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The role of built environment characteristics and residential self-selection on car use and active travel

Thesis submitted for examination for the degree of Master of Science in Technology.

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Abstract of master's thesis

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Abstract

Robust correlations between several built environment characteristics and travel mode choice have been established in the travel behavior literature. However, the majority of the studies have not taken into account the possible confounding role of travel-related attitudes and preferences, i.e. a hypothesis also known as residential self-selection. Omitting the possibility that residents may choose their residential location based on travel attitudes and preferences may exaggerate the effect of the built environment on travel behavior. Consequently, this may lead to flawed estimations of the impact of land-use policies on travel.

This thesis investigates the relationship between built environment characteristics, travel attitudes, and travel behavior in the Finnish context. The aim is to examine, to what extent are built environment and attitudes associated with car use, walking, and cycling. The data was collected in early 2020 from residents in the Turku region with an online survey. In total 472 responses were eligible for this study. The research methods include factor and cluster analyses, statistical tests, and multiple linear regression models.

According to the results, both built environment characteristics, measured by an aggregate measure *urban zone of residence*, and travel-related attitudes and preferences are related to differences in car use, walking, and cycling. However, living in an intensive transit zone was found to have an independent negative association with car use and a positive association with walking once the attitudes and socio-demographics were accounted for. For cycling, such associations were not found. In addition, car ownership is positively associated with car use and negatively associated with walking and cycling.

The results indicate, that living in an intensive transit zone is likely to increase walking and decrease car use even among those residents, who have car-oriented attitudes and preferences. Furthermore, a positive attitude towards sustainable modes of travel is likely to increase levels of active transportation in all kinds of urban zones. These results highlight the need for land use and transportation policies and measures, which enable more people to live in intensive transit zones, and target changing residents' attitudes towards sustainable modes of travel.

Keywords travel behavior, active transportation, residential self-selection, built environment, travel attitude

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Tiivistelmä

Liikkumistutkimuksissa on löydetty vahvoja yhteyksiä joidenkin rakennetun ympäristön ominaispiirteiden ja asukkaiden liikkumisvalintojen välillä. Valtaosa tutkimuksista ei ole kuitenkaan huomioinut mahdollisuutta, että asukkaat saattavat valita asuinpaikkansa osittain liikkumisasenteiden ja -mieltymysten perusteella. Jos liikkumisasenteiden mahdollisesti sekoittavaa roolia ei oteta tutkimusasetelmissa huomioon, voivat havaitut korrelaatiot rakennetun ympäristön ominaispiirteiden ja liikkumisvalintojen välillä olla liioiteltuja. Tämä taas voi johtaa vääriin arvioihin ja toimenpidesuosituksiin maankäytön suunnittelun vaikutuksesta liikkumiseen.

Tämän tutkimuksen tarkoituksena on tarkastella rakennetun ympäristön ominaisuuksien, liikkumisasenteiden ja liikkumisvalintojen välistä suhdetta, ja vastata kysymykseen, missä määrin liikkumisvalintoja ohjaavat henkilökohtaiset asenteet ja asuinpaikan ympäristön ominaispiirteet. Tutkimusaineisto perustuu vuoden 2020 alussa toteutettuun internet-kyselyyn Turun seudun asukkaille. Kyselyyn tulleista vastauksista 472 oli tähän tutkimukseen soveltuvia. Tutkimuksessa käytettyjä menetelmiä ovat faktori- ja klusterianalyysit, tilastolliset testit sekä usean selittäjän lineaariset regressioanalyysit.

Tutkimuksessa havaittiin, että rakennettu ympäristö, jota tutkimuksessa tarkasteltiin yhdyskuntarakenteen vyöhykkeiden avulla, sekä liikkumisasenteet ovat kummatkin yhteydessä eroihin liikkumisvalinnoissa. Intensiivisellä joukkoliikennevyöhykkeellä asumisella löydettiin kuitenkin olevan itsenäinen negatiivinen yhteys auton käyttöön ja positiivinen yhteys kävelyyn, kun sosioekonomisten tekijöiden ja asenteiden vaikutus vakioitiin. Sen sijaan vastaavaa tilastollisesti merkittävää suhdetta yhdyskuntarakenteen vyöhykkeen ja pyöräilyn välillä ei löydetty. Lisäksi autonomistuksen havaittiin olevan positiivisesti yhteydessä auton käyttöön ja negatiivisesti yhteydessä kävelyyn ja pyöräilyyn.

Tulokset viittaavat siihen, että intensiivisellä joukkoliikennevyöhykkeellä asuminen todennäköisesti lisää kävelyä ja vähentää auton käyttöä myös sellaisten asukkaiden osalta, jotka mielellään autoilevat. Lisäksi myönteisempi suhtautuminen kestäviin kulkumuotoihin todennäköisesti lisää kävelyä ja pyöräilyä kaikilla kaupunkivyöhykkeillä. Tulokset korostavat tarvetta maankäyttö- ja liikennepolitiikalle ja toimenpiteille, jotka mahdollistavat yhä useampien kaupunkilaisten asumisen intensiivisen joukkoliikenteen vyöhykkeellä, ja jotka kohdentuvat parantamaan asukkaiden asenteita kestäviä kulkumuotoja kohtaan.

Avainsanat liikkumisvalinnat, itsevalinta, rakennettu ympäristö, liikkumisasenteet

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A desire for healthy and sustainable living environments, which support active mobility and residents' well-being motivated me to apply to the Master's programme in Spatial Planning and Transportation Engineering at Aalto University. I was fortunate to be able to end my studies by conducting a thesis related to this topic.

The work with this thesis began while I was employed as a research assistant in the EU project HUPMOBILE at the Aalto University during the final year of my master's degree. I want to thank Professor Marketta Kyttä for this opportunity, and for her continuous encouragement and bright ideas. I am also thankful to Dr. Samira Ramezani, from whom I have learned a lot during my first steps in the world of quantitative academic research. Finally, I am grateful to my family and friends for all their support through this journey.

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Abbreviations

DEP	Daily Errand Points
FTIA	Finnish Transportation Infrastructure Agency
GIS	Geographical Information Systems
NLS	National Land Survey of Finland
OSF	Official Statistics of Finland
PBC	Perceived behavioral control
PPGIS	Public Participation Geographical Information Systems
SEM	Structural equations modeling
TOD	Transit-oriented development
TPB	Theory of Planned Behavior
YKR	Monitoring System of Spatial Structure and Urban Form

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1 Introduction

Active transportation, or in other words, means of travel based on physical activity, i.e. walking and cycling, is nowadays widely understood to be essential for sustainable and healthy communities. Increasing the modal share of active modes of travel is likely to bring various indisputable environmental, economic, and health benefits.

Walking and cycling in everyday journeys are acknowledged to be significant contributors to overall physical activity (Bassett et al., 2008; Besser & Dannenberg, 2005; Lee & Buchner, 2008), which has implications both on individual and societal levels. Higher physical activity is in general associated with better physical and mental health, which in turn reflect public health care costs on the societal level. Moreover, a higher number of people walking and cycling has been found to increase pedestrian and cyclist safety and reduce the risks for traffic accidents with motorists (Elvik & Bjørnskau, 2017).

Walking and cycling for transport, and as part of multimodal trip chains, play a vital role in sustainable transportation systems. In the United Nations' Agenda 2030 for Sustainable Development, sustainable transportation is acknowledged to be essential for several Sustainable Development Goals and targets. In addition, the transportation sector is expected to play a key role in the achievement of the Paris Agreement within the United Nations' Framework Convention on Climate Change (The UN, 2020). In Finland, traffic constitutes about the fifth of the total greenhouse gas emissions and approximately 95 percent of this share originates from road traffic. Further, from this fraction passenger car traffic constitutes approximately 60 percent (Traficom, 2019). Finland's aim to achieve carbon neutrality by 2035 requires efficient emission reduction targets and measures also in the transportation sector. Promoting and enhancing walking and cycling can contribute to lowering both emissions, pollution, and congestion.

Due to the abovementioned reasons, strategies and policies to promote walking and cycling have become increasingly favored among decision-makers, urban planners, and public health professionals. Special attention has been paid to the role of the physical environment on travel behavior, as neighborhoods can be adapted by evidence-based land use planning and transportation policies that promote active transportation and overall physical activity.

In academia, promising evidence on the correlations between built environment characteristics and active travel behavior have been found (see for example Christiansen et al., 2016; Ewing & Cervero, 2001, 2010; Panter & Jones, 2010). However, it has been argued, that a correlation does not necessarily signify a causal relationship and the observed associations between the built environment and travel can be confounded by multiple factors. Among the most influential hypotheses is the confounding role of travel-related attitudes and residential preferences (Bagley & Mokhtarian, 2002). In other words, this hypothesis known as residential self-selection suggests that residents may choose to reside in a location, that best meets their travel needs and desires, which in turn reflects their behavior (Schwanen & Mokhtarian, 2005a). However, the majority of the empirical studies examining the built environment-travel associations have not attempted to rule out the possible effect of residential self-selection, which has raised doubts and concerns about the reliability of the results and consequent policy recommendations.

It is still under debate, how far the observed differences in travel behavior are attributable to built environment characteristics or instead stem from individual preferences for certain travel modes and residential locations. If the latter association is stronger, the effectiveness of modification of the built environment to alter individuals' travel behavior may be limited.

This thesis investigates the role of built environment characteristics, travel attitudes, and neighborhood preferences on travel behavior in the Finnish context. By analyzing questionnaire data collected in the Turku region in 2020, this thesis aims to examine, whether the built environment in the residential neighborhood is associated with differences in car use, walking, and cycling after the possible effects of socio-demographic characteristics and residential self-selection have been accounted for.

The thesis is organized as follows: the upcoming section presents the theoretical background for this thesis, focusing on the built environment and psychological determinants of active travel mode choice. In addition, it discusses the residential self-selection problem highlighted in the built environment-travel literature. Moreover, the research questions of this thesis are presented at the end of the background section. The thesis continues with a section concerning research methodology including descriptions of data collection procedure and data analyses. Section 4 presents the findings drawn from the statistical analyses and section 5 discusses the findings with relation to research questions and their possible implications for policy-making and planning practice. Finally, the thesis ends with a section concerning the limitations of the methodology and data of this study.

2 Background

2.1 Active transportation in the context of health behavior research

Travel mode choice has been an active area for theoretical and empirical research for multiple decades. Travel mode choice is a complex process influenced by a multitude of domains, including the physical environment, the social environment, the policy context, and personal and trip attributes (Götschi et al., 2017). Active mobility has been studied widely in the context of health behavior. In health behavior research and practice, ecological models, which emphasize multiple levels of influences on behavior, have gained great interest during past decades.

The ecological models are founded on certain core principles. First, specific behaviors have multiple levels of determinants, which interact across levels. These levels include environmental and policy contexts of behavior, as well as social and psychological determinants. In addition, ecological models are usually behavior-specific so that the most relevant determinants of behavior have been identified. Finally, multi-level interventions are considered as the most comprehensive and effective approaches in changing behavior, since the variables on different levels operate together (Sallis et al., 2008).

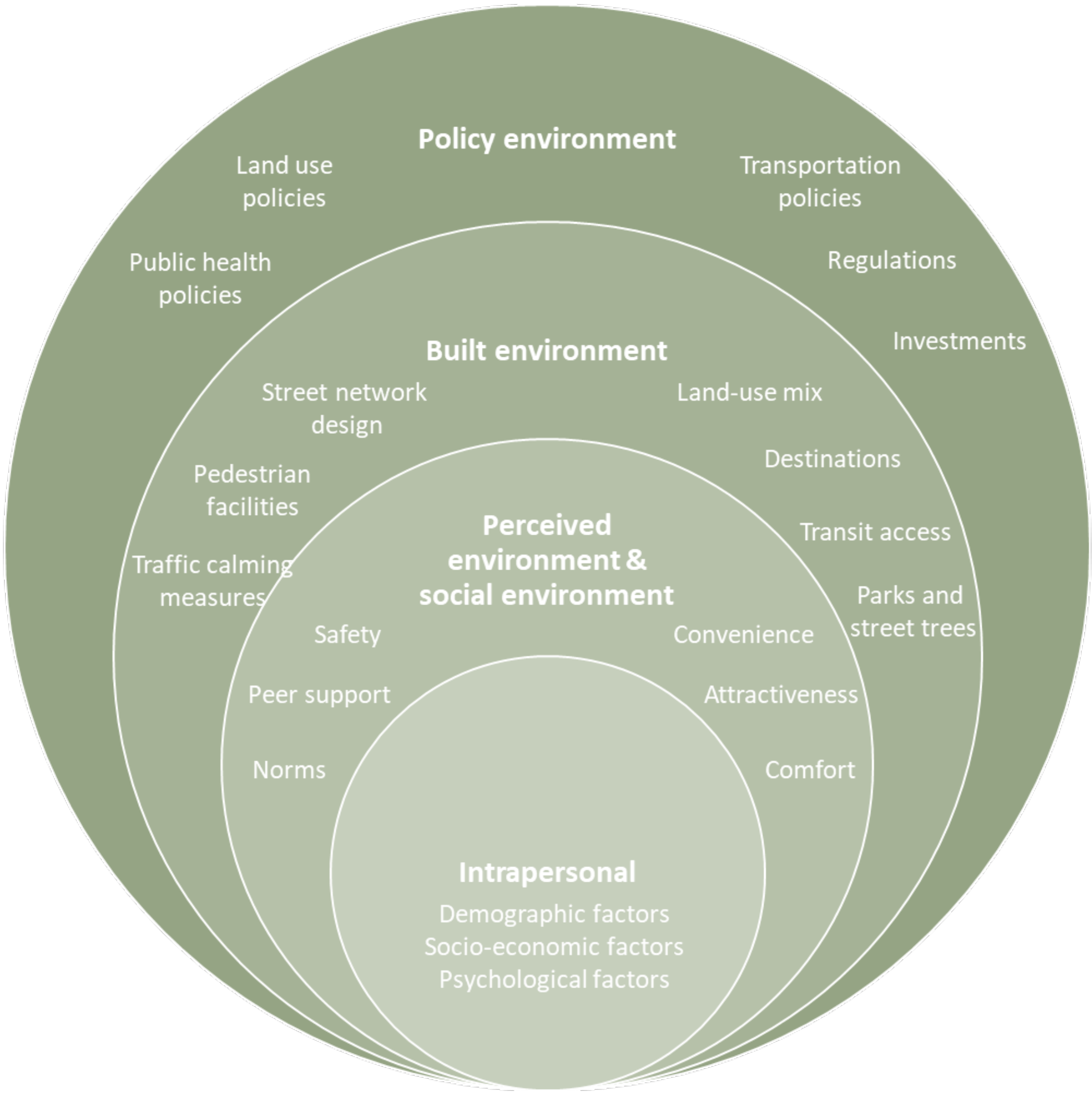

Figure 1. An example of a socio-ecological model of walking for transport adapted from Sallis et al., (2008).

Socio-ecological models help to build holistic frameworks for understanding the various interacting determinants of behavior. Figure 1 represents a socio-ecological model of walking for transport, including some of the potential determinants of walking on multiple different levels. The example demonstrates, that walking behavior can be influenced by a variety of factors. In empirical research, various hypotheses have been derived from ecological models. However, the majority of the studies have focused only on certain levels of influence, often due to challenges in research design. In addition, the studies, which aim to account for the correlations and interactions between different levels of influences remain limited. For example, the majority of the studies focusing on built environmental correlates of active travel have not determined the relative importance of the individual, social and environmental attributes on behavior (Sallis et al., 2008).

Due to an immense amount of produced research knowledge on different factors associated with travel mode choice decisions, an extensive literature review synthesizing the available evidence from all levels of influences would not be feasible within the limits of this thesis.

As such, the background section of this thesis focuses on the determinants of active travel behavior, and more precisely, it aims to provide a synopsis of the existing evidence on the relationship between built environment characteristics, personal attitudes, and walking and cycling.

The vast spectrum of research fields, viewpoints, and applied methodologies make the research evidence on determinants of active travel behavior rather complicated to compare, analyze and summarize. However, the psychological and environmental correlates of active travel have been attempted to compile in numerous literature review papers over the years. Furthermore, the empirical evidence on residential self-selection has been reviewed for example by Cao et al., (2009) and Bohte et al., (2009) and further examined in multiple papers. Therefore, the following parts of this section presenting the theoretical background for this thesis are based on the findings from previous literature reviews as well as some individual studies providing more detailed evidence.

The theoretical background is divided into several sections. The first part introduces the key findings from the past research on the relationship between the built environment and travel behavior, with a particular reference to the physical environment correlates of walking and cycling. The second part introduces some of the key viewpoints and theories on the psychological correlates of active travel behavior. In addition, the section demonstrates, how personal attitudes towards travel have been used as a means for traveler segmentation in previous travel behavior research. The third section combines the environmental and personal perspectives by introducing the residential self-selection hypothesis and presents one of the common methodologies of addressing the issue in empirical research. Finally, empirical evidence and implications of residential dissonance are presented.

2.2 Built environment and active travel behavior

The relationship between built environment characteristics and travel has been a rich and sprawling area of research for several decades. With regard to environmental influences on walking and cycling, the research has mainly focused on neighborhood-scale design principles and characteristics. However, the methodologies to examine such associations have varied greatly, which makes the existing evidence complex and somewhat difficult to draw explicit conclusions from.

One of the major factors that complicate the comparability of the research outcomes is the variability in measuring the built environment and travel outcome variables. There are several examples to illustrate this. First, the examined built environment variables can be measured either objectively, such as through GIS analysis (e.g. Christiansen et al., 2016), or subjectively as perceived by each research participant (e.g. Mertens et al., 2016), which naturally affects the measurement outcome. Second, the exposure to the built environment characteristics can be measured in different geographical contexts. Typically, the built environment variables are calculated from a buffer around an individual's home location (e.g. Christiansen et al., 2016; Sallis et al., 2016), but a smaller number of studies have also examined built environment at the destinations, or along the routes to destinations (e.g. Rodríguez et al., 2015). Moreover, increasingly sophisticated methods, which try to take into account the complexity of human behavior and environmental exposure, such as different applications of activity spaces and local activity spaces, have become more common (e.g. Hasanzadeh et al., 2018).

Finally, the ways of measuring and collecting the dependent travel behavior variables vary considerably between different research settings. As an example, walking and cycling have been treated in travel behavior research both as separate modes of transport and as an aggregate measure of active travel behavior (McCormack & Shiell, 2011). However, there is nowadays more evidence suggesting that the individual and environmental factors associated with walking and cycling mode choice differ to some extent. Therefore, it is better acknowledged that travel behavior can be predicted more accurately with behavior-specific models, in which the behavior, i.e. walking or cycling, is examined in relation to particular environmental, social, and psychological variables expected to be associated with that behavior. In addition, many researchers suggest context-specific research settings, in which the travel outcome variable is defined by the trip purpose (Giles-Corti et al., 2005). The determinants of cycling for transport, as an example, can vary considerably from cycling for recreation. Furthermore, regarding utilitarian trip-making, the commute trip may have very different determinants than trips to other destinations (Heinen et al., 2010).

Partly due to the abovementioned reasons, studies examining the determinants of active travel behavior have yielded significantly varying outcomes depending on the examined dependent and independent variables, and the way these variables have been measured. Roughly speaking, there is more robust evidence on determinants on walking for transport (e.g. Ewing & Cervero, 2010; Saelens & Handy, 2008), whereas research focusing solely on determinants of cycling for transport is still rather scarce (e.g. Fraser & Lock, 2011; Titze et al., 2007, 2008).

Despite the complexity of analyzing and summarizing the previous research outcomes, some fairly certain associations between the physical environment and walking and cycling have been established. In their review article based on forty-three quantitative studies on active travel behavior determinants, Panter & Jones (2010) found that certain environmental components have shown consistent positive associations with adult's active travel behavior, but a great variety of physical environmental characteristics have been widely studied but resulted with varying outcomes. To structure the variegated evidence on the relationship between built environment characteristics and active travel, the authors placed the factors under four categories representing the physical environment: **functionality, safety, aesthetics, and destinations.** The same categorization will be used in the following sections, where different physical environment features associated with active travel will be presented in more detail.

Functionality

The functionality of the physical environment relates to the availability of walking and cycling infrastructure and street network design. The features related to street network design and connectivity have generally been measured as average block size, the proportion of four-way intersections, or the number of intersections per unit of area (Ewing & Cervero, 2010). The findings on the relationship between street design measures and walking are varying. For example, rather surprisingly the presence of sidewalks has been reported to have mixed associations with levels of walking (Panter & Jones, 2010). Furthermore, according to Saelens & Handy (2008), the studies examining environmental correlates of walking have resulted in mixed outcomes regarding street network connectivity with roughly an equal share of the reviewed articles reporting positive, negative, and null associations. However, a meta-analysis of over 200 independent built environment-travel studies conducted by Ewing & Cervero (2010) concluded that intersection density had the largest effect size of all the examined built environment variables and thus, was the strongest predictor of walking mode choice. While the relationship between street design features and walking outcomes does not seem explicit, several authors have concluded, that there is more robust evidence suggesting that the presence, proximity, and connectivity of bicycle lanes is associated with higher levels of cycling (Panter & Jones, 2010; Titze et al., 2008).

Safety

The outcomes and associations between active travel and safety and aesthetic features of the environment have also varied considerably. According to Panter & Jones (2010), the perceived safety of the neighborhood has been found to represent mixed and even unintuitive associations with active transportation. For instance, Titze et al., (2007) found, that regular cycling among the student population in Graz, Austria was negatively associated with the perception of traffic safety, possibly suggesting that those who cycle regularly are more aware of the traffic-related dangers than those who are not regular cyclists. However, Mertens and colleagues (2016; 2017) found that both living in a neighborhood with speed limits below 30 km/h and subjectively perceived lower traffic speed have been associated with higher odds for cycling in five regions around Europe.

Aesthetics

Similar fluctuation has been found in the results of the studies examining the associations between the aesthetic features of a neighborhood and walking and cycling (Panter & Jones, 2010). The commonly studied aesthetics features include factors such as pleasant scenery, the tranquility of a neighborhood, or the presence of natural features, which is one of the most studied physical environment characteristics in relation to active travel behavior. The greenness of the neighborhood has been measured both objectively, often by utilizing satellite imagery or other raster land-use datasets, and subjectively, with individually perceived and scored greenness measures. However, these different ways of measuring have generated varying results even within a single study. In their study in Seattle, Washington, Tilt et. al., (2007) found, that residents who perceived their residential neighborhood as green and aesthetically pleasant reported higher levels of walking. Interestingly, the objectively measured greenness from satellite imagery showed no association with walking trips. Regarding the relationship between the attractiveness of the environment and cycling, the associations are also varying. In their study among university students in the Netherlands, Titze et al., (2007) found a positive association between attractiveness (a latent variable consisting of perceived air pollution level, green areas, attractiveness of the buildings, and interesting things to look at) of the surroundings and irregular cycling for transport. However, in the following study among the adult population in Graz, Germany, such association was not found (Titze et al., 2008).

Destination accessibility

Walking and cycling are travel modes based on physical activity, which makes them suitable especially for short-distance trips. Therefore, walking and cycling on everyday journeys require that there are workplaces, services, recreational facilities, and other *destinations* within a walkable or cyclable distance from residential settlements. The availability of destinations relates to several physical environment factors such as facility provision, land-use mix, different measures of density, and public transport availability. Several indicators related to the availability of destinations have been associated with non-motorized travel.

A mixture of complementary land-uses, including residential, commercial, and industrial functions, is a widely favored principle in current urban planning since it is suggested to have several advantages in relation to transportation. First and foremost, land-use mix allows more people to live closer to workplaces and other daily activities, creating shorter distances between origins and destinations and possibilities for the use of non-motorized travel modes. Moreover, it has been suggested that more varying streetscape with diverse functions encourages longer walk trips and generates "natural surveillance", which enhances both perceived safety and walkability of the streets (Gehl, 2010).

In the simplest way, accessibility to destinations can be measured as a distance or travel time from home to various attraction points. Closely related to destination accessibility are different measures of land-use mix, typically measured with ratios between various land-uses or entropy measures. Different measures of land-use mix have been consistently found to have positive associations with walking and cycling (McCormack & Shiell, 2011; Panter & Jones, 2010). In their meta-analysis, Ewing & Cervero (2010) found that the ratio between workplaces and residents was a stronger predictor of walking compared to land use mix entropy measure.

In travel behavior research, measures of density can include various variables of interest, such as population, workplaces, dwelling units, or services calculated per unit of area. Population or residential density has especially gained interest in relation to active travel behavior since it is considered a necessity for many other physical environment components that support active transportation. For example, adequate local patronage is required for creating and supporting a variety of local services (destinations) and an affordable and extensive public transportation network. Residential density has been fairly consistently positively associated with active transportation (McCormack & Shiell, 2011; Panter & Jones, 2010). However, Ewing & Cervero, (2010) found that several variables, which often go hand-in-hand with residential density, such as distance to a store, distance to the nearest transit stop, and intersection density had stronger elasticities than that of residential density. Thus, it appears, that high residential density solely may not bring about higher levels of walking or cycling, but it allows other such built environment characteristics that stimulate active travel mode choice to emerge.

Public transportation availability is often included in studies examining the determinants of active transportation since a transit trip always includes both access and egress journeys, which are often made by active modes of travel. Availability of public transport is usually measured as the shortest distance route from a residence to the nearest station or transit stop or as the density of transit stops or transit routes per unit area. According to Sallis et al., (2016), different measures of public transportation availability have repeatedly been associated with prevalence for walking.

To summarize, it has been fairly consistently reported that especially a greater mixing of complementary land-uses and access to a variety of utilitarian and recreational destinations is associated with higher levels of active transportation (Ewing & Cervero, 2010; Panter & Jones, 2010). Moreover, the high net residential density of a neighborhood has been consistently associated with higher levels of walking (Panter & Jones, 2010) and overall physical activity (Gebel et al., 2007; Sallis et al., 2016), but as previously explained, residential density may function as a requisite for other built environment characteristics, which support non-motorized travel. In various walking-related studies, the measures of residential density, commercial density, land-use mix, and street network connectivity of a neighborhood are subsumed into an aggregate measure of 'walkability' (Frank et al., 2010). Living in a 'high walkable' neighborhood has been consistently associated with higher levels of walking (Panter & Jones, 2010).

2.3 Psychological determinants of active travel

The psychological influences on travel behavior and mode choice, including personal attitudes, preferences, values, motivations, and habits among others, have been widely studied especially in the fields of behavioral and social psychology. Travel behavior researchers have been especially interested in the psychological construct of attitudes, which appeared in several travel behavior theories already in the 1970s. More recently, attitudes have emerged in empirical studies (Bohte et al., 2009). According to a widely established definition by Eagly & Chaiken, (1993, p.1) attitude is "a psychological tendency that is expressed by evaluating a particular entity with some degree of favor or disfavor". More precisely, the definition of "evaluating" refers to affective, behavioral, and cognitive responses. Affective responses involve a person's emotions about the attitude object (e.g. "I like walking"). Behavioral responses refer to the way the attitude influences the way of acting (e.g walking to work) and cognitive responses involve a person's beliefs and knowledge about an attitude object (e.g. "Walking is good for my health") (Eagly & Chaiken, 1993).

Various theoretical models have been applied to explain differences in travel behavior between individuals. Among the most well-known and applied theories on the connection between attitudes and behavior is the Theory of Planned Behavior (TPB) developed by Ajzen (1991). According to TPB, individual attitudes towards the behavior, perceived behavioral control (PBC) and subjective norms determine intentions to act, which in turn relate to behavior. In TPB, attitudes are considered as people's positive or negative evaluations of the expected outcomes of the behavior. Perceived control of the behavior signifies the extent to which people feel they have the capability to enact the behavior and subjective norms concern a person's perception about how the people around them think about them performing the behavior. (Dill et al., 2014).

However, it has been noted that behavior can exist also without conscious intention, which is why there is some variation in the emphasis between studies. Some of the studies applying the TPB focus on the influence of psychological factors on intention to travel, while others investigate their direct association with actual travel behavior (Panter & Jones, 2010). In their review article of 57 studies applying TPB or other psychological models to pro-environmental behaviors, Bamberg & Möser, (2007) found that attitudes, PBC, and subjective moral norms were important determinants of sustainable travel behavior. Dill et al., (2014), instead, found that among 15 individual studies using TPB to explain walking and cycling behavior, attitudes and PBC were found to be important in predicting the behavior, but social norms were not. Although studies utilizing TPB have generally concluded that travel mode choice is mainly a reasoned decision, some researchers have argued, that daily travel patterns are often habitual and do not always precede consideration of alternatives. These authors have suggested, that inclusion of a variable measuring habituality could improve the reliability of travel behavior studies (Verplanken et al., 1994).

Some researchers have examined certain elements of TPB together with other factors to explain active travel behavior. Especially the attitudes towards certain travel modes have gained great interest. In a study by Handy et al., (2006), a pro-bike/walk attitude was positively associated with walking to the store with the highest standardized coefficient of all the examined variables. Moreover, a pro-transit attitude was also positively associated with walking frequency. On the contrary, those who valued a safety of a car had a negative association with walking to the store. Similar findings were reported by (Cao et al., 2009b), who found that travel attitudes were associated with travel mode choice in non-work trips. Those who in general liked to travel or felt as being dependent on a car made more auto trips. The pro-transit attitude was positively associated both with transit use, walking and cycling, and pro-bike/walk attitude with the use of non-motorized travel modes, respectively. However, a positive or negative attitude towards certain travel modes does not necessarily reflect behavior. In their review article on determinants of active travel, Panter & Jones, (2010) found studies, which reported associations between positive attitudes towards cycling and cycling for transport but in contrast also a few studies with no associations.

A few studies have examined psychological factors beyond TPB to understand cycling mode choice. Heinen et al., (2011) extended the TPB framework with variable measuring cycling habit, which was positively associated with a decision to cycle at all distances. In addition, the authors tested 13 attitudinal characteristics to identify underlying latent factors associated with decisions to cycle to work. Three latent factors were found. Direct trip-based benefits such as time-saving and comfort were influencing the decision to cycle to work at all distances. Awareness, including variables such as environmental benefit, health benefit, and mentally relaxing, was related to cycling only on longer distance commute trips. Safety factor consisting of social safety and traffic safety, instead, did not show a statistically significant association with cycling to work. The findings from Titze et al., (2007) from Austria emphasize the importance of emotional satisfaction related to travel. Those university students who valued the enjoyment of cycling and perception of freedom and good mobility were likely to cycle regularly. Furthermore, the same authors found that perceived barriers of cycling, such as physical discomfort and impracticality, were negatively associated with cycling frequency among Austrian city dwellers after adjusting for socio-demographic variables and distance from home to destination (Titze et al., 2008).

2.3.1 Attitudes as a foundation for traveler segmentation

Several empirical studies have utilized attitudes as a foundation for traveler segmentation as a means for analyzing daily travel determinants. Segmentation is an act of defining individuals or objects into meaningful groups that are mutually exclusive and have distinctive characteristics. In general, the purpose of segmentation is to reduce the number of residents into a manageable number of groups to predict how resident groups with certain characteristics respond to situations, strategies, and policies (Anable, 2005). In travel behavior research, segmentation can be applied for example to target mobility management campaigns to those traveler groups, who are most likely to change their behavior, or on the contrary, identify those travelers, who are least likely to respond to new transportation strategies or policies.

A variety of approaches and methods have been applied for traveler segmentation. In general, the approaches can be divided into a priori and post-hoc methods. In a priori methods, commonly utilized in the past travel behavior research, the researcher declares the segments based on the known characteristics of the individuals, such as demographics or frequency of use of a travel mode. In post-hoc approaches, instead, the segment groups are identified by applying some form of statistical analyses with variables that represent measured attitudinal, behavioral, or personality characteristics of the individuals. Since the segments are determined by the data, neither the initial number of segments nor their size is known until the statistical analyses have been completed (Anable, 2005).

Even though a priori approaches have traditionally been more common in travel behavior research, Anable (2005) argues that a priori defined segments may lead to false assumptions of homogeneity, and bias in interpretation and explanation of the travel behavior of the resident groups. Therefore, a more detailed post-hoc segmentation based on multivariate statistical techniques is more likely to reveal the underlying associations that distinguish traveler groups from each other.

Kuppam et al., (1999) examined the role of traveler attitudes and perceptions in explaining commuter mode-choice behavior. The authors tested two models including solely demographic or attitudinal variables, as well as a third model including both. The first two models indicated that both demographic and attitudinal factors were important in explaining differences in commute mode choice. However, the model with solely attitudinal variables was found to perform slightly better than the model with solely socio-demographic variables. Nevertheless, even though the contribution of attitudes was greater than that of demographics, the model including both attitudinal and demographic variables outperformed the other two models.

Anable, (2005) extended the TPB framework with notions of moral norm and psychological attachment to a car in order to identify groups of museum visitors with varying susceptibility to use other modes than a car when visiting the destination. The factor and cluster analyses resulted in six distinct groups of visitors: *Malcontented motorists*, *Complacent car addicts*, *Die hard drivers*, *Aspiring environmentalists* (all four of them car-owning groups), *Car-less crusaders,* and *Reluctant riders* (both non-car-owning groups).

Only a few statistically significant differences in socio-demographic characteristics between the four car-owning market segments were observed. However, the segmentation revealed, that some traveler groups shared similar norms and attitudes regarding alternative modes to a car, but their behavior was significantly different (Anable, 2005). As also suggested by Panter & Jones (2010) this result indicates that environmental concerns and positive evaluations towards alternative modes do not themselves always bring about favorable behaviors. Furthermore, the author found out, that the measures of psychological attachment to car and notion of driving habit played a key role in distinguishing the car-owning segments from each other, which would have not been possible by only using the more traditional measures of preference or attitude (Anable, 2005).

Prillwitz & Barr (2011) used both a priori and post-hoc segmentation approaches based on behavioral and attitudinal characteristics, to define the traveler clusters from questionnaire data collected in Exeter, Devon (UK) in 2008. The first segmentation approach based on daily travel behavior resulted in four clusters with diverging daily travel practices. In addition to distinctive mobility patterns, these clusters were found to differ from each other in terms of age, income, and political views.

The second approach utilized attitudes towards certain modes of transport, the environment, and sustainability as a basis for segmentation for evaluation of daily mobility behavior. This approached based on attitudinal factors combining statistical factor and cluster analyses resulted in four distinctive attitudinal clusters: *Addicted car users*, *Aspiring green travelers*, *Reluctant public transportation users,* and *Committed green travelers*. Similar to the study by Anable, (2005), the authors found mainly insignificant differences in terms of socio-demographic characteristics between the clusters. This demonstrates that attitudes tend to cut across socio-demographic groups and indicates, that relying only on socio-demographic characteristics in behavioral research is likely to lead to biased outcomes. However, the clusters differed significantly from each other in terms of daily travel behavior, and the reported mode choice in daily mobility represented the clusters' main attitudes accurately.

By combining and comparing the results from the two segmentation approaches, i.e. segmentation based on behavior and attitudes, Prillwitz & Barr (2011) concluded that the utilized segmentation approaches can fill knowledge gaps and improve the effectiveness of marketing measures targeting to change daily travel behavior.

2.4 Residential self-selection

As was demonstrated in the previous sections, the two fairly separate research branches on the psychological and environmental determinants of active travel mode choice have both appeared to be associated with differences in travel behavior. Approximately two decades ago researchers started to raise questions about the predominant causal links and confounding factors behind the associations between the built environment and travel behavior. Since it had become evident, that personal travel-related attitudes are associated with differences in travel outcomes, it was suggested, that preferences for certain kinds of neighborhoods and travel modes may also be interconnected with a residential location choice. The residential self-selection hypothesis suggests that the observed differences in travel behavior may in fact result from a selective location choice of individuals or households, who have decided to reside in an area that supports their desired mode of travel. For example, residents who prefer to cycle for transport may consciously decide to live in a location that enables and supports cycling trips, and thus cycle more.

The possible confounding effect of the residential self-selection raised concerns about the validity of the research efforts on built environment and travel, which have not accounted for the personal travel-related attitudes and preferences for residential locations. If the attitudes and preferences towards neighborhood characteristics or travel modes are not taken into account, the effect of the built environment attributes on travel behavior could be exaggerated and lead to non-valid estimations of the impact of land-use policies on travel.

The residential self-selection issue can be addressed in travel behavior research with various methodological approaches. Statistical control of residential self-selection, which is one of these approaches, will be examined further in the following sections. The same methodology to address the residential self-selection problem will also be utilized in the empirical part of the thesis.

2.4.1 Statistical control of residential self-selection

Statistical control is one of the most applied methodologies to address residential self-selection and has been operationalized in two ways: (1) by measuring the attitudinal factors and incorporating them directly in the travel behavior model or (2) by comparing the consonant and dissonant residents. In this section, the first approach will be presented in more detail, while the second approach will be discussed in section 2.4.2.

In the first approach of statistical control of residential self-selection, attitudes are generally measured from survey participants with multiple, overlapping statements regarding land-use preferences and/or attitudes towards different travel modes and travel in general. In this case, statistical factor analysis is then applied in order to identify clusters of highly correlating variables, which enables reducing the large set of data to a smaller subset of variables. These variables can then be entered to travel behavior models alongside other variables of interest.

One of the first and well-known studies utilizing statistical control approach to examine attitudes in relation to land-use characteristics and travel behavior was carried out by Kitamura et al. in 1997. The published paper created a foundation for the residential self-selection hypothesis, which was established in the research literature some years later.

Based on household survey data collected in five distinctive neighborhoods in the San Francisco Bay area, Kitamura et al., (1997) investigated how land-use characteristics and attitudes towards various aspects of urban life were associated with transit trips, automobile trips, and non-motorized trips. In addition, the authors aimed to find out whether land-use characteristics had an individual association with travel demand once the attitudes and socio-demographic characteristics were included in the travel behavior models.

By comparing models with and without eight attitude factors, the authors found that attitudes were strongly associated with different travel demand measures and they explained the highest proportion of variation in the data. Even though those neighborhood variables that had the strongest association with travel demand measures remained an independent effect on travel behavior after the attitudes were introduced to the models, their relative contribution to the explanatory power of the models was much weaker than that of attitudes.

A few years later, Handy et al., (2006) investigated two types of pedestrian behavior (walking to the store and strolling) in eight different neighborhoods in Northern California and statistically controlled for residential self-selection. The authors found out, that residents who preferred walking tended to self-select into walkable neighborhoods. The preference for stores within walking distance from home was found to be the most important factor explaining walking to the store among all the variables tested. However, the attitudes did not account for all the variation in pedestrian behavior. After controlling for residential self-selection, certain built environment qualities were found to have an independent effect on walking. When examining the determinants of walking to the store, both objective and perceived distance to potential destinations were found to have the most important effects, and perceived safety and neighborhood attractiveness had significant, but less important effects after the travel attitudes and preferences were accounted for.

Furthermore, two built environment measures, socializing perception and attractiveness perception, were positively associated with frequency of strolling, after attitudinal and sociodemographic variables were accounted for. Thus, for strolling, the quality of the environment was found to be more important than accessibility to destinations. This result also supports the notion, that the built environment determinants vary depending on the purpose of walking. These findings from Handy et al., (2006) indicated, that residential self-selection partially contributed to differences in walking behavior, but certain characteristics of the built environment still had an autonomous influence beyond that.

Using the same data from Northern California as Handy et al., (2006), Cao et al., (2009b) examined the influence of the built environment and residential self-selection on non-work travel behavior. By comparing two different models – both models consisting of socio-demographics and built environment characteristics, but the second model extended with neighborhood preferences and travel attitudes – the authors suggested, that residential self-selection influenced especially non-motorized travel behavior. The incorporation of preferences for neighborhood accessibility and physical activity options in the second model dropped out some of their corresponding built environment variables, which were found to have a significant effect on non-motorized travel in the first model.

However, a comparison of the two models suggested, that certain neighborhood characteristics were associated with individuals' travel decisions even after the residential self-selection was accounted for. Mixed land-use was found to encourage transit use, walking, and cycling, and restrain car use. Furthermore, the availability of a good quality transit service and walking and cycling infrastructure were associated with the use of transit and non-motorized travel modes. In addition, walking and cycling were also positively associated with the aesthetic quality and opportunities for socializing in the neighborhood, suggesting that pedestrian and cyclist-friendly design tends to lower the psychic costs of active travel by making walking and cycling more convenient and pleasant.

2.4.2 Residential mismatch and travel behavior

Residential location in a preferred type of neighborhood can be constrained by multiple factors, such as financial issues, availability of dwellings, or distance to workplace. A mismatch between the preferred and actual residential neighborhood can have an impact on travel behavior, since the preferred modes of transportation may not be available in the neighborhood, or the neighborhood may not support the use of certain travel modes due to its location or infrastructure. Consequently, the actual transportation mode choices do not always match with the preferred way of traveling (De Vos et al., 2012).

The second statistical approach to address residential self-selection is the comparison of travel behavior of consonant and dissonant residents. In this approach, the measured travel attitudes and/or land-use preferences are used to categorize the study participants into matched (consonants) or mismatched (dissonant) residents in relation to their current residential neighborhood type. After that, the travel behavior of the dissonant residents is compared to that of consonant residents in their desired and their current neighborhood (Cao et al., 2009a).

This approach can be illustrated with an example concerning preferences for walkable neighborhoods. First, residents with a preference for a low-walkable neighborhood but living in a high-walkable neighborhood (dissonants) are compared to residents with similar preferences, but who in contrast live in a low-walkable neighborhood (consonants). If their travel behavior is similar despite the different environment, it suggests that the attitudes dominate their travel behavior. Second, the same group of dissonant residents in high-walkable neighborhood is compared to consonants in the same neighborhood. If their travel behavior is more alike, it suggests that regardless of the possible self-selection effect of the consonant residents, the built environment outweighs the attitudes and preferences and has a separate effect on travel behavior.

Among the first studies to utilize this method, Schwanen & Mokhtarian, (2005) examined the travel behavior of residents in the San Francisco Bay area by classifying them into consonants and dissonants based on their current residential location and preferences regarding the population density of the neighborhood. As a result, the authors found that suburban residents, whether dissonants or consonants, traveled considerably more compared to urban residents. Furthermore, urban dissonants were found to drive more than urban consonants, but less than suburban consonants, which suggests that the urban environment influenced car use, either by offering more alternatives or by imposing constraints to car travel. Moreover, there were statistically significant differences in total distance traveled only between matched and mismatched urban residents, while sub-urban residents' travel behavior was fairly similar regardless of whether or not their preferences matched with their residential location. In other words, the land-use preferences seemed to have an impact on travel behavior only among those residents who live in an urban neighborhood, and even that effect did not outweigh the effect of the residential location. Thus, the authors concluded that the physical neighborhood structure appeared to have a stronger influence on total distance traveled than preferences towards a neighborhood type.

De Vos et al., (2012) investigated the effect of residential dissonance in a European context in Flanders, Belgium. The authors came to similar conclusions regarding built environment and driving, but also examined the relationship between residential dissonance and walking, cycling, and transit use. The comparison of urban and rural consonants and dissonants indicated, that walking, cycling, and the use of public transport were mainly determined by attitudes. Those respondents with urban land-use preferences made considerably more trips with sustainable transport modes compared to those participants with rural land-use preferences, regardless of the residential location. Car use, instead, seemed to be more clearly influenced by the built environment. Urban consonants used car the least, followed by urban dissonants, rural dissonants, and rural consonants, who drove the most. However, the car use was almost on the same level between urban dissonants and rural dissonants, but similar uniformity was not found regarding the use of other modes. Therefore, the authors speculated, that dissonants in urban areas were more constrained to use car and travel according to their preferences, while dissonants in rural areas had better opportunities to fulfill their travel preferences and travel by public transport, walking, and cycling.

Frank et al., (2007) applied both methods of statistical control in their study in Atlanta, USA. First, neighborhood preferences and walkability index of the current residential neighborhood were incorporated into the travel behavior model in order to examine the possible effect of residential self-selection. After that, the residents were classified into matched and mismatched residents based on the walkability (high walkable/low walkable) of the preferred and current neighborhood.

The comparison of the matched and mismatched residents indicated, that the mean distance driven was almost the same for those living in a high walkable neighborhood despite the neighborhood preference, which is a contrary finding to previously presented studies.

Regarding walking behavior, the authors found that the likelihood of taking any walking trip, taking a walking trip for purpose of transport, or for leisure was significantly higher, as the walkability of the neighborhood or preferences for walkable neighborhood increased. However, similarly to the findings by De Vos et al., (2012), the authors concluded, that preference for a walkable environment was found to be a stronger predictor of walking than living in a walkable environment.

Kajosaari et al., (2019) developed a framework specific for different walking outcomes for assessing walking-related residential dissonance and its associations with walking for transport amongst young adults in Helsinki metropolitan area. The authors found evidence, that associations between the walkability of the environment, walkability preference, and walking behavior varied by trip purpose. Preference for high-walkable environments was found to have a stronger effect on walking to recreational than on walking to utilitarian purposes, whereas walking for utilitarian purposes was more consistently associated with walkability of the environment.

As the previous examples demonstrate, the comparisons of dissonant and consonants residents have yielded slightly varying results between studies. One explanation for these differing results may be found from the geographical context, relating to the differences in American and European urban structures and transportation cultures. In Atlanta, the United States, both consonant and dissonant residents living in high-walkable environments drove as much regardless of their differing preferences (Frank et al., 2007). This result indicated, that driving was a very common and convenient mode of transport also in those urban neighborhoods, which were categorized as ‘high walkable’. In Belgium, instead, residents with rural land-use preferences were constrained to use a car when living in urban areas, while residents with urban land-use preferences seemed to have better opportunities for walking, cycling, and transit use even when living in rural areas (De Vos et al., 2012). Moreover, in Atlanta, for those residents who preferred low-walkable environments, the absolute amount of walking was very low regardless of where they lived, indicating that built environment-related measures to promote active transportation would at best result in only a modest increase in walking for this segment of the population (Frank et al., 2007). However, in Helsinki, the built environment was found to influence the walking behavior also of those residents who did not prefer to live in a high-walkable neighborhood but actually lived in one (dissonants) (Kajosaari et al., 2019).

As presented in the previous sections, both methods of statistically addressing residential self-selection can provide additional insights into the relationship between the built environment, attitudes, and travel. Travel behavior models with travel-related attitudes included enable us to observe, whether built environment characteristics remain as significant predictors of travel behavior after the possible residential self-selection effect has been considered. The comparison of the dissonant and consonant residents, instead, enables us to compare how residents with similar attitudes behave when living in varying environments.

According to a review by Cao et al., (2009) in most of the residential self-selection studies at least certain built environment variables remained an autonomous association with travel behavior once the travel attitudes and/or neighborhood preferences were accounted for. However, in a majority of these studies, the effect of the built environment characteristics diminished after the attitudes were included in the analyses, indicating that attitudes did play a confounding role between the built environment and travel behavior. Since the examined built environment variables and methods of assessing the self-selection issue vary considerably, it is more difficult to draw explicit conclusions of the strength of the autonomous influence of the built environment relative to the effect of self-selection. Moreover, as the previous examples demonstrate, also the studies comparing consonant and dissonant residents have yielded varying outcomes. Therefore, it is reasonable to argue, that more knowledge from different kinds of geographical contexts is needed to strengthen the evidence base of built environment-travel studies, which consider multiple levels of influence and properly take into account the effect of residential self-selection.

2.5 Research objectives

This study aims to examine the relationship between built environment characteristics, attitudes and preferences, and travel behavior in the Finnish context by utilizing questionnaire data collected in the Turku region in early 2020. The study takes into account the possible confounding effect of residential self-selection on the relationship between the built environment and travel behavior. Thus, the study aims to investigate to what extent are built environment and attitudes associated with car use, walking, and cycling. Public transportation use was left out of the analyses of this study since the previous analysis with the same data showed that the public transportation use among the survey sample was very low during spring, summer, and autumn (Ramezani et al., 2020).

The specific research questions are as follows:

- Are there statistically significant differences in travel behavior between residents living in different urban zones?

- Are there statistically significant differences in travel behavior between residents who have different neighborhood preferences and attitudes towards travel?

- Is built environment associated with differences in car use and active transportation after attitudes and socio-demographic characteristics have been accounted for?

- Are there statistically significant differences in travel behavior between residents with similar attitudes, but living in different kinds of environments?

3 Research methodology

3.1 Empirical context

The empirical part of this study was executed by utilizing questionnaire data collected in the Turku region in January 2020. The Turku region is located in the Southwest Finland and it consists of the City of Turku and ten surrounding municipalities. It is the third-largest urban region in Finland with approximately 335 000 residents in total, of which over 194 000 residents live in the city of Turku (Table 1).

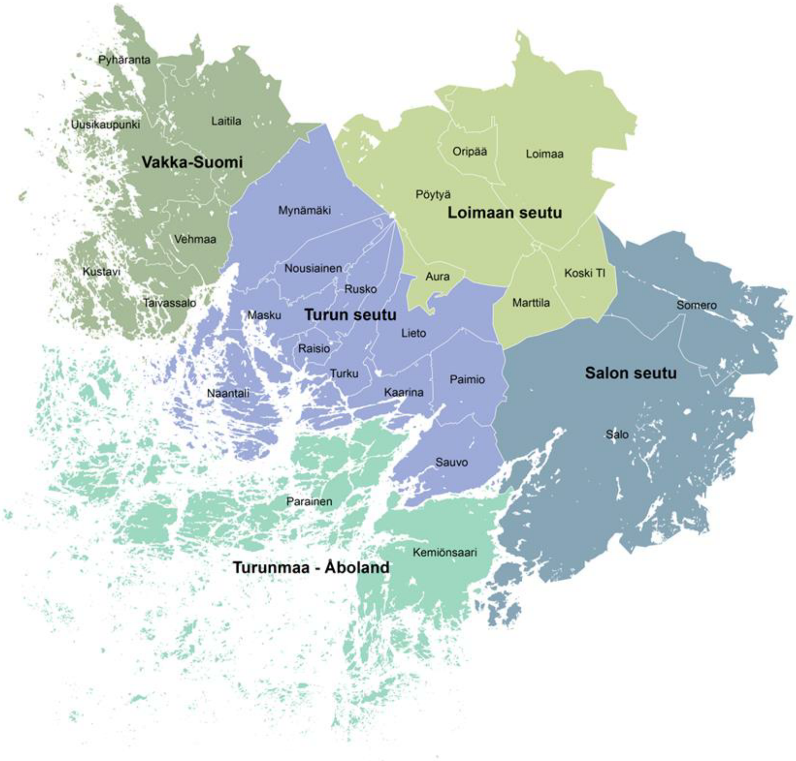

Figure 2. The Turku region (Regional Council of Southwest Finland, 2021)

The location along the coast of the Baltic Sea characterizes the region (Figure 2). Large areas of the region are located on the Archipelago Sea, although the population centers have concentrated on the mainland. Moreover, the location reflects the region’s livelihoods: the Turku region is the most significant cluster of maritime expertise in Finland, including two significant seaports and shipyard industry.

Table 1. Municipalities in the Turku region by population and land area. (NLS, 2020; OSF, 2020)

Municipality	Population (2020)	Land area km2 (2020)
Turku	194 601	245,66
Kaarina	34 599	150,65
Raisio	24 404	48,76
Lieto	20 094	300,52
Naantali	19 378	312,46
Paimio	10 920	238,41
Masku	9 543	174,75
Mynämäki	7 650	519,8
Rusko	6 355	127,15
Nousiainen	4 684	198,99
Sauvo	2 937	252,6

3.2 Data collection

3.2.1 Questionnaire

The data for this study were collected using a participatory online mapping tool Maptionnaire, which combines traditional surveys with online maps. The benefit of using a PPGIS (Public Participation Geographical Information Systems) tool instead of a traditional survey is that it enables collecting both non-spatial data and spatial data from the residents in the context of place.

Web-based mapping surveys have been applied in a variety of fields, both in research and planning, in order to understand perceptions, preferences, values, experiences, and behavior with relation to place (Fagerholm et al., 2021). In the Finnish context, several research projects have employed online mapping in examining spatial behavior patterns of the citizens. Mapping of everyday mobility practices and activities have been employed in order to examine changes in the travel behavior of recently moved dwellers (Ramezani et al., 2021), walking behavior of young adults (Kajosaari et al., 2019) and older adults (Laatikainen et al., 2019), and active mobility patterns of children (Kyttä et al., 2018) among others.

Web-based mapping surveys enable efficient data collection, but the quality and usability of the data are reliant on multiple factors. First, a variety of strategies can be applied to recruit survey participants, including random sampling from population registers, purposive sampling, and volunteer sampling through traditional and social media. However, the selected method can significantly influence the representativeness of the collected data. According to a recent article by Kahila-Tani et al. (2019), random sampling seems to result in more balanced sample representativeness compared to volunteer sampling methods. In addition to the sampling method, other factors that influence the quality of the PPGIS data include mapping effort, accuracy and precision, and the type of spatial data collected. Some of these factors will be further discussed in relation to the limitations of this study in section 6.

3.2.1.1 Questionnaire design

This study utilized questionnaire data, which was collected as a part of the European project HUPMOBILE – Holistic Urban and Peri-urban Mobility, co-funded by the European Regional Development Fund. The research outputs of the project (Work package 3 - Mobility Management and the Needs of Residents) have been reported by Ramezani et al., (2020). This thesis is otherwise independent of the HUPMOBILE project.

The online questionnaire that was used to collect data for the HUPMOBILE project consisted of 11 sections in total, including both mapping tasks and more traditional survey instruments such as non-spatial structured and open-end questions. However, since the questionnaire was aimed at collecting data for multiple different research purposes, only the sections relevant for this study are presented below.

The first section regarding respondents' background information consisted of various questions regarding the demographic and socio-economic status of the respondents. These included gender, age, the highest level of completed education, household type, and personal monthly income after taxation. In addition, the respondents were asked to report the number of cars in the household to account for the possibility of car usage. Associations between various demographic and socio-economic variables, car ownership, and travel mode choice have been found in the literature. Thus, these variables were measured and added to the travel behavior models to prevent any of these variables from causing spuriousness to the relationship between built environment and travel.

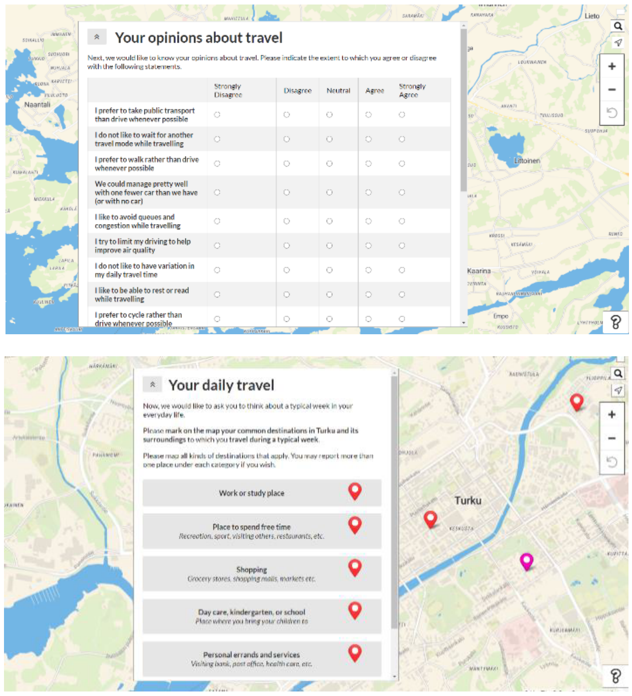

Figure 3. Two screenshots of the online survey portraying the attitudinal statements about travel (top) and mapping task of frequently visited destinations (bottom).

The travel-related attitudes and preferences for neighborhood characteristics were measured with two separate sections including multiple overlapping statements. First, the respondents were provided with a structured set of 15 statements regarding their attitudes towards travel and asked to rate their opinion on a 5-point Likert scale ranging from 'Strongly disagree' to 'Strongly agree' (Figure 3). In a similar way, the respondents were asked to indicate, how important different neighborhood characteristics were when they were choosing their current residential neighborhood. This section consisted of 29 statements, which were evaluated with a 5-point Likert scale varying from 'Not at all important' to 'Very important'. For both sections, the statements were acquired from Handy et al., (2005) examining residential self-selection and travel behavior in Northern California, and from Ramezani et al., (2018) who modified and extended the same set of statements to account for more personality traits.

Two separate mapping tasks aimed at collecting spatial data relevant for this study. In the first task, the respondents were asked to map the location of their current home. The second task focused on the travel behavior of the residents (figure 3). In this section, the respondents were asked to map their daily errand points (DEP's), i.e. those locations to which they usually travel during a typical week in their everyday life. The mapping task was provided with five different place marking categories, including work or study place, a place to spend free time, shopping, day care/kindergarten/school, and personal errands/services. After each marking, a pop-up question with more defined questions opened for the respondent. These included trip purpose, mode of transportation during winter and other seasons, and frequency of visit. There were no guidelines or restrictions on how many places or which categories the respondents should mark.

3.2.1.2 Procedure

In January 2020, an invitation letter to take part in a study was sent to 5000 respondents between 15 and 75 years old and living in the Turku region. These respondents were selected based on a random sample from municipalities over 10 000 residents in the Turku region, including Turku, Kaarina, Raisio, Naantali, Lieto, and Paimio. The names and addresses of the invited residents were obtained from the Population Register Center of Finland. After three weeks from the invitation letter, a reminder postcard was sent to the same sample. As an incentive to participate in the study, the respondents who would leave their email addresses would be entered a drawing of 5 prizes.

In total 704 people out of the invited 5000 residents answered the survey, which makes the response rate 14 %. Simultaneously, an identical questionnaire was open for the public and it was marketed on the City of Turku's website and social media channels. The open questionnaire received 102 responses. The responses from the invitation-only and open surveys were combined, resulting in 806 responses in total. However, answering all the questions was voluntary. Since all the respondents did not complete every section of the questionnaire, the number of responses eligible for further analyses declined.

3.2.2 Other geospatial datasets

Two additional geospatial datasets were utilized in the analyses of this study. These included YKR urban zone classification produced by the Finnish Environment Institute and a road and street network dataset provided by the Finnish Transportation Infrastructure Agency Agency (FTIA). The content of these datasets and their utilization in this study will be explained in more detail in sections 3.3.2.2 and 3.3.3.

3.3 Data analysis

The data analysis was conducted in two stages. After the preparation and coding of the raw questionnaire data, the first stage of the data analysis involved reclassification of the urban zone data, calculation of the travel outcome variables, and statistical factor and cluster analyses for resident segmentation based on respondents' neighborhood preferences and attitudes towards travel. The second stage of the data analysis consisted of the statistical analyses, in which the variables measured in the previous stage were utilized in Kruskal-Wallis H -tests and regression models to examine the relationship between built environment characteristics, attitudes, and travel behavior. These steps will be explained in more detail in the following sections.

Data preparation and calculation of the explanatory and response variables were made in ArcMap 10.6 and Microsoft Excel 2016.

3.3.1 Data preparation

The raw questionnaire data required data preparation as the first step before any calculations or statistical analysis could be done. This included the removal of obviously fault mappings, such as daily errand points or home location points located in the water or other arbitrary or outlying locations.

The statistical analyses in this study utilized data about respondent's socio-demographic background, home location, daily errand points, travel attitudes, and neighborhood preferences. Therefore, only those respondents who had completed all these sections in the questionnaire were included in the further analyses, which reduced the number of eligible respondents. In addition, after the calculation of the travel outcome variables - a step, which will be explained later - a few outlier residents with extreme monthly traveled distances were excluded from the sample. After data preparation, the sample size of the study was 472 respondents.

3.3.2 Independent variables

3.3.2.1 Demographic and socio-economic variables

The examined demographic and socio-economic variables that were measured and added in travel behavior models included:

(a) Gender
The question regarding gender had three answer options including; female; male; other. However, due to zero answers in the 'other'-category, the gender was included in the models as a dummy variable, where females were assigned a value 1 and males value 0.

(b) Age
Age was measured in five categories including 15-14; 25-34; 35-44; 45-64; above 64 years.

(c) Highest level of education
Education level was categorized into basic education; upper secondary education; undergraduate level; graduate level; postgraduate level.

(d) Having a child/children
In the questionnaire, the question concerning household type was divided into six categories including living alone; living alone with a child/children; living with a partner; living with a partner and a child/children; several people with separate budgets; other. However, we decided to test, whether having a child/children in the household was associated with travel choices. Thus, a new dummy variable was created by assigning a value 1 for those respondents belonging to group 'living alone with a child/children' or 'living with a partner and a child/children' and a value 0 if otherwise.

(e) Average monthly income
The question regarding the average monthly income of the respondent consisted of four categories in total: less than 1500 euros; 1500-3000 euros; 3000-4500 euros; more than 4500 euros a month.

(f) Number of cars in the household
The number of cars in the household consisted of four categories including no car; one car; two cars; three or more cars.

3.3.2.2 Urban zone of residence

In this study, the YKR urban zone classification was used as a variable to describe the physical environment around each respondent's home location. YKR urban zone classification 2017 is a geospatial dataset produced by Finnish Environment Institute, available for 34 urban regions in Finland. The dataset is founded on 250 m x 250 m grid, where each cell is categorized into a pedestrian zone, public transport zone, car zone or a combination of them. In total, the classification consists of ten different categories.

The categorization of each cell is based on three indicators including public transport service level, distance to the city center, and distance to nearest public transportation stop. Thus, the zones represent urban environments that differ from each other in terms of public transport availability and can be utilized for various purposes, such as investigating travel behavior in different parts of the urban fabric or the distribution of population, workplaces, and services in relation to available transportation possibilities (The Finnish Environment Institute, 2017).

The YKR urban zone classification data has been utilized in previous travel behavior studies in Helsinki region. Hasanzadeh et al., (2018) applied YKR urban zone classification to study the relationship between the location of the domicile and local activity spaces of the aging citizens in the Helsinki area. In their study, the original urban zones were aggregated into urban, semiurban, suburban, and rural settings. By utilizing the same dataset in another study, Hasanzadeh (2019) reclassified the YKR zoning into pedestrian, transit, and car zones in order to examine the relationship between the location of domicile in the Helsinki region and the centricity of activity spaces.

In this study, the original zoning was aggregated into three zones based on the public transportation availability. The re-classified zones in this study were labeled as *an intensive transit zone*, *basic transit zone,* and *car zone*. Departing from the original dataset, the edge zones of the city center and pedestrian zones in the local centers were also classified as car zones, since they have poor or no public transportation (Table 2). The re-classified zones in the Turku region are presented in Figure 4.

According to previous research, public transportation density has been associated with higher levels of walking or overall physical activity of adults (Cerin et al., 2018; Christiansen et al., 2016; Ewing & Cervero, 2010; Sallis et al., 2016). Moreover, those built environment variables associated with higher levels of walking are often found in central urban environments (Panter & Jones, 2010). As can be seen from the map, the intensive transit zones are located in the central areas of the city of Turku as well along the main transport corridors between Turku and the surrounding municipalities. Thus, the urban zone variable in this study can be considered to describe not only the availability of public transportation but also how urban and walkable the environment is.

After the reclassification of the zones, the zoning data was overlapped with the home location points of the survey respondents in ArcMap. Those residents who lived outside of the three urban zones were categorized as living in a car zone. Thus, each respondent was designated an urban zone of residence.

Table 2. Original and re-classified urban zones

Original YKR urban zone classification (SYKE)	Re-classification
Pedestrian zone in the city center	Intensive transit zone
Intensive transit zone	Intensive transit zone
Pedestrian zone / intensive transit zone in the local center	Intensive transit zone
The edge zone of the city center / intensive transit zone	Intensive transit zone
Basic transit zone	Basic transit zone
Pedestrian zone / basic transit zone in the local center	Basic transit zone
The edge zone of the city center / basic transit zone	Basic transit zone
The edge zone of the city center	Car zone
Pedestrian zone in the local center	Car zone
Car zone	Car zone

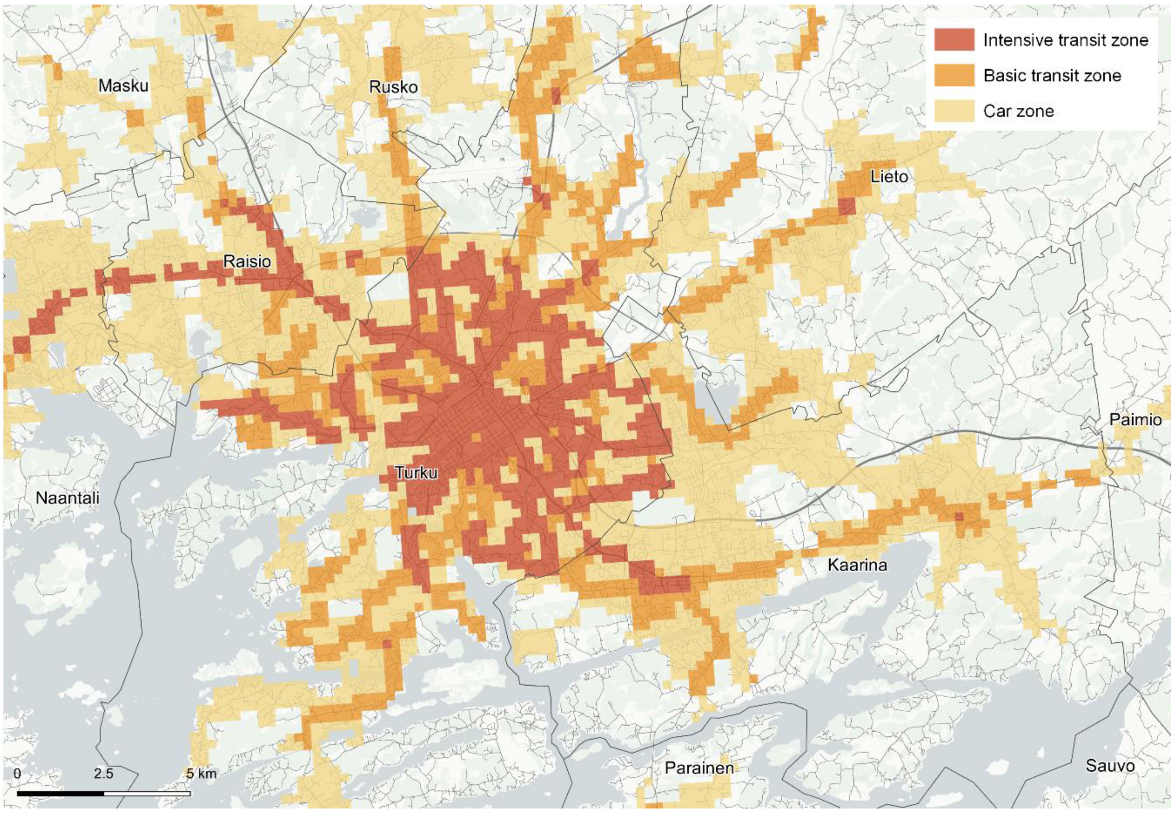

Figure 4. Re-classified urban zones in the Turku region.

3.3.2.3 Resident segmentation based on travel attitudes and neighborhood preferences

In order to identify segments of residents with distinctive attitudes and preferences, a set of factor and cluster analyses were performed based on the travel attitudes and neighborhood preferences surveyed in the questionnaire. This thesis utilizes the results of preparatory statistical analyses performed with the same data sample for other research purposes. The results of the factor analysis and cluster analysis have been first reported in Ramezani et al., (2020).

The common objective of exploratory factor analysis (EFA) is to represent a large set of variables in a reduced number of hypothetical measurement variables, i.e. factors. The identified factors explain patterns of correlations within the larger set of observed variables, which in this study, are the statements about neighborhood preferences and attitudes towards travel. The method is most appropriate in situations, where the number of factors and the mutual associations of the variables are not known beforehand.

Separate factor analyses for both sets of statements were conducted with IBM SPSS Statistics to identify the underlying latent attitudinal factors. The 29 statements regarding neighborhood characteristics resulted as 7 factors, of which 4 were found to have sufficient internal reliability (Cronbach's Alpha > 0,5) and were kept for further analyses. These factors include (1) *Neighborhood walkability, access to transit and city center,* (2) *Accessibility to school, work, and free-time facilities,* (3) *Spacious housing, access to main roads and shopping center,* and (4) *Quiet, attractive and green neighborhood*. The factors and their associated statements with factor loadings are presented in Table 3. The 15 statements regarding travel attitudes (Table 4) were reduced to 3 factors which were all kept for further analyses. The travel-attitude factors include (5) *Pro-sustainable travel,* (6) *Time-sensitive,* and (7) *Cost-sensitive.*

Table 3. Factors for neighborhood preferences.

Factor	Measurement indicator	Loading[a]
Neighborhood walkability, access to transit and city center	Safe and convenient to walk and bike for errands	0,770
	Easy access to a good public transport service	0,712
	Easy to walk and/or cycle in the neighborhood	0,711
	Easy access to the city center	0,691
	Local shops within walking distance (e.g. grocery store)	0,560
Accessibility to school, work, and free-time facilities	Easy access to school or university	0,777
	Neighborhood school quality (for my children)	0,751
	Proximity to work location	0,563
	Other facilities such as a community center or places to spend free time available nearby	0,506
Spacious housing, access to main roads and shopping center	Easy access to highway network or main road	0,746
	Easy access to a district shopping center	0,671
	Good street lighting	0,544
	Clean neighborhood	0,470
	Spacious housing available	0,470
Quiet, attractive, and green neighborhood	Low level of car traffic on neighborhood streets	0,653
	Quiet neighborhood	0,641
	Tree-lined street	0,571
	Attractive appearance of neighborhood	0,520
	Parks and green spaces nearby	0,474

[a] Represents the degree of association between the statement and the factor
Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

Table 4. Factors for travel attitudes.

Factor	Measurement indicator	Loading[a]
Pro-sustainable travel	Changing how people travel is a great way to improve the environment	0,738
	I prefer to take public transport than drive whenever possible	0,697
	I prefer driving to other modes of transportation	-0,696
	I prefer to walk rather than drive whenever possible	0,686
	I try to limit my driving to help improve air quality	0,677
	I prefer to cycle rather than drive whenever possible	0,648
	Vehicles should be taxed on the basis of the amount of pollution they produce	0,581
	I like to be able to rest or read while traveling	0,502
	We could manage pretty well with one fewer car than we have (or with no car)	0,489
Time-sensitive	I do not like to have variation in my daily travel time	0,718
	I like to avoid queues and congestion while traveling	0,695
	I do not like to wait for another travel mode while traveling	0,671
Cost-sensitive	Transit fare affects my choice of daily travel by public transport	0,808
	Fuel price and/or price of parking affects my choice of daily travel by car	0,767

[a] Represents the degree of association between the statement and the factor
Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

The second part of the preparatory analyses, a statistical cluster analysis, aimed at identifying groups of people with similar travel attitudes and neighborhood preferences. This was executed by utilizing the seven attitudinal factor scores calculated for each individual in the factor analyses.

The cluster analysis was executed in two parts since the final number of clusters was not known beforehand. First, hierarchical clustering with Ward's method and squared Euclidean distance was conducted to define the suitable number of clusters. After that, a non-hierarchical clustering (K-mean) defined a cluster membership for each respondent.

The first analysis suggested that the suitable number of clusters was four. The identified clusters are presented in Table 5.

Table 5. Identified clusters (final cluster centers)

Factors	Clusters			
	1	**2**	**3**	**4**
Factor 1. Neighborhood walkability, access to transit and city center	0,663	0,481	-0,831	-0,424
Factor 2. Access to school, work, and free-time facilities	-0,228	0,559	0,309	-0,876
Factor 3. Spacious housing, access to main roads and shopping center	-1,009	0,350	0,196	0,337
Factor 4. Quiet, attractive and green neighborhood	0,382	-0,296	0,683	-0,742
Factor 5. Pro-sustainable travel	1,055	0,131	-0,467	-0,600
Factor 6. Time-sensitive	-0,121	0,078	0,486	-0,316
Factor 7. Cost-sensitive	-0,108	0,710	-0,766	-0,173

The attitudinal characteristics of the identified clusters could be portrayed as follows:

- Cluster 1: The residents of this cluster care for living environments that are convenient to walk and cycle and that have good access to public transportation and the city center. In addition, they appreciate the pleasant appearance and greenness of the neighborhood. In their everyday journeys, these residents prefer to use sustainable transport modes rather than drive, and their travel choices are not either very time- or cost-sensitive.

- Cluster 2: The residents in this cluster do not have a strong preference towards any particular travel mode, but they are cost-sensitive in their travel mode choices. They value proximity to their everyday locations and city center by sustainable travel modes but also place importance on easy access to main roads. The quietness and attractiveness of the neighborhood is not an important criterion when these residents are choosing their residential area to live in.

- Cluster 3: The residents in this cluster value the traditional suburban qualities, such as the quietness and greenness of the neighborhood. In addition, proximity to good quality school and recreational facilities is considered important. In their travel choices, the residents in this cluster are time-sensitive and do not want to have time variation or waiting during their travel. Thus, they are car-oriented, rather than advocates of sustainable travel.

- Cluster 4: This segment of residents value living environments that enable convenient travel by car. These neighborhood qualities include good access to the main roads and district shopping center. In addition, they value the cleanness of the neighborhood and spacious housing. These residents' attitudes towards travel are in accordance with the car-oriented neighborhood preferences, showing no support for walking, cycling, or public transport.

After the clusters were identified, a preliminary Kruskal-Wallis H test was executed to observe, whether the four clusters significantly differed in their travel behavior. The test indicated that the travel behavior of clusters 3 and 4, both with car-oriented preferences, did not differ statistically significantly in terms of any travel mode. In fact, these two clusters differ mainly in terms of their neighborhood preferences. While the residents in cluster 4 show clear preference only towards spacious housing and access to main roads, the residents in cluster 3 also value good access to utilitarian destinations and a green and quiet neighborhood. Since both clusters ultimately value car-oriented environments and have negative attitudes towards sustainable travel modes, clusters 3 and 4 were merged. This resulted in more distinctive resident segments for further analysis: cluster 1 named as *Pro-sustainable residents*, cluster 2 named as *Multimodal residents,* and clusters 3 and 4 combined named as *Pro-car residents.* However, the tradeoff with the three-cluster solution is that the cluster sizes became more uneven.

3.3.3 Dependent variables

The study aimed to examine differences between resident groups in terms of car use, walking, and cycling. To do so, several travel outcome variables were calculated based on the home location and daily errand point markings of each respondent. The shortest distance routes from home to DEP's of each respondent were measured with Network Analyst in ArcMap 10.6 by utilizing the Digiroad street network data. Digiroad is a national database containing the geometry of the Finnish road and street network. The dataset is provided as open data by the Finnish Transport Infrastructure Agency (FTIA).

As was mentioned previously, each of the DEP trips included additional information about the frequency and purpose of the visit and primary travel mode in winter and other seasons. The seasonal variation in travel behavior was, however, left out of the scope of this study. Therefore, from this point forward in the empirical part of this study, the travel mode of respondents refers to the reported mode of transport during spring, summer, and autumn.

The respondents were asked to report their daily errand points during a typical week in spring, summer, and autumn. To get an estimation of total travel distance and the total number of trips during a month, each trip was weighted based on the reported frequency and purpose of the visit. The weighting criteria and given weights are presented in Table 6. After multiplying each trip distance with the given weight, the weighted distances were added up by each mode and in total. From these results, two different outcome variables describing the use of different transportation modes were calculated for each mode: *(1) the share of traveled distance by each mode* and *(2) the share of trips by each mode from the total number of trips.*

This study examines the travel behavior in terms of car use, walking, and cycling. Thus, the calculation resulted in six outcome variables in total: the share of travel distance by car, walking and cycling, and the share of the total number of trips by car, walking and cycling.

Table 6. The weighting criteria and weights for calculation of estimated total travel distance in a month

Weighting criteria	Weight
Frequency: Once a month	1
Frequency: A couple of times a month	2
Frequency: Once a week	4
Frequency: A couple of times per week	8
Frequency: Every day AND Trip purpose: Work, school, kindergarten	22*
Frequency: Every day AND Trip purpose: *Other* than work, school, or kindergarten	30

* Since there are approximately 22 workdays in a month, the reported daily trips to work, school, or kindergarten were given a smaller weight compared to daily trips to other destinations.

3.3.4 Data validation

The data utilized in this study was collected with a digital PPGIS survey through random sampling. It has been previously observed, that random sampling often promotes better representativeness compared to open marketing PPGIS surveys (Kahila-Tani et al., 2019). However, when comparing the socio-demographic structure of the respondents in this study to that of the Turku region in total, certain imbalances could be found (Table 7).

When considering the age structure of the sample, the 25-34 years old and 45-64 years old respondents were overrepresented compared to the Turku region average. Young respondents aged 15-24 years old, as well as respondents between 35-44 years and above 64 years, were underrepresented in the sample, respectively.

Females were slightly overrepresented among the sample compared to the Turku region average. Furthermore, a comparison of the education profile of the respondents showed, that residents with tertiary education were overrepresented in the sample, while residents with basic or upper secondary education were underrepresented, respectively.

Table 7. Socio-demographic characteristics of the respondents

	Sample	Population in the Turku region [a]
Gender (%)		
Female	52,5	51,4
Male	47,2	48,6
Age, years (%)		
15-24	12,3	14,5
25-34	19,7	17,0
35-44	12,9	15,4
45-64	36,7	27,9
above 64	18,4	25,2
Highest level of education (%)		
Basic education	7,6	26,2 [b]
Upper secondary education	33,3	41,2 [b]
Undergraduate	32,8	11,7 [b]
Graduate	23,1	9,2 [b]
Postgraduate	2,3	1,3 [b]

[a] The reference sample is based on the preliminary population statistics in the Turku region in January 2021.
[b] The reference sample consists of the population aged 15 and over in the Southwest Finland region in 2019.

3.3.5 Statistical analysis procedure

The second stage of the data analysis consisted of the statistical analyses examining the relationship between the built environment, attitudes, and travel behavior. These analyses were done in four parts. First, the demographic and socio-economic characteristics of the respondent groups were observed by stratifying the respondents based on their identified attitude cluster and urban zone of residence. Second, rank-based non-parametric tests (Kruskal-Wallis H) were utilized to determine statistically significant differences in travel behavior between different groups. These tests were made both for residents living in different urban zones and residents belonging to different attitude clusters. Third, separate multiple linear regression models for each travel outcome variable were made to investigate whether the built environment was associated with driving, walking, and cycling after demographic and socio-economic characteristics and attitudes were accounted for. Finally, the residents were re-categorized into nine groups based on their attitude cluster and urban zone of residence. The in-group differences related to travel behavior of attitude clusters living in different zones were again examined with Kruskal-Wallis H non-parametric test.

All the statistical analyses were performed with IBM SPSS Statistics.

4 Findings

4.1 Socio-demographic characteristics of the respondents

The first part of the statistical analyses provided descriptive statistics of the different respondent groups. The data was stratified both by the identified attitude clusters and urban zones of residence (Table 8).

The examined attitude clusters differed from each other in terms of their demographic and socio-economic characteristics. On average, the pro-sustainable cluster group had a higher share of females and young adults compared to other groups, while over 67 percent of the pro-car cluster consisted of adults over 45 years old. Furthermore, one-person households were more common among pro-sustainable residents, whereas in multimodal and pro-car cluster groups higher share of residents lived with a partner or with a partner and one or more children.

A monthly income below 1500 euros was more common in the pro-sustainable and multimodal clusters compared to the pro-car cluster. In addition, 11 percent of the car-oriented residents earned over 4500 euros a month, whereas only a minor share of pro-sustainable and multimodal residents belonged to the same salary group.

While over 45 percent of the pro-sustainable residents lived without a car and an equal share of residents had one car in the household, nearly every pro-car cluster household had at least one car, and over half the households two or more cars. The majority of the multimodal households had one car, but on average an equal share either had two or more cars in the household or did not own a car at all.

The socio-demographic characteristics of the respondents living in different urban zones followed a similar pattern as was observed between the attitude clusters. Residents living in intensive transit zone were in general younger compared to residents in basic transit and car zones. This also reflects differences in average monthly income between residents in different zones. The share of residents having a monthly salary below 1500 euros was highest in the intensive transit zone, followed by basic transit and car zone.

The share of respondents living with a partner and a child was considerably higher in the car zone, and the share of respondents living alone considerably lower, respectively. As was anticipated, having no car in the household was more common in the intensive transit and basic transit zones than in the car zone. Moreover, the share of households owning two or more cars was higher in the car zone compared to other zones.

Table 8. Socio-demographic characteristics of the respondents

	Cluster [a]			Urban zone of residence [b]			
	Pro-sustainable	Multimodal	Pro-car	Intensive transit zone	Basic transit zone	Car zone	Total
	n=109	n=149	n=214	n=245	n=82	n=144	n=472
Gender (%)							
Female	63,3	53,0	46,7	51,8	53,0	53,5	**52,5**
Male	35,8	47,0	53,3	48,2	45,8	46,5	**47,2**
Age, years (%)							
15-24	14,7	18,1	7,0	15,9	8,4	8,3	**12,3**
25-34	30,3	22,1	12,6	27,3	18,1	7,6	**19,7**
35-44	11,9	13,4	13,1	11,0	14,5	15,3	**12,9**
45-64	25,7	30,9	46,3	29,0	38,6	48,6	**36,7**
above 64	17,4	15,4	21,0	16,7	20,5	20,1	**18,4**
Highest level of education (%)							
Basic education	9,2	6,7	7,5	7,8	7,2	7,6	**7,6**
Upper secondary education	33,0	34,9	32,2	35,5	36,1	27,8	**33,3**
Undergraduate	27,5	32,9	35,5	33,5	24,1	36,8	**32,8**
Graduate	27,5	21,5	22,0	21,2	26,5	24,3	**23,1**
Postgraduate	2,8	3,4	1,4	1,6	3,6	2,8	**2,3**
Household type (%)							
Living alone	38,5	21,5	16,4	29,0	25,3	11,8	**23,1**
Living alone with child	1,8	2,0	2,8	2,0	4,8	1,4	**2,3**
Living with a partner	34,9	47,7	45,3	46,5	37,3	42,4	**43,6**
Living with a partner and a child	14,7	18,8	29,4	13,9	26,5	35,4	**22,7**
Several people with separate budgets	0,9	2,7	1,9	2,0	1,2	2,1	**1,9**
Other	9,2	7,4	4,2	6,5	4,8	6,9	**6,4**
Average monthly income (%)							
< 1500 euros	33,9	36,2	18,2	31,8	28,9	19,4	**27,5**
1500-3000 euros	49,5	47,0	48,1	49,0	42,2	50,0	**48,1**
3000-4500 euros	11,0	6,7	15,9	9,4	14,5	14,6	**11,9**
> 4500 euros	0,9	1,3	11,2	3,3	8,4	8,3	**5,7**
No. of cars in HH (%)							
No car	45,9	22,8	4,2	28,6	16,9	6,3	**19,7**
1	45,0	53,7	43,0	52,7	45,8	37,5	**46,8**
2	6,4	17,4	41,6	15,1	26,5	43,8	**25,8**
3 or more	2,8	4,7	10,7	2,9	10,8	11,8	**7,0**

[a] In-group differences are significant (Pearson Chi-Square, $p = <0.05$) for gender, age, household type, income, and the number of cars in the household.
[b] In-group differences are significant (Pearson Chi-Square, $p = <0.05$) for age, household type, income, and the number of cars in the household.

4.2 Urban zone and travel behavior

The second part of the analyses focused on the differences in car use, walking, and cycling between residents. The differences in travel behavior were examined both between residents living in different urban zones and between residents belonging to different attitude clusters.

According to the results of the one-way non-parametric ANOVA test (The Kruskal-Wallis H), the residents living in different urban zones differed in terms of car use and active travel behavior.

Table 9. Urban zone and driving

		Share of traveled kilometers by car		**Share of trips by car**	
	n	Mean	Kruskal-Wallis mean rank [a]	Mean	Kruskal-Wallis mean rank [a]
Intensive transit zone	244	36,8 %	193,13	30,0 %	190,09
Basic transit zone	83	53,9 %	246,12 [b]	50,2 %	249,95 [b]
Car zone	144	71,1 %	302,81 [b c]	66,6 %	304,22 [b c]

[a] Significance values have been adjusted by the Bonferroni correction for multiple tests.
[b] Significantly different to Intensive transit zone ($p < 0,05$)
[c] Significantly different to Basic transit zone ($p < 0,05$)

The share of traveled kilometers and share of trips by car was significantly higher for residents living in the car zone compared to residents in living intensive transit and basic transit zones. In addition, there was a significant difference between intensive transit and basic transit zones regarding both variables (Table 9).

Table 10. Urban zone and walking for transport

		Share of traveled kilometers by walking		**Share of trips by walking**	
	n	Mean	Kruskal-Wallis mean rank [a]	Mean	Kruskal-Wallis mean rank [a]
Intensive transit zone	244	21,4 %	275,55	32,0 %	275,42
Basic transit zone	83	6,5 %	208,28 [b]	12,6 %	204,68 [b]
Car zone	144	4,4 %	184,96 [b]	8,5 %	185,41 [b]

[a] Significance values have been adjusted by the Bonferroni correction for multiple tests.
[b] Significantly different to Intensive transit zone ($p < 0,05$)

Expectedly, the share of walking distance and share of walking trips was significantly higher in the intensive transit zone compared to the other zones. In addition, there was a small difference in the prevalence for walking between basic transit and car zone, but the difference did not show statistical significance (Table 10).

Table 11. Urban zone and cycling for transport

		Share of traveled kilometers by cycling		Share of trips by cycling	
	n	Mean	Kruskal-Wallis mean rank [a]	Mean	Kruskal-Wallis mean rank [a]
Intensive transit zone	244	29,3 %	249,67	28,4 %	248,37
Basic transit zone	83	29,0 %	252,64	28,3 %	250,13
Car zone	144	14,2 %	203,24 [b c]	16,1 %	205,36 [b c]

[a] Significance values have been adjusted by the Bonferroni correction for multiple tests.
[b] Significantly different to Intensive transit zone ($p < 0,05$)
[c] Significantly different to Basic transit zone ($p < 0,05$)

Bicycle use both in terms of the share of traveled kilometers and share of trips was almost equal in the intensive and basic transit zones, and significantly higher compared to car zone (Table 11).

4.3 Travel attitudes, neighborhood preferences, and travel behavior

Similar Kruskal-Wallis T-tests as presented in the previous section were conducted for the three attitude clusters to examine whether differences in travel-related attitudes and neighborhood preferences reflected actual travel behavior.

Table 12. Attitudes towards travel and driving

		Share of traveled kilometers by car		Share of trips by car	
	n	Mean	Kruskal-Wallis mean rank [a]	Mean	Kruskal-Wallis mean rank [a]
Pro-sustainable	109	17,1 %	133,92	13,1 %	133,11
Multimodal	147	40,2 %	207,62 [b]	33,9 %	205,60 [b]
Pro-car	214	74,3 %	307,62 [b c]	68,3 %	308,19 [b c]

[a] Significance values have been adjusted by the Bonferroni correction for multiple tests.
[b] Significantly different to Pro-sustainable cluster ($p < 0,05$)
[c] Significantly different to Multimodal cluster ($p < 0,05$)

The residents with a pro-car attitude traveled by car significantly more than pro-sustainable and multimodal residents both in terms of share of total kilometers and share of trips. Furthermore, multimodal residents used a car more than pro-sustainable residents (Table 12).

Table 13. Attitudes towards travel and walking for transport

		Share of traveled kilometers by walking		Share of trips by walking	
	n	Mean	Kruskal-Wallis mean rank [a]	Mean	Kruskal-Wallis mean rank [a]
Pro-sustainable	109	25,0 %	291,31	36,3 %	289,58
Multimodal	147	16,3 %	245,06 [b]	23,8 %	244,61 [b]
Pro-car	214	5,9 %	201,57 [b c]	12,2 %	201,70 [b c]

[a] Significance values have been adjusted by the Bonferroni correction for multiple tests.
[b] Significantly different to Pro-sustainable cluster (p < 0,05)
[c] Significantly different to Multimodal cluster (p < 0,05)

Residents preferring walkable neighborhoods and sustainable travel modes walked significantly more than other clusters of residents. For instance, the share of travelled kilometers by walking was almost five times higher and the share of walking trips three times higher for pro-sustainable residents compared to pro-car residents. In addition, the multimodal cluster with no preference towards any travel mode walked significantly more compared to the pro-car cluster (Table 13).

Table 14. Attitudes towards travel and cycling for transport

		Share of traveled kilometers by cycling		Share of trips by cycling	
	n	Mean	Kruskal-Wallis mean rank [a]	Mean	Kruskal-Wallis mean rank [a]
Pro-sustainable	109	39,1 %	286,18	36,6 %	281,04
Multimodal	147	31,1 %	256,71	31,6 %	257,61
Pro-car	214	12,8 %	196,12 [b c]	13,7 %	197,11 [b c]

[a] Significance values have been adjusted by the Bonferroni correction for multiple tests.
[b] Significantly different to Pro-sustainable cluster (p < 0,05)
[c] Significantly different to Multimodal cluster (p < 0,05)

Residents with car-oriented attitudes cycled significantly less compared to pro-sustainable and multimodal residents. The cycling behavior between pro-sustainable and multimodal residents, instead, did not differ significantly (Table 14).

4.4 Regression models for car use, walking and cycling

As the previous sections demonstrate, there were significant differences in travel behavior between residents living in different zones, but also the attitudes and preferences of the resident clusters did reflect differences in their travel behavior. Therefore, separate multiple linear regression models for each travel outcome variable were created to examine, whether the built environment was related to differences in car use, walking, and cycling once attitudes, preferences, and socio-demographic characteristics were controlled for. These models tested the hypothesis that neighborhoods that are located closer to destinations, and where residents have better opportunities for using sustainable travel modes are associated with less driving and more walking and cycling, regardless of the possibility that residential self-selection might occur.

Table 15. Regression model for driving

	Share of traveled kilometers by car				Share of trips by car			
	B	β	t	p-value	B	β	t	p-value
(Constant)	-0,229		-2,860	0,004	-0,266		-3,441	0,001
Gender (ref. male)								
Female	0,003	0,003	0,079	0,937	0,017	0,020	0,548	0,584
Age, years (ref. 15-24)								
25-34	0,046	0,042	0,707	0,480	0,089	0,084	1,422	0,156
35-44	**0,215**	**0,167**	**2,859**	**0,004**	**0,227**	**0,181**	**3,109**	**0,002**
45-64	**0,182**	**0,200**	**2,790**	**0,006**	**0,170**	**0,193**	**2,708**	**0,007**
above 64	0,127	0,114	1,955	0,051	**0,139**	**0,129**	**2,220**	**0,027**
Education (ref. basic education)								
Upper secondary education	0,116	0,125	1,714	0,087	0,106	0,119	1,629	0,104
Undergraduate	0,082	0,089	1,171	0,242	0,058	0,064	0,848	0,397
Graduate	0,094	0,092	1,266	0,206	0,059	0,059	0,824	0,411
Postgraduate	-0,106	-0,037	-0,863	0,389	-0,055	-0,019	-0,462	0,645
Having a child (ref.no)	-0,067	-0,067	-1,546	0,123	-0,058	-0,060	-1,378	0,169
Monthly income (ref. < 1500 euros)								
1500-3000 euros	-0,017	-0,019	-0,407	0,684	-0,011	-0,013	-0,282	0,778
3000-4500 euros	0,054	0,042	0,868	0,386	0,049	0,039	0,804	0,422
> 4500 euros	-0,085	-0,047	-1,069	0,286	-0,092	-0,052	-1,189	0,235
No. of cars in HH (ref. no car)								
1	**0,342**	**0,391**	**7,542**	**0,000**	**0,284**	**0,335**	**6,481**	**0,000**
2	**0,497**	**0,504**	**8,737**	**0,000**	**0,459**	**0,480**	**8,356**	**0,000**
3 or more	**0,528**	**0,287**	**6,490**	**0,000**	**0,452**	**0,254**	**5,757**	**0,000**
Urban zone of residence (ref. intensive transit zone)								
Basic transit zone	0,038	0,033	0,852	0,395	**0,095**	**0,084**	**2,197**	**0,029**
Car zone	**0,117**	**0,123**	**2,998**	**0,003**	**0,164**	**0,178**	**4,343**	**0,000**
Cluster (ref. pro-sustainable)								
Multimodal	**0,130**	**0,137**	**2,961**	**0,003**	**0,119**	**0,129**	**2,801**	**0,005**
Pro-car	**0,313**	**0,357**	**6,842**	**0,000**	**0,315**	**0,370**	**7,128**	**0,000**
R-square	0,493				0,498			
Adjusted R-square	0,468				0,474			

Statistically significant values (p < 0,05) are bolded.

In the regression model for driving (Table 15) only age and car ownership were associated with car use of all the examined socio-demographic variables. When controlling for other socio-demographic variables, urban zone of residence, and attitudes, those above 35 years were found to drive more than those belonging to the youngest age group. In addition, residents having one or more cars in the household traveled by car significantly more, than those with no car. The more there were cars in the household, the stronger was the observed association.

Both multimodal and pro-car residents had a significantly higher share of traveled distance by car and made more car trips compared to pro-sustainable residents after controlling for other variables (Table 15).

The coefficients of the urban zone of residence indicated, that the share of traveled distance by car was approximately 12 percent higher and the share of trips by car 16 percent higher for those living in car zone versus for those living in intensive transit zone after socio-demographics, car ownership, travel-related attitudes and neighborhood preferences had been accounted for. Thus, the model suggested, that the urban zone of residence significantly affected car use, regardless of the possible effect of residential self-selection.

Similar to the model for car use, the regression model for walking (Table 16) resulted in only a few statistically significant associations between socio-demographic characteristics and walking outcomes. Those having upper secondary education or higher walked a larger share of their total monthly travel distance compared to those with basic education. Similar associations applied to the share of walking trips, but those associations were not statistically significant. In addition, having a car in the household was found to significantly decrease walking, both in terms of share of traveled kilometers and share of trips. For example, those having one or two cars in the household had a 17 percent smaller share of walked kilometers than those with no car after the other variables were accounted for. Moreover, those with one or more cars in the household made 15 to 20 % fewer walking trips than those having no car.

Belonging to pro-car and multimodal clusters was negatively associated with walking. Those with car-oriented attitudes walked approximately 10 % smaller share of their monthly traveled kilometers and made 14 % fewer walking trips than pro-sustainable residents. Furthermore, multimodal residents walked approximately 6 % smaller share of their monthly traveled kilometers (sig. $p < 0,1$) and made 9 % fewer walking trips compared to pro-sustainable residents.

Nevertheless, after the attitudes, socio-demographic variables, and car ownership were accounted for, the urban zone of residence remained a significant predictor of walking. Having other variables constant, the share of walking distance was approximately 10 % higher and the share of walking trips 16 % higher for those living in intensive transit zone than for those living in basic transit or car zones.

Table 16. Regression model for walking

	Share of traveled kilometers by walking				Share of trips by walking			
	B	β	t	p-value	B	β	t	p-value
(Constant)	0,312		5,034	0,000	0,432		5,960	0,000
Gender (ref. male)								
Female	-0,012	-0,022	-0,494	0,622	-0,021	-0,032	-0,707	0,480
Age, years (ref. 15-24)								
25-34	-0,011	-0,016	-0,219	0,827	0,040	0,049	0,677	0,499
35-44	-0,039	-0,048	-0,670	0,503	-0,006	-0,006	-0,082	0,935
45-64	0,035	0,061	0,688	0,492	0,093	0,139	1,581	0,115
above 64	0,021	0,030	0,413	0,680	0,068	0,082	1,152	0,250
Education (ref. basic education)								
Upper secondary education	**0,105**	**0,182**	**2,014**	**0,045**	0,075	0,110	1,231	0,219
Undergraduate	**0,116**	**0,200**	**2,135**	**0,033**	0,118	0,172	1,850	0,065
Graduate	**0,115**	**0,179**	**2,003**	**0,046**	0,117	0,154	1,741	0,082
Postgraduate	0,168	0,092	1,758	0,079	0,089	0,041	0,799	0,425
Having a child (ref.no)	-0,041	-0,065	-1,226	0,221	-0,024	-0,033	-0,614	0,540
Monthly income (ref. < 1500 euros)								
1500-3000 euros	-0,036	-0,066	-1,118	0,264	**-0,078**	**-0,121**	**-2,081**	**0,038**
3000-4500 euros	-0,054	-0,066	-1,112	0,267	-0,102	-0,106	-1,793	0,074
> 4500 euros	0,029	0,025	0,465	0,642	0,003	0,002	0,044	0,965
No. of cars in HH (ref. no car)								
1	**-0,173**	**-0,315**	**-4,918**	**0,000**	**-0,153**	**-0,236**	**-3,717**	**0,000**
2	**-0,172**	**-0,278**	**-3,911**	**0,000**	**-0,176**	**-0,241**	**-3,409**	**0,001**
3 or more	**-0,232**	**-0,201**	**-3,687**	**0,000**	**-0,199**	**-0,146**	**-2,698**	**0,007**
Urban zone of residence (ref. intensive transit zone)								
Basic transit zone	**-0,105**	**-0,145**	**-3,054**	**0,002**	**-0,162**	**-0,188**	**-3,996**	**0,000**
Car zone	**-0,104**	**-0,175**	**-3,443**	**0,001**	**-0,169**	**-0,240**	**-4,771**	**0,000**
Cluster (ref. pro-sustainable)								
Multimodal	-0,060	-0,100	-1,760	0,079	**-0,091**	**-0,129**	**-2,286**	**0,023**
Pro-car	**-0,098**	**-0,178**	**-2,758**	**0,006**	**-0,139**	**-0,214**	**-3,353**	**0,001**
R-square	0,228				0,242			
Adjusted R-square	0,190				0,206			

Statistically significant values ($p < 0,05$) are bolded.

Table 17. Regression model for cycling

	Share of traveled kilometers by cycling				Share of trips by cycling			
	B	β	t	p-value	B	β	t	p-value
(Constant)	0,595		6,834	0,000	0,550		6,474	0,000
Gender (ref. male)								
Female	-0,050	-0,067	-1,434	0,152	-0,044	-0,061	-1,281	0,201
Age, years (ref. 15-24)								
25-34	0,029	0,032	0,414	0,679	-0,026	-0,029	-0,380	0,704
35-44	-0,136	-0,124	-1,666	0,097	**-0,168**	**-0,159**	**-2,100**	**0,036**
45-64	-0,124	-0,161	-1,760	0,079	**-0,167**	**-0,224**	**-2,412**	**0,016**
above 64	-0,105	-0,111	-1,487	0,138	**-0,139**	**-0,153**	**-2,016**	**0,044**
Education (ref. basic education)								
Upper secondary education	**-0,147**	**-0,188**	**-2,011**	**0,045**	-0,122	-0,162	-1,707	0,089
Undergraduate	-0,133	-0,168	-1,733	0,084	-0,116	-0,153	-1,551	0,122
Graduate	-0,125	-0,144	-1,555	0,121	-0,110	-0,131	-1,400	0,162
Postgraduate	0,000	0,000	0,000	1,000	0,029	0,012	0,224	0,823
Having a child (ref.no)	**0,104**	**0,122**	**2,198**	**0,028**	**0,093**	**0,112**	**1,994**	**0,047**
Monthly income (ref. < 1500 euros)								
1500-3000 euros	**0,099**	**0,133**	**2,194**	**0,029**	**0,120**	**0,168**	**2,723**	**0,007**
3000-4500 euros	0,026	0,023	0,378	0,706	0,075	0,071	1,130	0,259
> 4500 euros	0,125	0,081	1,437	0,151	0,139	0,094	1,644	0,101
No. of cars in HH (ref. no car)								
1	**-0,111**	**-0,149**	**-2,250**	**0,025**	-0,080	-0,112	-1,661	0,097
2	**-0,201**	**-0,240**	**-3,251**	**0,001**	**-0,183**	**-0,227**	**-3,032**	**0,003**
3 or more	**-0,189**	**-0,121**	**-2,133**	**0,033**	-0,169	-0,112	-1,956	0,051
Urban zone of residence (ref. intensive transit zone)								
Basic transit zone	0,056	0,057	1,164	0,245	0,057	0,060	1,201	0,230
Car zone	-0,041	-0,051	-0,971	0,332	-0,024	-0,031	-0,573	0,567
Cluster (ref. pro-sustainable)								
Multimodal	-0,034	-0,042	-0,717	0,474	-0,012	-0,015	-0,254	0,799
Pro-car	**-0,163**	**-0,218**	**-3,270**	**0,001**	**-0,138**	**-0,192**	**-2,838**	**0,005**
R-square	0,171				0,148			
Adjusted R-square	0,131				0,107			

Statistically significant values ($p < 0,05$) are bolded.

In the regression model for cycling (Table 17) age, having a child, and the number of cars in the household showed statistically significant associations with levels of cycling. Those residents above 35 years made significantly fewer bicycle trips than younger residents below 25 years. Those having a child or children cycled significantly more compared to those with no children. In addition, similarly to the observed association between car ownership and walking, having one or more cars in the household was associated with lower levels of cycling. For example, residents with two cars in the household had a 20 % smaller share of cycled distance and made 18 % fewer cycling trips than those having no car.

In an earlier stage of the analysis, the Kruskal-Wallis H test applied to examine differences in cycling between urban zones (Table 11) indicated, that those living in car zone cycled significantly less than those in intensive and basic transit zones. However, this difference in levels of cycling was not statistically significant after the socio-demographic characteristics and attitudes were controlled for. Moreover, those having pro-car attitudes cycled significantly less compared to those with pro-sustainable attitudes. Together these results indicate that travel attitudes and neighborhood preferences had a more determining role for the propensity for cycling than the urban zone of residence.

4.5 Residential mismatch & travel behavior

The aim of the final statistical analyses was to observe, whether there were significant differences in the travel behavior of residents who shared similar travel attitudes and preferences but lived in different types of environments. To do so, the respondents were re-categorized into nine groups in total based on their attitude cluster and urban zone of residence. This categorization revealed groups of residents, who could be considered matched or mismatched in terms of their preferred and actual neighborhood.

The term consonant was being used to describe residents, who lived in a neighborhood matching their preferences and travel-related attitudes, and dissonants the vice versa. Of the nine groups formed, pro-sustainable residents living in the intensive transit zone and pro-car residents living in the car zone were considered as consonants, while pro-sustainable residents in the car zone and pro-car residents in the intensive transit zone were both dissonants. Since the multimodal residents did not show clear preference towards any travel mode or type of neighborhood, the terms couldn't be applied to that cluster of residents. However, it was still possible to examine, whether the residential neighborhood was associated with travel behavior for such a group of residents who were not clearly oriented towards any certain mode of transport. In the following sections, the results of the Kruskal-Wallis T-tests will be presented.

The highest shares of car use were found among the pro-car residents, who on average made most of their trips by private vehicle regardless of the urban zone of residence. The share of car trips and traveled kilometers by car was highest among the pro-car residents living in car zone (consonants), followed by pro-car residents in basic transit zone and intensive transit zones (dissonants). However, regardless of the high level of car use of pro-car residents altogether, there was a statistically significant reduction in car use between pro-car consonants and dissonants.

Among the survey sample, the pro-sustainable residents living in intensive transit zone (consonants) and basic transit zone traveled by car less than their counterparts living in car zone (dissonants). However, these differences were not statistically significant. Furthermore, the location of the residence seemed to affect car use also for the multimodal residents who had no strong preference towards any travel mode. Those multimodal residents living in intensive transit neighborhoods traveled by car significantly less compared to those with similar attitudes but living in basic transit zone or car zone (Table 18).

Table 18. Residential dissonance and driving

	n	Share of traveled kilometers by car		Share of trips by car	
		Mean	Kruskal-Wallis mean rank [a]	Mean	Kruskal-Wallis mean rank [a]
Pro-sustainable					
Intensive transit zone (consonants)	73	15,4 %	-	9,9 %	-
Basic transit zone	16	13,5 %	-	12,8 %	-
Car zone (dissonants)	20	26,3 %	-	25,0 %	-
Multimodal					
Intensive transit zone	85	29,2 %	62,64	22,2 %	61,11
Basic transit zone	27	48,3 %	84,78 [b]	45,7 %	86,92 [b]
Car zone	36	59,9 %	94,81 [b]	52,8 %	95,11 [b]
Pro-car					
Intensive transit zone (dissonants)	86	62,5 %	87,82	54,8 %	87,04
Basic transit zone	40	74,0 %	104,94	68,1 %	105,46
Car zone (consonants)	88	85,9 %	127,90 [b]	81,6 %	128,42 [b]

[a] Significance values have been adjusted by the Bonferroni correction for multiple tests.
[b] Significantly different to Intensive transit zone ($p < 0,05$)

Table 19. Residential dissonance and walking

	n	Share of traveled kilometers by walking		Share of trips by walking	
		Mean	Kruskal-Wallis mean rank [a]	Mean	Kruskal-Wallis mean rank [a]
Pro-sustainable					
Intensive transit zone (consonants)	73	30,9 %	62,12	45,3 %	62,76
Basic transit zone	16	14,3 %	41,97 [b]	18,3 %	39,78 [b]
Car zone (dissonants)	20	11,9 %	39,45 [b]	17,6 %	38,85 [b]
Multimodal					
Intensive transit zone	85	23,2 %	84,88	32,7 %	84,52
Basic transit zone	27	8,4 %	66,19	14,0 %	63,56 [b]
Car zone	36	5,7 %	56,22 [b]	9,7 %	56,69 [b]
Pro-car					
Intensive transit zone (dissonants)	86	11,5 %	122,21	20,0 %	121,84
Basic transit zone	40	2,0 %	102,95	9,5 %	103,41
Car zone (consonants)	88	2,1 %	95,19 [b]	5,9 %	95,35 [b]

[a] Significance values have been adjusted by the Bonferroni correction for multiple tests.
[b] Significantly different to Intensive transit zone ($p < 0,05$)

The share of walking trips was highest among pro-sustainable consonants living in the intensive transit zone (consonants), followed by multimodal residents in the intensive transit zone and pro-sustainable residents in the basic transit zone. On the contrary, the lowest shares of walked distances and walking trips were found among pro-car residents in the car zone (consonants) and basic transit zone, followed by multimodal residents in the car zone.

The in-group comparisons showed that the pro-sustainable consonants walked significantly more compared to their dissonant counterparts who lived in the car zone, as well as the pro-sustainable residents in the basic transit zone.

In addition, those multimodal and pro-car residents living in intensive transit zone walked significantly more compared to their counterparts living in car zone. Furthermore, those living in intensive transit zone walked more than those living in basic transit zone among both multimodal and pro-car residents, but only the difference in the share of walking trips among multimodal residents showed statistical significance (Table 19).

Table 20. Residential dissonance and cycling

		Share of traveled kilometers by cycling		**Share of trips by cycling**	
	n	Mean	Kruskal-Wallis mean rank [a]	Mean	Kruskal-Wallis mean rank [a]
Pro-sustainable					
Intensive transit zone (consonants)	73	38,7 %	-	35,0 %	-
Basic transit zone	16	58,3 %	-	56,6 %	-
Car zone (dissonants)	20	24,8 %	-	26,3 %	-
Multimodal					
Intensive transit zone	85	35,2 %	-	34,8 %	-
Basic transit zone	27	29,5 %	-	27,5 %	-
Car zone	36	22,7 %	-	27,0 %	-
Pro-car					
Intensive transit zone (dissonants)	86	15,4 %	-	16,4 %	-
Basic transit zone	40	17,0 %	-	17,6 %	-
Car zone (consonants)	88	8,3 %	-	9,3 %	-

[a] Significance values have been adjusted by the Bonferroni correction for multiple tests.

Among the survey sample, the pro-sustainable residents living the in basic transit zone (e.g. the edge zones of the city center) had the highest share of bicycle trips (56,6 %) and cycled kilometers (58,3 %) compared with other clusters. In addition, pro-sustainable consonants cycled more than their dissonant counterparts. The lowest shares of bicycle trips and traveled kilometers were found among the pro-car cluster, where pro-car residents living in car zone (consonants) cycled the least of all the examined groups. Among multimodal and pro-car residents, those living in intensive transit zone or basic transit zone cycled more than those in car zone. For example, pro-car residents in intensive transit and basic transit zones cycled on average almost twice as much compared to their counterparts in the car zone. However, none of the in-group differences regarding cycling among any of the cluster groups proved to be statistically significant (Table 20).

5 Discussion and conclusion

This study aimed to investigate the role of the built environment, travel attitudes, and neighborhood preferences on travel behavior in the Finnish context. More precisely, the study had four main objectives, which were examined through various statistical analyses as presented in the previous sections. In this section, the findings and their implications for land-use and transportation planning will be discussed further.

The first objective of the study was to examine, whether there were differences in travel behavior between residents living in different urban zones. The comparison of the car usage in different urban zones indicated, that the share of driven kilometers and the share of car trips were highest in areas further away from the city center with basic or poor public transport service level and lowest in urban areas with the intensive public transportation service level. Moreover, walking frequency was considerably higher in intensive transit zones compared to other zones, and cycling frequency almost equal in intensive transit and basic transit zones and significantly higher than in car zone.

These results are in accordance with the key findings of the built environment-travel research indicating that living in urban areas with better accessibility to destinations and public transport and mixed land-use is associated with higher levels of active transport and lower levels of car use (Ewing & Cervero, 2001, 2010; Panter & Jones, 2010). As such, these results would suggest, that living in an intensive transit area would reduce both driven kilometers and the number of trips by car and increase walking and cycling respectively. However, as it is presumed by the residential self-selection hypothesis, some of the residents may have gravitated to car zone since they like driving and prefer environments convenient for car use, and some of the residents may have chosen to reside in intensive transit zone since they value good accessibility by other modes of transport.

The second research objective was to observe, whether travel-related attitudes and neighborhood preferences were related to differences in travel behavior. The comparison of the identified attitude cluster groups with distinctive travel attitudes and neighborhood preferences revealed significant differences in the use of different travel modes. On the whole, all the three attitude cluster groups used different travel modes in accordance with their stated attitudes and preferences. The ones who preferred accessible neighborhoods and sustainable travel modes traveled by car significantly less and walked and cycled significantly more than those who had car-oriented attitudes and preferences. Similar findings pointing that both attitudes and built environment are associated with travel behavior have been reported previously in several research settings (Bohte et al., 2009; Cao et al., 2009b; Dill et al., 2014; Handy et al., 2006). The results indicated, that residential self-selection was likely to occur at least to some extent, and its impact should be examined further.

The third objective for this study was to examine, whether the built environment characteristics were associated with car use, walking, and cycling after the socio-economic characteristics and possible effect of residential self-selection were accounted for. Therefore, the attitude clusters and urban zones were incorporated in multiple linear regression models together with demographic and socio-economic variables.

Of the examined socio-economic variables, car ownership was most strongly associated with driving, walking, and cycling. Furthermore, the more there were cars in the household, the stronger was the association with car use. A similar pattern, though with a negative association, was found regarding walking and cycling, suggesting, that having a car in the household tempts to drive more, and discourages choosing active modes of travel. The findings are in accordance with the widely established consensus about car ownership being an important determinant of travel mode choice (Van Acker & Witlox, 2010).

The models indicated that the in-group differences in car use and walking behavior of residents living in different urban zones remained significant after the socio-demographic characteristics and possible residential self-selection effect were accounted for. In other words, regardless of the possibility that some of the residents may have chosen to reside in an area that responds to their travel needs and preferences, the urban zone of residence remained as a significant predictor of car use and walking. However, the attitudes and built environment seemed to be associated with car use and walking on different magnitudes. In the regression model for driving, having car-oriented attitudes and preferences had larger standardized coefficients on both the share of traveled kilometers by car and the share of car trips than living in the car zone. In other words, having pro-car attitudes instead of pro-sustainable attitudes seemed to increase driving more than living in the car zone instead of living in the intensive transit zone. In the regression model for walking, instead, attitudes and built environment seemed to play fairly an equal role in walking mode choice. Other scholars have reported similar findings suggesting, that residential neighborhood type may be a better predictor for non-motorized trips than for car trips (Cao et al., 2009b; Handy et al., 2005, 2006).

In the regression model for cycling, however, the differences between residents living in different urban zones were insignificant, after the socio-demographics and attitudes were controlled for. Moreover, only the difference between pro-car and pro-sustainable residents remained significant. The result suggests, that attitudes played a stronger role in cycling mode choice than the urban zone of residence. However, the overall goodness-of-fit of the regression model for cycling was rather low (adjusted R-square 0,131), indicating, that the examined variables were not the most suitable for predicting cycling behavior.

Finally, the last objective was to examine whether the residential mismatch was related to differences in travel behavior by re-grouping the residents based on their preferred and actual neighborhood.

Certain patterns were observed from the car usage of resident clusters living in different urban zones. Residents with pro-sustainable attitudes used cars more in car zone than in other zones, but the differences were not statistically significant. For multimodal residents, the location of the residence seemed to affect car use more clearly, since the share of driven kilometers and car trips were significantly smaller in intensive transit zone compared to other zones. As expected, the car-oriented residents living in the car zone (consonants) traveled by car the most of all the examined groups. While some of these residents might have purposively resided in areas most convenient for car travel, the significantly smaller share of car usage both among pro-car residents (dissonants) and multimodal residents in intensive transit zone suggests, that living in intensive transit zone affects travel mode choice either by restricting residents to fulfill their desired travel behavior (driving), by creating appealing possibilities for using alternative travel modes, or both.

The residents who preferred sustainable travel modes and walkable environments walked significantly more in intensive transit zones than their counterparts in basic transit or car zones. The result is in accordance with previous studies (Frank et al., 2007; Kajosaari et al., 2019) reporting that high-walkable neighborhood consonants tend to walk more than low-walkable neighborhood dissonants. Even though part of the observed difference may be explained by residential self-selection, also this test result indicates that the built environment appears to have an individual effect on walking, which outweighs that of attitudes. If the environment was not related to travel behavior, all pro-sustainable residents would be expected to walk equally regardless of the urban zone of residence or walkability of the neighborhood. A similar pattern was found also among multimodal and pro-car residents. Among these resident clusters, the share of walking, measured both in terms of traveled kilometers and number of trips, was considerably higher in intensive transit zones, compared to basic transit and car zones. These results provide more evidence, that living in a high walkable environment (measured here as an intensive transit zone) increases the prevalence of walking regardless of the person's travel attitudes and neighborhood preferences. According to our findings, even those residents with pro-car attitudes made approximately a fifth of their trips by walking when living in the intensive transit zone, while for their counterparts in the car zone the share of walking trips was only 6 %.

The in-group differences in cycling behavior were not statistically significant among the examined resident groups in different urban zones. This may be due to a low total number of respondents who reported cycling trips in the questionnaire. Moreover, as the analyses showed, the differences in cycling were statistically significant only between pro-sustainable and pro-car residents and intensive transit zone and car zone. However, the similar prevalence for cycling in intensive and basic transit zones demonstrates, that the basic transit zone neighborhoods, which are often are located at the fringes of the urban center, can be well-suitable for cycling, even though the same environments would not support walking trips very well. The trips originating from the fringe areas may exceed the generally preferred walking distance, but for such trips, cycling can provide a convenient alternative.

Our findings indicate that both attitudes and built environment are associated with travel, and built environment seems to have an individual effect on car use and walking after self-selection has been accounted for. Thus, the question is, what kind of land-use and transportation policies can be expected to bring about positive changes in travel behavior?

The previous findings from built environment-travel literature emphasize mixed land-use and availability of destinations as key built environment determinants of walking and cycling since land-use mixing generally shortens the distance between dwellings and destinations, providing better possibilities for active everyday mobility (Panter & Jones, 2010). Even though the built environment variable tested in this study did not measure land use mix as such, it can be assumed that intensive transit zones fairly well represent those urban areas that have the highest mix of residential and other land uses. According to our findings, living in such areas is likely to decrease car usage and increase walking even among those residents, who have auto-oriented attitudes and preferences. This result provides support for policies, which aim to bring about a positive impact on travel behavior by increasing housing supply in intensive transit zones or TOD (transit-oriented development) neighborhoods.

Enlarging the housing stock in the urban areas is in general expected to reduce the prices of urban dwellings to some degree, which in turn could attract more residents with urban land use preferences to live in their preferred type of neighborhood. However, more affordable housing could also attract rural residents with car-oriented lifestyles to reside in more central locations. In recent years researchers have been showing increasing interest in travel behavior after residential relocation, since the newly moved residents may either stick to their old travel habits or change their behavior according to their new surroundings. Furthermore, it is also possible, that over time residents' travel attitudes are shaped by the built environment, which in turn can reflect travel decisions. However, investigating this so-called reverse causality between built environment and attitudes requires more sophisticated statistical methods and longitudinal or semi-longitudinal data, which measures attitudes and travel behavior before and after residential relocation. A few empirical studies examining interrelationships between various determinants of travel mode choice have resulted in consistent findings indicating that residents tended to adjust their travel attitudes according to the surrounding built environment after moving to a new residential location (Ramezani et al., 2021; Van Acker et al., 2014).

Adapting travel-related attitudes can be considered as another strategy to bring about a change in travel behavior. According to our results, residents with pro-sustainable attitudes were found to walk and cycle more than residents belonging to other attitudes clusters in all kinds of neighborhoods. Thus, it can be expected that bringing about a more positive attitude towards sustainable travel modes would likely increase the levels of active transportation in all kinds of neighborhoods. Moreover, a possible increase of residential dissonance especially among pro-sustainable residents living in basic transit and car zones could eventually lead to a relocation of those residents to more accessible and central locations. However, strong habitual patterns may confound also the relationship between attitudes and behavior, why adopting an improved image of active travel modes may not always lead to a change in travel behavior. Therefore, many researchers have suggested, that further investigation of the habits would be appropriate and would improve the reliability of travel behavior models (Bohte et al., 2009).

However, it should be noted, that it is not plausible to expect, that all the citizens would eventually move to intensive transit zones or other urban areas with good accessibility to various destinations by public transport and active travel modes. Even though the urbanization trend is expected to continue also in the Turku region (MDI, 2019), there will be a substantial share of citizens who will live in car-oriented environments, and the development of those environments can either sustain the car-oriented lifestyle or promote active everyday mobility. For example, outside the urban cores and intensive transit zone neighborhoods, the availability of near services within a close distance to residential locations can enhance running everyday errands by active modes of travel. However, the recent trend of centralizing local services into shopping centers, large retail units, and gas stations along the highways is doing exactly the opposite. Thus, providing various public and private services also in the suburban neighborhoods would require a systemic change in the allocation of resources citywide. Moreover, the lack of proper and safe infrastructure for pedestrians and cyclists may hamper active transportation even if the near services or other destinations would be available.

In addition to the abovementioned approaches, also other strategies that would enable more people to have car-free lifestyles would likely promote higher levels of walking and cycling since car ownership was found to be an important determinant of travel mode choice. Even though public transportation use was not investigated in this study, different transit solutions hold great potential in reducing auto-dependency, offering viable alternatives to a private car on longer trips that are no longer convenient to walk or cycle. However, walking and cycling play an important role in the access and egress journeys of a public transportation trip and have potential to increase the competitiveness and attractiveness of public transportation in relation to a private car. Therefore, in addition to enhancing the transit network and service level, special attention should be paid to seamless transfers between modes and the accessibility of the transit stops and stations. Moreover, shared mobility solutions, including car-sharing and car-pooling systems as well as bike, e-bike, and cargo bike-sharing solutions, can provide prospective alternatives for privately owned cars.

6 Limitations of the study

This study has several limitations that are important to point out. First, the utilized data and data collecting methods are vulnerable to certain limitations. In general, the PPGIS survey design strongly reflects the user experience, participation rates, and quality of the collected data (Fagerholm et al., 2021). The Maptionnaire questionnaire that was generated to collect data for this study and other research and planning purposes had eleven sections in total, which made the survey rather lengthy. It was possible to observe that many respondents had not completed the last sections of the survey, which were relevant for the data analyses of this study. Thus, the length of the survey decreased the number of eligible responses.

Second, the travel outcome variables were calculated from the home location and daily errand point mappings of the respondents. However, the truthfulness of the calculated travel outcome measures depends on the mapping effort of the respondents, i.e. how conscientiously the respondents marked their weekly visited destinations. In addition, as the respondents were asked to map destinations visited during a typical week in their everyday life, some trips made less frequently were inevitably left out total traveled distances. Moreover, calculating the trip distances through a street network by utilizing the shortest route function and weighting the distances by certain criteria are vulnerable to errors and can provide at best a rough estimate of the total travel distances of each individual.

Third, the examined independent variable describing the built environment (urban zone) proved to have certain tradeoffs. Since the built environment around each respondents' neighborhood was represented with an aggregate measure, it was not possible to distinguish the relative importance of individual features that constituted the urban zone classification (i.e. distance to the center, distance to a transit stop, and public transport service level). Moreover, some compromises had to be made when reclassifying the urban zone dataset based on transit availability. Edge zones of the city center and pedestrian zones in the local centers were classified as car zones, even though these zones presumably support walking and cycling at least to some extent. This may have caused some bias to the found associations between built environment and travel.

The previous travel behavior research has suggested, that future research should aim for matching the behavior and its determinants appropriately (Giles-Corti et al., 2005). For example, findings from active travel literature suggest that the psychological and environmental variables associated with walking and cycling differ to some extent. In this study, the relatively weak goodness-of-fit of the walking and cycling models suggested that the examined independent variables were not the most relevant ones for predicting walking and cycling for transport. Although the variable describing the urban zone of residence consists of different indicators, which have been associated with active transportation previously in the literature, many other built environment characteristics have been found to have stronger associations. According to previous findings, built environment measures related to design, land-use mix, and distance to various destinations may have explained levels of walking more accurately. For cycling, instead, small-scale built environment characteristics, such as variables describing the traffic speed limits or the presence and quality of the cycling infrastructure could have offered a better explanation (Mertens et al., 2017).

Finally, the selected research method of statistically controlling for residential self-selection inherently has certain limitations (Cao et al., 2009). For instance, simply measuring attitudes with statements is not straightforward, and questions may not cover all the relevant attitudes in relation to travel and residential decisions. Bohte et al., (2009) argued, that a common weakness of attitude-behavior studies is the mismatch in the specificity of analyzed attitudes, built environment measures, and behavior. In addition, they pointed out, that travel-related attitudes and mode choice are often context-specific, meaning, that a person's travel attitudes and mode choice can vary depending on the destination, travel companion, time of the day, and so forth. Therefore, residential self-selection could be best identified, if the attitudes, built environment characteristics, and behavior were measured in a similar level of specificity or generality, and if the context was also incorporated in the travel attitudes that are measured.

Statistical control enables testing whether attitudes cause spuriousness to the relationship between built environment and travel. However, like other cross-sectional study designs, this method can only provide insight into one direction of causality, and it does not verify whether the cause precedes the effect in time. Our results provided evidence about an association between attitudes and travel behavior as well as the built environment and travel behavior, but there are also other plausible directions on how these variables interact. For example, travel decisions and the built environment may alter attitudes over time (e.g. Ramezani et al., 2021). Since the research method does not allow to take this possibility into account, the effect of the attitudes on travel behavior may be overestimated.

In fact, the mechanisms of how attitudes interact with the built environment and travel behavior are still not fully understood, and investigating these mechanisms poses certain methodological challenges. To meet the methodological requirements of examining the influence of residential self-selection on travel behavior, structural equations modeling (SEM) has been suggested as the most suitable method for analysis (Bohte et al., 2009; Cao et al., 2009a). SEM can combine the strengths of multiple other methods by enabling testing multiple directions of causality, indirect associations, and measurement at multiple points in time. In addition, compared to cross-sectional studies, longitudinal study design could provide more dependable evidence on the relationship between the built environment and travel behavior. These research designs include natural experiments, which examine the impact of a change in the built environment on travel behavior, and panel studies including residents who move to a new neighborhood with measurement of attitudes and travel behavior before and after the move as well as reasons behind the move (Cao et al., 2009a).

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