage-point increase in walking and PT mode share, all else kept the mean value.

To specifically investigate the relationship of mode share with PMA and PSA, we conducted a marginal effects analysis using the estimated regional models. We defined a representative profile: a 45-year-old full-time employed man in a two-person household who identifies as a transit user, considers proximity to PT important in residential choice, reports knowing how the PT system operates in his region, and have positive perceived accessibility. The analysis was conducted for both low-income and other-income households.

Figure 5.6 presents the predicted weekly walking and PT mode share as calculated proportional accessibility increases for low- and other-income individuals. The mode share difference between income groups is most pronounced in the three large regions in addition to Victoria and Halifax with people in low-income households making 3.7 to 5 percentage points more trips than in other-income ones (as shown in Appendix 5.A), This is illustrated by the green lines being consistently higher than the grey ones in the figure. These higher mode shares among low-income households reflect greater reliance on walking and public transport, suggesting that accessibility thresholds may have stronger behavioural consequences for these groups (Freeland et al., 2013; Negm & El-Geneidy, 2024).

For brevity, we report the low-income household case. In large regions, PMA is associated with approximately 33% of walking and PT mode share on average, while PSA is associated with a heightened range of approximately 46% mode share on average. In mid-size and small regions, PMA is associated with a range of 24 to 39% mode share, with an average of 32%, similar to the large regions. Overall, PMA achieves basic levels of walking and PT mode share, while PSA (as shown in the large regions) dramatically increases this mode share.

Mode share targets are a common metric in transport planning. For example, the cities of Montréal, and Vancouver aim for 75% and 67% of trips to be conducted by PT and active modes, respectively (City of Vancouver, 2012; Ville de Montréal, 2025). Our analysis shows that these targets are unattainable if planning focuses solely on PMA, which can only provide basic access to destinations. Planning for the PSA in these large regions have the potential of approaching the planned mode share targets and achieving sustainable goals. While we do not specify the PSA for mid-sized and small regions since the PA-score rarely exceeded 75% (**Figure 5.3**), planning beyond the PMA in these regions remains important to increase sustainable mode share and promote equitable access.

Table 5.5 Weighted linear regressions with weekly walking and transit mode share to grocery, healthcare and leisure as the dependent variable (Subset from each region size)

	Toronto (Large region)			**Ottawa - Gatineau (Medium region)**			**Halifax (Small region)**		
Predictor	**Coef.**		**CI**	**Coef.**		**CI**	**Coef.**		**CI**
Intercept	6.47		-1.50 – 14.44	**6.41**		-0.51 – 13.32	4.85		-4.20 – 13.91
Socioeconomic characteristics									
Gender [Woman]	2.00		-0.48 – 4.48	-1.38		-3.68 – 0.93	**-3.87**	**	-6.80 – -0.94
Age	**-0.13**	**	-0.21 – -0.05	**-0.18**	***	-0.26 – -0.11	-0.06		-0.16 – 0.03
Low-income household	**3.82**	**	1.22 – 6.43	2.35		-0.25 – 4.96	**4.46**	**	1.30 – 7.62
Household size	**-1.13**	*	-2.13 – -0.13	-0.33		-1.35 – 0.69	0.31		-0.98 – 1.60
Full time empl.	**-9.23**	***	-12.03 – -6.43	**-7.80**	***	-10.46 – -5.15	**-8.54**	***	-11.82 – -5.27
Travel and residential variables									
RSS near transit	1.48		-1.26 – 4.22	2.43		-0.05 – 4.92	**7.67**	***	4.53 – 10.82
Know how PT system work	**5.24**	**	1.32 – 9.15	**5.20**	**	2.10 – 8.30	-1.62		-5.58 – 2.34
Ident: PT user and/or Ped.	**19.96**	***	16.69 – 23.22	**13.71**	***	10.98 – 16.44	**15.56**	***	12.16 – 18.95
Perceived Accessibility									
By walking and/or PT to all destinations	**10.56**	***	7.90 – 13.22	**13.63**	***	11.12 – 16.14	**10.30**	***	7.20 – 13.41
Calculated Accessibility by PT									
% of jobs access. by PT	**1.10**	***	0.97 – 1.24	**0.78**	***	0.67 – 0.90	**0.55**	***	0.44 – 0.65
Observations	**1950**			**1764**			**1100**		
R 2 / R 2 adjusted	**0.373 / 0.369**			**0.354 / 0.350**			**0.349 / 0.344**		

* p<0.05 ** p<0.01 *** p<0.001

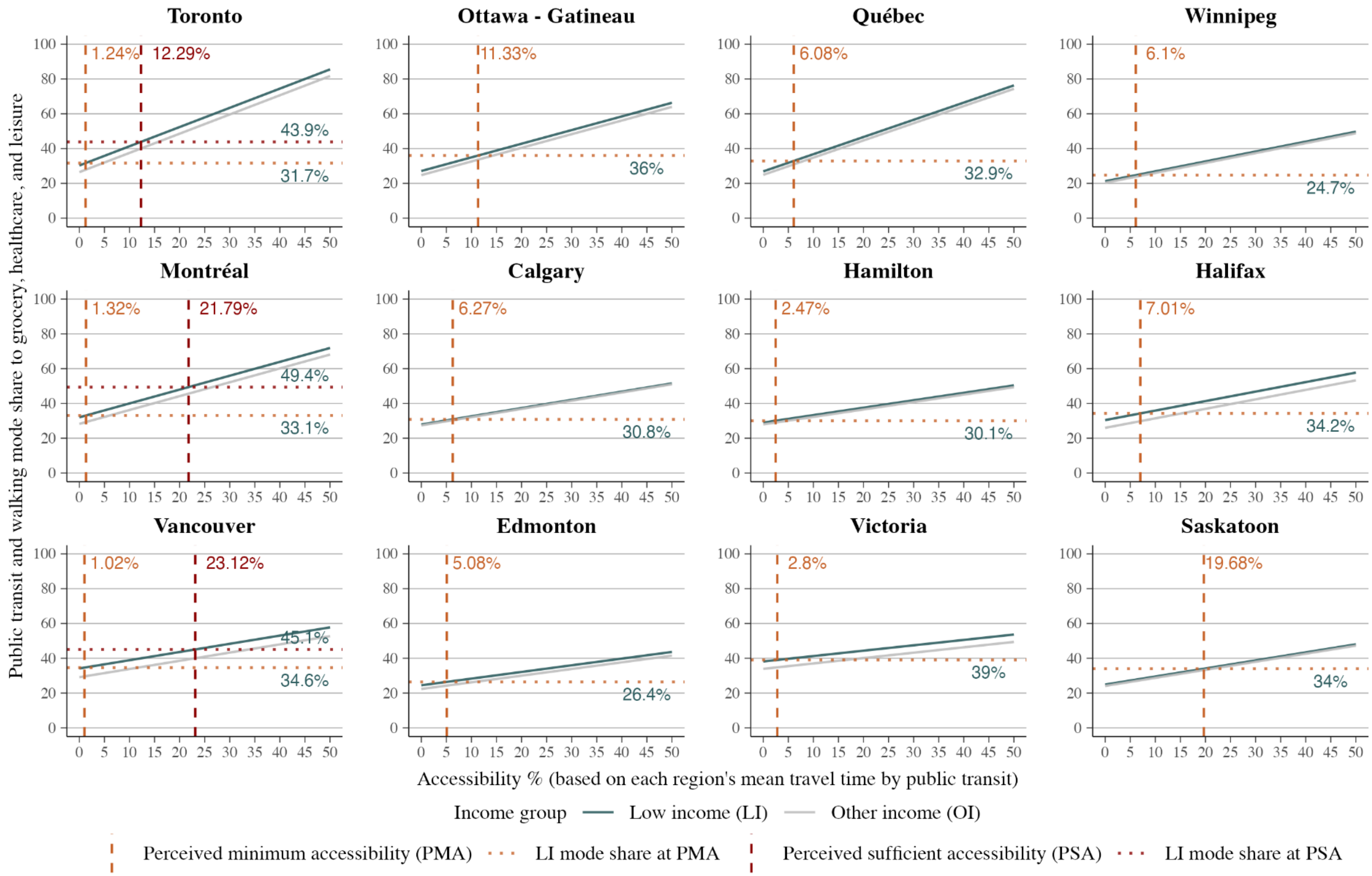

Figure 5.6 Marginal effects of accessibility on PT and walking mode share, with reference lines showing the low-income sample's mode share at PMA and PSA

5.7 Conclusion

Paving the way for the implementation of accessibility in practice, this paper provides a methodology to identify region-specific PMA thresholds that allow the population basic access to essential destinations, as well as PSA thresholds that ensure convenient access to these destinations. Rather than prescribing normative standards, these benchmarks are grounded in observed distributions of calculated and perceived accessibility, offering a replicable and transferable tool to support transport planning and evaluation. In doing so, the paper responds to calls for more operational approaches to accessibility that can be readily applied in practice (Karner et al., 2024; Martens, 2016; Pereira et al., 2017; Ryan & Martens, 2023).

Using 12 regions in Canada as case studies and relying on nationwide transport survey data, we examine the share of the population meeting PMA and PSA levels. We find that large metropolitan regions such as Toronto, Montréal, and Vancouver have relatively small gaps to close in achieving PMA for their low-income populations, enabling basic access to essential destinations by walking or PT However, further efforts are required to extend this basic access to the entire population. In contrast, substantially greater efforts are needed to close PSA gaps. For example, in Toronto, only 29% of the low-income population surpasses the PSA threshold.

Our analysis highlights critical transport and land use planning challenges in several regions. For instance, in Ottawa–Gatineau, the 11.3% PMA level translates into an extremely high job count (67,400 jobs) needed just to achieve basic access to essential destinations, with only 16.7% of the total population and 35.8% of the low-income population meeting that threshold. These diagnostics are crucial for identifying regions that require targeted policy intervention.

When examining the relationship between PMA and PSA and weekly walking and PT mode share to shopping, leisure, and healthcare destinations, we find that substantially higher levels of sustainable mode share can be achieved when planning targets sufficient rather than merely minimum accessibility. This finding highlights the need for stronger planning ambitions to achieve regional sustainable mode share targets (Negm & El-Geneidy, 2024).

This research provides practical value for planning and transport professionals seeking to promote equitable access through transparent metrics and replicable benchmarks. Based on the identified thresholds, planners and policymakers should prioritize improvements in underserved areas by enhancing public transport systems, improving walkability and street design, and conducting outreach campaigns that introduce residents to available transit options. Perceived accessibility plays a central role in these metrics; interventions that increase perceived accessibility scores can make PMA and PSA thresholds more attainable.

A consideration when using perceived accessibility to inform thresholds is that perceptions may not fully capture unmet needs, particularly among disadvantaged groups who may have adapted their expectations under constrained conditions. Clifton and Moura (2017) describe this phenomenon in the context of latent and suppressed demand. In this sense, thresholds derived from perceived accessibility may partly reflect current patterns of experienced access rather than an ideal level of sufficiency. We therefore propose that PMA and PSA be interpreted as descriptive benchmarks grounded in observed distributions of calculated and perceived accessibility, rather than normative standards of what access ought to be. Their value lies in providing an empirically grounded and replicable reference point to support planning decisions, complementing rather than replacing broader deliberative processes for defining sufficient access.

Future research could explore whether income- or gender-stratified analyses yield different accessibility thresholds. It could develop purpose-specific accessibility thresholds for destination types such as grocery stores, healthcare, and leisure, which would allow for more direct comparisons with perceived accessibility measures. Moreover, while the quartile-based approach used to define PMA and PSA ensures transparency and replicability, it relies on the availability of perceived accessibility data, which may not be available in all regions. Future research could also focus on low-mobility populations, such as those making fewer than four trips per week, who tend to be older, more likely to report a disability, and in some regions more likely to be low-income. Future research should explore alternative approaches that incorporate lived experience when defining accessibility thresholds.

Appendix 5.A

Table 5.A.1 Large regions weighted linear regressions with weekly walking and transit mode share to grocery, healthcare and leisure as the dependent variable

	Toronto			Montréal			Vancouver		
Predictor	**Coef.**		**CI**	**Coef.**		**CI**	**Coef.**		**CI**
Intercept	6.47		-1.50 – 14.44	**7.28**	*	0.43 – 14.14	**10.81**	*	1.20 – 20.42
Socioeconomic characteristics									
Gender [Woman]	2.00		-0.48 – 4.48	1.30		-1.01 – 3.61	**6.89**	***	4.05 – 9.73
Age	**-0.13**	**	-0.21 – -0.05	**-0.21**	***	-0.28 – -0.13	**-0.17**	***	-0.26 – -0.09
Low-income household	**3.82**	**	1.22 – 6.43	**3.77**	**	1.23 – 6.31	**5.05**	**	1.95 – 8.16
Household size	**-1.13**	*	-2.13 – -0.13	-0.75		-1.69 – 0.19	**-1.92**	**	-3.16 – -0.68
Full time empl.	**-9.23**	***	-12.03 – -6.43	**-7.46**	***	-9.98 – -4.93	**-10.59**	***	-13.83 – -7.35
Travel and residential variables									
RSS near transit	1.48		-1.26 – 4.22	**6.15**	***	3.57 – 8.74	**6.83**	***	3.81 – 9.85
Know how PT system work	**5.24**	**	1.32 – 9.15	1.54		-1.92 – 5.00	-0.45		-6.02 – 5.11
Ident: PT user and/or Ped.	**19.96**	***	16.69 – 23.22	**17.16**	***	14.19 – 20.12	**18.29**	***	14.49 – 22.09
Perceived Accessibility									
By walking and/or PT to all destinations	**10.56**	***	7.90 – 13.22	**14.33**	***	11.79 – 16.87	**15.90**	***	12.95 – 18.85
Calculated Accessibility by PT									
% of jobs access. by PT	**1.10**	***	0.97 – 1.24	**0.80**	***	0.70 – 0.89	**0.47**	***	0.36 – 0.58
Observations	**1950**			**2036**			**1612**		
R^2 / R^2 adjusted	**0.373 / 0.369**			**0.385 / 0.383**			**0.329 / 0.325**		

* p<0.05 ** p<0.01 *** p<0.001

Table 5.A.2 Mid-size regions weighted linear regressions with weekly walking and transit mode share to grocery, healthcare and leisure as the dependent variable

	Ottawa - Gatineau			Calgary			Edmonton		
Predictor	**Coef.**		**CI**	**Coef.**		**CI**	**Coef.**		**CI**
Intercept	**6.41**		-0.51 – 13.32	**13.45**	**	3.97 – 22.93	-0.33		-7.56 – 6.90
Socioeconomic characteristics									
Gender [Woman]	-1.38		-3.68 – 0.93	**-2.99**	*	-5.97 – -0.01	1.83		-0.55 – 4.22
Age	**-0.18**	***	-0.26 – -0.11	**-0.11**	*	-0.21 – -0.00	-0.01		-0.09 – 0.07
Low-income household	2.35		-0.25 – 4.96	0.50		-2.73 – 3.73	2.13		-0.39 – 4.64
Household size	-0.33		-1.35 – 0.69	**-1.60**	*	-2.85 – -0.34	-0.65		-1.62 – 0.32
Full time empl.	**-7.80**	***	-10.46 – -5.15	**-8.35**	***	-11.66 – -5.04	**-4.26**	**	-6.85 – -1.67
Travel and residential variables									
RSS near transit	2.43		-0.05 – 4.92	**5.32**	**	2.11 – 8.53	**4.95**	***	2.21 – 7.69
Know how PT system work	**5.20**	**	2.10 – 8.30	-0.81		-4.90 – 3.28	-0.20		-3.37 – 2.98
Ident: PT user and/or Ped.	**13.71**	***	10.98 – 16.44	**16.88**	***	13.42 – 20.34	**15.63**	***	12.88 – 18.39
Perceived Accessibility									
By walking and/or PT to all destinations	**13.63**	***	11.12 – 16.14	**8.83**	***	5.72 – 11.94	**8.51**	***	6.02 – 11.00
Calculated Accessibility by PT									
% of jobs access. by PT	**0.78**	***	0.67 – 0.90	**0.47**	***	0.36 – 0.58	**0.38**	***	0.27 – 0.49
Observations	**1764**			**1052**			**1254**		
R 2 / R 2 adjusted	**0.354 / 0.350**			**0.271 / 0.264**			**0.270 / 0.265**		

* p<0.05 ** p<0.01 *** p<0.001

Table 5.A.3 Small regions weighted linear regressions with weekly walking and transit mode share to grocery, healthcare and leisure as the dependent variable

	Québec			Winnipeg			Hamilton		
Predictor	**Coef.**		**CI**	**Coef.**		**CI**	**Coef.**		**CI**
Intercept	10.30	*	2.09 – 18.50	3.81		-4.86 – 12.49	3.97		-5.76 – 13.69
Socioeconomic characteristics									
Gender [Woman]	-0.35		-2.99 – 2.28	-0.08		-2.85 – 2.68	0.34		-2.74 – 3.42
Age	**-0.17**	***	-0.26 – -0.08	-0.03		-0.12 – 0.06	**-0.16**	**	-0.26 – -0.05
Low-income household	1.97		-1.07 – 5.01	0.92		-2.21 – 4.05	1.03		-2.37 – 4.44
Household size	-0.56		-1.86 – 0.74	**-1.35**	*	-2.48 – -0.22	-0.21		-1.48 – 1.06
Full time empl.	**-8.78**	***	-11.84 – -5.71	**-6.04**	***	-9.13 – -2.95	**-9.45**	***	-12.97 – -5.93
Travel and residential variables									
RSS near transit	**6.53**	***	3.58 – 9.48	**3.18**	*	0.18 – 6.19	**5.93**	***	2.57 – 9.28
Know how PT system work	0.05		-3.71 – 3.80	1.58		-2.42 – 5.58	**7.23**	***	3.43 – 11.03
Ident: PT user and/or Ped.	**15.57**	***	12.61 – 18.53	**15.30**	***	12.07 – 18.53	**17.07**	***	13.35 – 20.78
Perceived Accessibility									
By walking and/or PT to all destinations	**10.11**	***	7.09 – 13.14	**6.31**	***	3.42 – 9.20	**10.74**	***	7.49 – 13.99
Calculated Accessibility by PT									
% of jobs access. by PT	**0.99**	***	0.81 – 1.17	**0.57**	***	0.44 – 0.70	**0.43**	***	0.27 – 0.59
Observations	**1301**			**1183**			**993**		
R 2 / R 2 adjusted	**0.396 / 0.391**			**0.220 / 0.213**			**0.287 / 0.280**		

* p<0.05 ** p<0.01 *** p<0.001

Table 5.A.4 Small region (Continued) weighted linear regressions with weekly walking and transit mode share to grocery, healthcare and leisure as the dependent variable

	Halifax			Victoria			Saskatoon		
Predictor	**Coef.**		**CI**	**Coef.**		**CI**	**Coef.**		**CI**
Intercept	4.85		-4.20 – 13.91	-7.63		-17.31 – 2.04	-4.24		-12.12 – 3.64
Socioeconomic characteristics									
Gender [Woman]	**-3.87**	**	-6.80 – -0.94	-1.91		-5.05 – 1.24	-1.73		-4.59 – 1.12
Age	-0.06		-0.16 – 0.03	0.02		-0.08 – 0.12	-0.02		-0.10 – 0.07
Low-income household	**4.46**	**	1.30 – 7.62	**4.25**	*	0.98 – 7.53	0.79		-2.28 – 3.87
Household size	0.31		-0.98 – 1.60	-0.42		-1.71 – 0.87	0.28		-0.96 – 1.52
Full time empl.	**-8.54**	***	-11.82 – -5.27	-3.01		-6.55 – 0.53	0.09		-2.97 – 3.15
Travel and residential variables									
RSS near transit	**7.67**	***	4.53 – 10.82	**8.55**	***	5.15 – 11.94	**9.27**	***	5.84 – 12.70
Know how PT system work	-1.62		-5.58 – 2.34	1.26		-3.17 – 5.68	1.98		-1.37 – 5.33
Ident: PT user and/or Ped.	**15.56**	***	12.16 – 18.95	**20.82**	***	17.01 – 24.63	**11.28**	***	8.02 – 14.54
Perceived Accessibility									
By walking and/or PT to all destinations	**10.30**	***	7.20 – 13.41	**13.83**	***	10.59 – 17.07	**5.86**	***	2.84 – 8.87
Calculated Accessibility by PT									
% of jobs access. by PT	**0.55**	***	0.44 – 0.65	**0.31**	***	0.20 – 0.42	**0.46**	***	0.34 – 0.59
Observations	**1100**			**1004**			**711**		
R 2 / R 2 adjusted	**0.349 / 0.344**			**0.311 / 0.304**			**0.252 / 0.241**		

* p<0.05 ** p<0.01 *** p<0.001

Chapter 6. Discussion

6.1 Overview

Through the four studies presented in Chapters 2 to 5, this dissertation addresses the main research question: How can calculated and perceived accessibility be operationalized in transport planning practice? Chapter 2 establishes a clear conceptual definition and empirical research framework for calculated and perceived accessibility. Chapter 3 confirms the association between accessibility and travel behaviour at the aggregate level, while Chapter 4 examines this relationship at the disaggregate level. Finally, Chapter 5 develops and tests perception-based accessibility thresholds to inform planning practice. Across these studies, calculated and perceived accessibility are linked to key transport planning outcomes, including mode share, travel behaviour, and accessibility planning thresholds. Because these relationships are interrelated, the findings collectively provide cohesive set of policy recommendations that advance the operationalization of accessibility in practice. This discussion chapter synthesizes the theoretical, empirical, and methodological contributions of the dissertation, along with its policy implications. It concludes by outlining the limitations of the dissertation followed by directions for future research.

6.2 Theoretical discussion

This dissertation advances several theoretical dimensions within transport planning across its four studies. First, Chapter 2 develops a clear definition and conceptual framework that positions perceived accessibility within the transport planning literature. Second, Chapters 3 and 4 situate accessibility within the *Capability Approach* as a comprehensive planning framework, examined through a top-down (aggregate) and bottom-up (disaggregate) perspective, respectively. Finally, Chapter 5 integrates these perspectives by complementing the *Capability Approach* with sufficientarianism.

Based on the literature review conducted in Chapter 2, perceived accessibility is defined as the ***perception of how easily one can access their desired destinations using a (range of) specific mode(s)***. This mode- and destination- specific definition captures the interaction between the core aspects of accessibility (land-use and transport system) and individual perception. Drawing on the reviewed empirical studies and conceptual work (De Vos et al., 2023; Pot et al., 2021; van der Vlugt et al., 2022; van Wee, 2022), the chapter introduces an accessibility-centered conceptual framework that consolidates established relationships in the transport field and proposes new ones. The framework illustrates the interrelationships among calculated and perceived accessibility, residential self-selection, socioeconomic characteristics and personal resources, travel experience, and travel attitudes. By recognizing both the direct and indirect effects of calculated and perceived accessibility on travel behaviour, the framework positions accessibility as a capability that can be examined from a top-down planning perspective at the aggregate level and/or from a bottom-up perspective at the disaggregate level.

Chapter 3 adopts the top-down perspective, focusing on transport and land use systems and conceptualizing accessibility as a capability enabling individuals to reach valued destinations. It examines the association between calculated accessibility and travel behaviour at the aggregate level across the three largest regions in Canada in the post–COVID-19 era. The findings confirm that calculated accessibility remains a robust planning tool despite shifts in travel behaviour and attitudes (Kroesen et al., 2017; Rahman & Sciara, 2022).

Chapter 4 advances the bottom-up perspective of the *Capability Approach* by focusing on individual experience. It investigates how perceived accessibility, alongside calculated accessibility, is associated with individuals' weekly mode share at both the local scale (for walking) and regional scale (public transit), while accounting for personal characteristics and attitudes, including gender, age, income, household size, employment status, and travel identity.

Finally, Chapter 5 bridges the top-down and bottom-up perspectives (as proposed in Section 1.2.3) by examining the interaction between calculated and perceived accessibility and by proposing a replicable methodology for identifying accessibility thresholds with direct policy relevance. Beyond the *Capability Approach*, the chapter engages with sufficientarianism by introducing two complementary thresholds: minimal access and sufficient access. In response to critiques that sufficiency thresholds may be set too low to meaningfully support well-being (Hananel & Berechman, 2016), the chapter distinguishes between basic access (minimal threshold) and convenient access to essential destinations (sufficient threshold). In doing so, it advances the theoretical discussion on *sufficientarianism* by clarifying how different levels of access relate to various outcomes.

6.3 Empirical discussion

This section synthesizes the empirical findings of Chapters 3 to 5 under three main themes: (1) the relationship between calculated and perceived accessibility and travel behaviour (2) the role of travel identity as a confounding factor in travel behaviour research, and (3) the mismatch between calculated and perceived accessibility.

6.3.1 Accessibility and travel behaviour

Throughout the three studies in Chapters 3 to 5, accessibility has been shown to be strongly associated with travel behaviour on the aggerate and disaggregate levels across different regions in Canada, income-groups, and travel purposes. In Chapter 3, aggregate-level analysis at the census tract scale in Toronto, Montréal, and Vancouver confirm that accessibility-based planning remains an effective strategy for supporting public transit commute mode share in the post-COVID-19 pandemic era. Higher levels of calculated accessibility continue to be positively associated with higher public transit commute shares. While the magnitude of this association has weakened compared to the pre-pandemic period, calculated accessibility continues to have a stronger association with public transit mode share among low-income groups than among other-income groups, consistent with pre-pandemic patterns.

The chapter confirms the quadratic nature of the relationship between calculated accessibility and public transit mode share, as shown by Cui and El-Geneidy (2019). Increases in accessibility are associated with increases in public transit mode share up to a certain threshold, beyond which further increases are associated with declining public transit shares. This non-linear pattern likely reflects the higher prevalence of active modes of travel (walking and cycling) in highly accessible areas near regional city centers where accessibility levels peak. Therefore, improvements in accessibility are beneficial only up to a context-specific threshold that must be carefully identified in planning practice. This relationship was still present after the COVID-19 pandemic highlighting the importance of understanding the association between accessibility and travel behaviour in the new normal. However, the link between calculated accessibility and public transit mode share is less pronounced in the post-pandemic era. While the association is still statistically significant, its magnitude has decreased. This indicates that to plan for increasing mode choice in the post-pandemic era professionals need to target higher level levels of accessibility to reach same levels of mode choices that were targeted or reached in the pre-pandemic times with much lower accessibility targets.

In Chapter 4, disaggregate-level analysis at the individual scale in Montréal confirms that calculated and perceived accessibility by walking and public transit are positively associated with the weekly walking and transit mode share, respectively, for all purposes, namely work, school, leisure, healthcare, and shopping. Since the literature on perceived accessibility and travel behaviour is still emerging (Andersson et al., 2023; Lättman et al., 2020; Mehdizadeh & Kroesen, 2025; Tanimoto & Hanibuchi, 2021; Vafeiadis & Elldér, 2024a), these findings provide important insights. After accounting for key confounding factors, individuals reporting positive perceived accessibility by walking are associated with 15.53 percent more of their trips being on foot, while those reporting positive perceived accessibility by public transit are associated with 10.57 percent more of their trips using public transit, compared to individuals with negative perceptions, holding all else constant. The findings from this chapter highlights the importance of perceived accessibility in travel behaviour decisions at the regional and local levels.

Finally, Chapter 5 that mainly aims to guide accessibility-based planning in practice utilizes a sample of 15,960 participants in 12 Canadian regions to reveal the magnitude of association between different calculated accessibility thresholds and the weekly mode share for essential destinations. Using perceived accessibility as a control variable among other confounding factors of travel behaviour in the statistical models, the study shows that a one-percentage-point increase in jobs accessible by public transit is associated with a 0.6 to 1.1 percentage-point increase in walking and public transit mode share, region-dependent, all else kept the mean value. The chapter shows how perceived accessibility can be incorporated in planning practice to set calculated accessibility targets, minimum and sufficient, and the impacts of these targets on mode choice.

Together, these three chapters demonstrate that both calculated and perceived accessibility by sustainable modes are consistently positively associated with sustainable travel behaviour, highlighting the value of incorporating accessibility into planning and policy to support equitable access to opportunities across different socioeconomic groups and travel purposes.

6.3.2 Travel identity as a confounding factor to travel behaviour

A key contribution of Chapters 3 and 4 is the inclusion of a travel identity variable to account for individuals' subjective preferences, as recommended by Heinen (2016), in the statistical models alongside established travel behaviour determinants such as socioeconomic characteristics and residential self-selection variables, discussed in Section 1.2.2. In the statistical models of both chapters, a binary variable was constructed based on participants' level of agreement with the statement: "I consider myself a [mode user]," including driving, public transit, walking, and cycling. Participants were able to identify with multiple modes, for example, "I consider myself a transit user and a pedestrian."

This variable allows the models to better isolate the association between calculated and perceived accessibility and travel behaviour by accounting for underlying preferences and self-identification with specific modes. The approach is conceptually similar to controlling for residential self-selection when examining how contextual factors tied to location, such as calculated accessibility, are associated with travel behaviour (Cao et al., 2009; van Wee, 2009).

Empirically, Chapter 4 shows that incorporating travel identity improves model fit, increasing R-squared values in predicting weekly walking and public transit trips by 0.014 and 0.093 respectively. In Chapter 5, identifying as a pedestrian or transit user is associated with an increase of approximately 13.7 to 19.9 percentage points in weekly walking and public transit mode share, holding other variables at their mean values. These findings underscore the importance of accounting for travel identity and attitudes to avoid overstating the association between calculated and perceived accessibility and travel behaviour.

6.3.3 Mismatch between calculated and perceived accessibility

Chapter 4 shows a visual mismatch between calculated and perceived accessibility levels through maps and three-variable scatter plots of the two accessibility variables and travel behaviour which aligns with the mismatch found in previous studies (Pot et al., 2023a, 2023b; Vafeiadis, 2024; Vafeiadis & Elldér, 2024b). However, this chapter uses a mode-specific but not destination-specific measure of perceived accessibility, which hindered the deeper examination of this mismatch. This limitation was addressed in Chapter 5, where participants evaluated a mode- and destination-specific statement: "By [mode], I can easily access my desired destination for [purpose]."

In this chapter, the term perceived accessibility score (PA-score) was used to represent the percentage of participants who agreed that they could easily access their desired destinations for grocery shopping, healthcare, and leisure separately, as well as for all three purposes combined, by walking and/or public transport.When plotting the PA-score against the calculated accessibility measure, a clearer and more detailed mismatch emerged. In a perfect alignment, the PA-score would begin at a relatively low level at the lowest calculated accessibility values (reflecting predominantly negative perceptions) and follow an increasing curve, reaching high values at the highest calculated accessibility levels (reflecting predominantly positive perceptions). Because the plot included separate lines for different purposes, it enabled the examination of mismatch patterns across regions in Canada.

The results indicate that the mismatch is most pronounced when considering the combined destinations measure. In contrast, the mismatch is substantially reduced when each purpose is examined individually. Notably, the three largest metropolitan regions (Toronto, Montréal, and Vancouver) exhibit a stronger alignment between perceived accessibility scores and calculated accessibility. The strongest alignment is observed for healthcare destinations, followed by grocery stores and leisure activities.

The mismatch between calculated and perceived accessibility can be understood through the theoretical lens outlined in Chapter 2. Perceptions of accessibility are shaped by prior experiences, attitudes, and evaluations of travel modes, such as comfort, safety, and reliability. As conceptualized in that chapter, calculated accessibility constitutes only one component influencing perceived accessibility, which mediates the relationship between the built environment and travel behaviour.

The stronger alignment observed for destination-specific measures and in large metropolitan regions likely reflects reduced cognitive ambiguity and greater experiential familiarity with transport options, underscoring the importance of using mode- and destination-specific measures when examining perceived accessibility, as emphasized in Chapter 2. Such specificity enables the capture of important nuances in accessibility experiences and supports the development of more targeted and context-sensitive planning strategies.

6.4 Methodological discussion

This section reflects on the methodological choices adopted throughout the dissertation and discusses their broader relevance for transport research and future empirical work.

6.4.1 Accessibility metrics

Throughout this dissertation, accessibility is investigated and operationalized quantitatively through both calculated and perceived measures. Calculated regional accessibility is represented using cumulative opportunity measures in Chapters 3 to 5 for two main reasons. First, because this dissertation aims to operationalize accessibility in planning practice, cumulative opportunity measures offer greater potential for implementation, as they are easier to interpret and communicate to the public and policymakers (El-Geneidy & Levinson, 2022). Second, studies in North America have consistently shown that cumulative opportunity measures are as effective in representing the built environment as more complex measures, such as gravity-based indicators, particularly when travel time thresholds are set at the regional mean travel time (Kapatsila, Palacios, et al., 2023; Palacios & El-Geneidy, 2022). Across all three empirical studies, cumulative accessibility by public transit was calculated using the r5r package in R, based on GTFS data and OpenStreetMap networks for each region (Pereira et al., 2021), alongside job counts for each spatial unit. Despite the consistent use of cumulative opportunity measures, specific methodological choices regarding their representation differed across chapters.

Chapter 4 employs the number of jobs accessible within 45 minutes by public transit at the census tract level in Montréal, as the analysis focuses on a single metropolitan region. Chapters 3 and 5 examine multiple regions; therefore, proportional accessibility is used, calculated by dividing the number of accessible jobs by the total number of jobs in each region. This approach enables meaningful comparisons across regions with differing employment totals. Proportional accessibility proved particularly important when comparing regions and income groups in Chapter 3 and was central to the establishment of accessibility thresholds in Chapter 5. In that chapter, thresholds are defined as percentages rather than absolute job counts, revealing both variation and convergence across regions. For instance, showing that minimum accessibility thresholds are nearly identical across large metropolitan areas despite differences in total employment.

Regarding spatial resolution, employment data were considered reliable only at the census tract level, as dissemination-area-level data were subject to bias due to strict data suppression imposed by Statistics Canada for confidentiality reasons. In Chapter 5, census tract employment data were proportionally allocated to dissemination areas based on land area to achieve finer spatial granularity. This approach facilitated a more even distribution of participants across calculated accessibility levels, resulting in a wider and more diverse accessibility range.

For calculated local accessibility, we utilize Walk Score® in Chapter 4 to represent access to various amenities (dining and drink, groceries, parks, schools, shopping, culture and entertainment, and errands) within a 30-minute walk of a certain location (Walk Score, 2024). While we confirm its association with weekly walking behaviour, it is important to acknowledge that this gravity-based measure is challenging in its interpretation, as it is difficult to understand what an increase of one unit implies. However, its widespread availability and recognition give it a major advantage over other walkability measures that are specific to Canada.

Finally, as discussed in Section 6.3.3, Chapter 5 adopts mode- and destination-specific measures of perceived accessibility, consistent with the definition introduced in Chapter 2. This specificity captures important nuances in how individuals perceive accessibility in different aspects of their lives, supporting context-sensitive transport planning strategies.

6.4.2 Visualization of results

This dissertation relies extensively on visual representation throughout its analyses to enhance the accessibility and interpretability of its results. Beginning with Chapter 2, the conceptual model is presented in a clear and simplified form to facilitate its adaptation by other researchers. In Chapter 3, scatter plots illustrating the relationship between public transit mode share and calculated accessibility for low- and higher-income groups in Toronto, Montréal, and Vancouver in 2016 and 2021 clearly demonstrate the non-linear association between calculated accessibility and public transit mode share, as well as the weakening of this association over time. Although these relationships are captured in the statistical models, they are considerably easier to explain and discuss when presented visually.

In Chapter 4, maps and three-variable scatter plots of accessibility and travel behaviour variables are indispensable for revealing individual-level mismatches between these measures. These patterns that would be difficult to discern through statistical outputs alone. The visualization approach was particularly crucial in Chapter 5, where calculated accessibility thresholds are identified based on the interaction between levels of calculated and perceived accessibility. The clear intersection between the fitted log-linear model and the 50% and 75% perceived accessibility score thresholds provides a strong visual cue, facilitating interpretation and strengthening the practical relevance of the findings.

6.5 Policy implications

This section synthesizes the policy implications emerging from the empirical findings under three main themes: (1) the need for more assertive planning for calculated accessibility in the post-pandemic era, (2) strategies for improving perceived accessibility by sustainable modes, and (3) the definition and application of accessibility-based planning thresholds. Together, these themes translate the dissertation's empirical insights into actionable guidance for transport planning practice.

6.5.1 Assertive planning for calculated accessibility

Through investigating the post-pandemic association of calculated accessibility with public transit mode share, Chapter 3 confirms that achieving higher ridership through accessibility-focused planning has become more challenging due to the pandemic's repercussions. Increased efforts are needed in transport planning, land-use zoning, and jobs distribution to achieve the mode share targets of each region that were set prior to the pandemic. It is essential to develop adaptive transport strategies that address the evolving needs of various communities to promote equity and provide services to those in need the most. This chapter has shown that targeting low-income areas with accessibility increase in the post-pandemic era will lead to higher return on such investments (mode choice) compared to investing these services in other-income areas. However, planning for accessibility now requires a more assertive approach, as the magnitude of the association between accessibility and public transit mode share, while statistically significant, is weaker than before the pandemic.

Chapter 4 further demonstrates that planning for calculated accessibility is not only crucial for increasing public transit mode share at the regional scale, but for promoting walking at the local scale. Density, diversity, and design of the built environment play a major role in shaping local accessibility and influencing active travel (Cervero & Kockelman, 1997). Targeted land use and transport interventions, such as increasing building density and providing essential amenities within walking distance, should be implemented to enhance walkability and promote more equitable access to diverse opportunities through active transport modes.

6.5.2 Improving perceived accessibility by public transit

Chapters 4 and 5 demonstrate that higher levels of perceived accessibility by sustainable modes are associated with increased mode share for these modes. Accordingly, planning efforts should not focus solely on improving calculated accessibility, but also on strengthening how accessibility is experienced and perceived by individuals. Planners and policymakers should therefore consider how infrastructure investments and service improvements are communicated to the public, as perception plays a critical role in shaping travel behaviour.

Perceived accessibility can be enhanced through targeted communication strategies that raise awareness of existing services, particularly in areas already characterized by high levels of accessibility. Initiatives such as car-free days, during which free public transit is offered, can serve as practical tools to encourage non-users to experiment with sustainable modes for social and environmental reasons. Similar approaches can be implemented during large-scale events to alleviate pressure on the transport network while introducing walking and public transit as viable and attractive alternatives.

Improving first- and last-mile connectivity through investments in the microscale-built environment surrounding transit stops can further strengthen perceived accessibility. Enhancing pedestrian infrastructure, safety, and comfort around stations may encourage residents to explore their neighbourhoods and reinforce their sense of accessible opportunities, thereby promoting active travel and public transit use. Finally, leveraging technology and real-time data to provide intuitive and user-friendly transit interfaces can further improve perceptions of accessibility and attract more users to sustainable travel modes (Pot et al., 2023b).

6.5.3 Defining accessibility-based planning thresholds

Chapter 5 provides a practical framework for applying accessibility in planning by identifying region-specific minimum and sufficient calculated accessibility thresholds using both calculated and perceived accessibility data. These thresholds offer clear, measurable indicators of transport and land-use system performance in Canadian regions, providing actionable guidance for planners and policymakers. By using these benchmarks, decision-makers can prioritise improvements in underserved areas, such as enhancing public transit, improving walkability and street design, and conducting outreach to increase residents' awareness of available mobility options, thereby promoting distributive justice and sustainable travel behaviour.

6.6 Limitations and future research

Through the establishment of a conceptual framework integrating calculated and perceived accessibility into transport research, this dissertation paves the way for future research directions. First, the use of panel data is essential for clarifying the directionality of relationships proposed in the conceptual model developed in Chapter 2 (**Figure 2.2**). Longitudinal data would allow researchers to examine, for example, the impact of perceived accessibility on travel behaviour and residential choice, the influence of calculated accessibility on perceived accessibility, and the role of travel behaviour in shaping perceived accessibility through travel experiences and attitudes. Such data would support the explanation of discrepancies between calculated and perceived accessibility and provide stronger confirmation and validation of potential causal pathways. The cross-sectional nature of the current data limits the ability to confidently establish time precedence, hindering the examination of bidirectional relationships between perceived accessibility and travel behaviour.

Methodologically, mediation analysis within the framework of structural equation modelling (SEM) could offer valuable insights into the complex interrelationships among perceived accessibility, calculated accessibility, travel behaviour, and well-being outcomes. However, researchers should remain mindful of limitations of SEM, including the requirement for large sample sizes, robust measurement of latent variables, and the potential difficulty of communicating complex models to broader audiences and practitioners.

Future research should further examine the influence of sociodemographic characteristics on perceived accessibility, with particular attention to how different population groups experience, interpret, and respond to the built environment around them. Qualitative methods, such as in-depth interviews or focus groups, could provide deeper insight into how individuals construct, interpret, and articulate their perceptions of accessibility, and how these perceptions are shaped by daily experiences, social context, and personal constraints. Qualitative analysis can else delve deeper to understand the mismatch that was noticed between calculated and perceived accessibility, for example why a person considers themselves having low levels of accessibility while at the calculated scale they reside in areas with top accessibility levels in a region and the vice versa.

As this dissertation is focused on the Canadian context, replicating this research in other regions with their diverse urban, suburban, and rural contexts would also be valuable, particularly to identify accessibility thresholds that can inform planning practice. Context-sensitive analyses would help determine whether the relationships observed in large metropolitan regions hold in smaller cities or rural environments, and whether different standards or benchmarks are required.

Chapter 7. Conclusion and summary

This dissertation addresses the central research question of how calculated and perceived accessibility can be operationalized in transport planning practice. Across four interconnected studies, each addressing a research objective, it demonstrates how accessibility can be measured, analyzed, and applied to inform equitable and sustainable transport and land-use planning.

Chapter 2 establishes a clear definition for the emerging perceived accessibility and constructs a conceptual framework, positioning accessibility within the transport planning literature and linking it to travel behaviour, travel experience and attitudes, residential selection, and individual characteristics and resources. Chapter 3 uses aggregate data to confirm the continuing association between calculated accessibility by public transit and its mode share in the three largest regions in Canada. Chapter 4 displays how both calculated and perceived accessibility are key to travel behaviour on the local and regional scale using disaggregate individual-level data in Montréal. Chapter 5 further expands this foundation by adopting a *Capability Approach* and *sufficientarianism* approach, distinguishing between minimal and sufficient access to essential destinations, develops a methodology for identifying calculated accessibility thresholds using calculated and perceived accessibility metrics, and identifies these thresholds for policy application in 12 Canadian regions.

The empirical findings consistently show that both calculated and perceived accessibility are positively associated with sustainable travel behaviour across aggregate and disaggregate levels. These results highlight the importance of planning to enhance accessibility through investments in public transport and improvements to the built environment, as well as planning by accessibility using defined thresholds to guide decision-making. By combining calculated measures with individual perceptions, the minimum and sufficient calculated accessibility thresholds provide planners and policymakers with clear, actionable metrics to assess and improve transport and land-use systems, target interventions in underserved areas, and promote equitable access to opportunities.

In summary, this dissertation advances the theoretical understanding, empirical measurement, and practical application of accessibility in transport planning. It bridges calculated and perceived dimensions, integrates individual perspectives, and provides actionable insights for promoting equity and sustainability in transport research and planning. By conducting policy-relevant analyses, it demonstrates that accessibility can be operationalized not only as a planning metric but also as a capability that shapes how individuals interact with their urban environments, ultimately supporting more inclusive, effective, and sustainable transport planning practices.

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