Walkability, Walking behavior, and Walking experiences

WALK
ABILITY

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AN ANALYSIS USING VIRTUAL REALITY AND REVEALED PREFERENCES APPROACHES

Bojing Liao

Bouwstenen **319**

Walkability, Walking behavior, and Walking experiences:An analysis using virtual reality and revealed preferences approaches

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SUMMARY

It has been recognized that walkability is an important concept in both urban planning, urban development and transportation. Walkability is not only related to physical activity of individuals but can also reduce the per capita resource use and greenhouse gas emissions. Empirical research recommended walkability as an essential enabler of sustainable urban development, contributing to both the wellbeing of people and the quality of the environment.

Over the last decades, an increasing number of researchers have examined the influence of walkability on walking behavior and walking experience of individuals. Despite the extensive research work investigating the relationships between walkability, walking behavior, and walking experience, there are still fundamental knowledge gaps in this research field. First, the empirical validation of objective walkability measures has received only limited attention, and the exact nature of the relationship between walkability and walking behavior is not clear. Second, although the effects of residential self-selection on walkability has received some attention in empirical studies, the independent roles of walking reasons for location and walking attitude in the relationship between walkability and walking behavior are not clear. Third and finally, combining conjoint experiments with virtual reality techniques at neighborhood and street level is increasingly seen as a promising research method to measure preferences and experiences related to walkability but has received only limited attention. Moreover, the question whether different virtual reality representation modes result in different experiences and preferences of individuals is still unanswered. Therefore, to fill these gaps, the aim of this dissertation is to explain the influence of walkability on walking behavior and walking experience in neighborhoods, and to provide deeper insights on walkability and walkable neighborhoods design, and methods of representation for walkability research. This dissertation consists of three main parts. The first part (Chapters 2 and 3) considers the relationship between (objective) walkability and walking behavior. The second part (Chapter 4) provides an analysis of the role of residential self-selection in the relationship between walkability (perceived) and walking behavior. The third and last part (Chapter 5 and 6) explores the association between walkability (perceived) and walking experience using new research methodologies based on VR techniques.

Part 1. In order to test assumptions made in existing objective walkability indices, this study

conducts regression analysis to identify the relationships between physical neighborhood characteristics and walking frequency, based on a national neighborhood data set combined with three years of national travel survey data from the Netherlands. In the regression model, distance to supermarket, number of daily goods stores within 1 km, number of cafeterias within 1 km, total inland water, land use for residential buildings, and high urban density were found to be significant. The analysis indicates that existing objective indices only partly capture variation in walkability. This study finds that mismatches emerge on the level of both the selection and weighting of variables in existing measures. Based on the results, thus, the study identifies ways to improve existing objective indices to measure walkability. A second analysis then focuses on the question through which activity-travel choices a better walkability leads to more walking trips. A neighborhood fixed effects regression analysis of frequency of walking trips was conducted in a first step to obtain a walkability (objective) score for each neighborhood in the Netherlands. Subsequently, the obtained walkability scores were used as walkability data for a path analysis. The analysis was conducted for different age groups (e.g., children, adults, and elderly) separately. The results of the path analysis show positive direct relationships of walkability with destination choice and transport mode choice, after controlling for the mutual relationships between the activity and trip variables. The findings indicate that walkability has a weak association with activity choice only in the adult group; the relationship is absent in the children and the elderly group. These differences between different vulnerable groups (e.g., children and elderly) mostly concerned the relationship between walkability and trip generation. Hence, the results indicate that conditions for walkability (objective) are not the same for all age groups.

Part 2. To determine the role of residential location choice and walking attitude in the relationship between walkability (perceived) and walking behavior, a structural equation model is formulated. Data were collected through an online survey, which focused on how individuals perceive their neighborhood. Respondents were recruited from a national consumer panel in the Netherlands and through social media. In total, the data of 295 persons were used to estimate the model. Results show that direct associations exist between walkability reasons for location and walkability, and between walking attitude and walking behavior. Walkability reasons for location only partly explains the variance in walkability. Furthermore, walking attitude appears to be a much stronger predictor of walking behavior compared to walkability. Thus, the findings indicated that walkability reasons for location and walking attitude play important roles in the relationship between walkability and walking behavior.

Part 3. To investigate the relationship between perceived walkability and walking experience, scenarios of a hypothetical neighborhood were created using a full-fledged experimental design (orthogonal design) and represented using a virtual reality environment. The main purpose of the experiment was to analyze how people perceive and experience walkability in virtual reality environments depending on attributes of walkability. Data were collected in an online conjoint experiment involving 295 respondents. Hypothetical virtual environments were presented to respondents using videos (3D videos) that visualize different street block designs from the viewpoint of a moving pedestrian. A latent class regression model and discrete choice analysis were used to identify how groups of individuals experience walkability differently, and what emotions of individuals are associated with walkability attributes. The results show that land use mix, connectivity, road size, open space, and green have an influence on individuals' perception of walkability. The study further found that walkability is mainly associated with feelings of comfort and feelings of security. Moreover, individuals from different socio-demographic backgrounds perceive attributes differently for walkability, and experience different emotions in relation to walkability. In a following study, the same experiment was repeated using different VR representation modes (the videos of virtual environments mode and the immersive VR mode using a VR headset) to identify possible effects of VR representation mode on experiences and preference measurements regarding walkability. Especially, the study tried to answer the question whether using the videos of virtual environments mode gives the same results compared to the immersive VR mode. Data were collected through an online survey (videos of virtual environments mode) and a lab experiment (the immersive VR mode) involving a total of 140 respondents. A random effects regression model was used to analyze interaction effects between VR mode and spatial attributes on the evaluation of walkability and walking experience in the VR environments. The results show no significant main effects of VR mode on overall satisfaction and walkability of neighborhoods, and only a weak increase of experience of positive emotion in the immersive VR mode. As for the evaluation of attributes, our results show that there are effects of mode. Especially, open space and to some extent also green is valued differently depending on the mode used. We conclude therefore that the video is a rather robust VR-method for this measurement purpose but may generate bias when it comes to attributes that are very salient in 3D space.

Overall, the findings of this dissertation give insights into the influence of walkability on walking behavior and walking experience. Furthermore, this thesis developed and tested approaches to comprehensively and systematically measure walkability, and to connect planning theory to design practice. These results will help urban planners to make better informed decisions about how to create walkable neighborhoods designs. Hereby, it is important that also the specific demands of certain vulnerable groups (e.g., children and elderly) related to walking trips are considered, such as their preference for green and open space. The results can also be used by national and local governments to promote the development of walkable neighborhoods and cities.

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CHAPTER I

INTRODUCTION

1.1 Background and motivation

Worldwide, nearly one in four adults do not meet the World Health Organization recommendation of 60 minutes of physical activity per day (WHO, 2014). Amongst adolescents in the age between 11 and 17 years, even 81% do not meet these recommendations (WHO, 2014). Numerous studies have shown that physically active behavior has positive effects on the physical and mental health of individuals. As the findings show, physical activity can significantly reduce the risk of overweight and related diseases such as cardiovascular diseases, type 2 diabetes, and certain types of cancer (Cerin, et al., 2016; Swinburn et al., 2011; WHO, 2014). More in general, inactivity is one of the triggers of the new life-style epidemics of the 21st century, which includes besides obesity also burn-outs and dementia.

Since the beginning of the 21st century, a renewed interest in planning for healthy cities is visible, triggered by challenges such as obesity, physical inactivity, loneliness, social inequalities, climate change, and air pollution (De Nazelle et al., 2011). International organizations such as the World Health Organization and the United Nations have recommended policy changes to assign higher priority to creating healthy cities.

Empirical research has shown that the design of the built environment has a significant influence on the extent to which individuals are physically active. Neighborhood features such as the presence of green, dwelling density, presence of local amenities (e.g., schools and shops), street connectivity, the safety of roads and aesthetically attractive routes for pedestrians, correlate with the extent to which individuals are inclined to walk in their direct environment for transport or recreational purposes (Howell et al., 2017; Owen et al., 2004; Saelens et al., 2003; Sallis et al., 2016). The degree to which the built environment supports walking is referred to as walkability. The term "walkability" refers to a measurement that takes into account built-environment characteristics and is interpreted as a measure of how walkable an area is (Adkins et al., 2017). It is widely acknowledged that walkability is linked to more than just physical activity; it can also minimize per capita resource use and greenhouse gas emissions, as well as lead to social engagement and, potentially, community building (Jacobs, 2002; WHO, 2018). As a result, walkability is essential for sustainable urban growth, benefiting both people and the environment.

In addition, different groups of people may benefit from neighborhood walkability to varying degrees, especially some vulnerable groups need attention. Van Holle et al. (2014) found that walkability positively relates to older adults' walking behavior and thereby positively affects physical as well as social, cognitive and mental functioning of the elderly. Empirical studies further pointed out that sufficient destinations and pedestrian-friendly facilities in the close vicinity of older adults' residences would increase their short walking trips in neighborhoods (Owen et al., 2007; Van Holle et al., 2014). Another vulnerable group that may benefit from neighborhood walkability is teenagers. De Meester et al. (2013) studied the association between neighborhood walkability and adolescents' physical activity. They found that neighborhood walkability may be most cost-effective, time-saving, and feasible to increase adolescents' physical activity. Apart from the elderly, children and teenagers, also the middle-aged have specific health risks related to physical inactivity.

The term walkability refers to a measure of how friendly an area is to people for walking for transportation, for leisure or recreation, or for exercise (Abley, 2005; Frank et al., 2006; Wang & Yang, 2019). Cervero and Kockelman (1997) identify three urban-space constituents of walkability analysis: density (household and job density), diversity (land-use mix) and design (intersection and street density), which was later expanded to also include destination (job accessibility) and distance (to transit) (Ewing & Cervero, 2001). Since then, other authors have expanded this scheme to also include other environmental aspects (e.g., residential density and retail floor area ratio) to measure walkability from objective or subjective perspectives.

Walkability is not only about physical neighborhood characteristics but also about positive experiences connected to walking. It is generally understood that a good walkable neighborhood is one in which people feel safe and have positive experiences (e.g., relaxed and happy) (Birenboim, 2018). As empirical research has shown, the benefits of walkable neighborhoods do not only concern the improvement of physical living conditions but also the promotion of subjective well-being of city dwellers (Ballas, 2013; Birenboim, 2018; Florida & Mellander, 2009; Glaeser et al., 2016).

Revealed preference is the dominant approach in empirical studies on walkability. This approach collects data from individuals via questionnaires using self-rating scales to measure their perception of walkability of their residential location, for example, the Neighborhood Environment Walkability Scale (NEWS) (Saelens et al., 2003). But with this approach it is hard to identify the separate effects of characteristics because of the strong correlations between neighborhood variables in the revealed preference data. More recently, the conjoint experiment is considered increasingly as an alternative research tool to increase resident participation, and to test the effects of the (costly) physical interventions before they are actually implemented (Adkins et al., 2012; Kelly et al., 2011; Kim et al., 2011). In a conjoint experiment, neighborhood characteristics can be varied independently such that the separate effects of neighborhood characteristics can be determined by analyzing the choice or preference data. Commonly, neighborhood characteristics are presented by means of static representations, such as text, photos, and images. Such static representations, however, demand quite a lot of people's ability to imagine the situation, and hence static representations may cause imagination bias. To avoid this shortcoming, virtual reality techniques which provide a more dynamic and integral impression of the neighborhood environments are considered as an alternative approach in a conjoint experiment (Birenboim et al., 2019).

While empirical research has contributed a great deal to insights in the effects of walkability and the design of walkable neighborhoods, there are still some notable limitations of this research field. First, the relationship between neighborhood design characteristics and walkability has not received systematic attention. The walkability concepts and measures that have been proposed and are used in studies lack comprehensiveness and empirical validation. Typically, only a few spatial and functional dimensions of the built environment are taken into account in existing measures and are combined in ad-hoc ways. For instance, the walkability index (Frank et al., 2003) is constructed on the basis of dwelling density, street connectivity, land use mix, and net retail area and has been used in several studies (Leslie et al., 2007). Grasser et al. (2016) based on Glazier used an index composed of dwelling density, population density, and intersection density. Dewulf et al. (2012) used an index constructed on the basis of street connectivity, residential density, and land use mix. The empirical derivation of measures of objective walkability has not received much attention in existing research. A broader range of factors that have an influence on the attractiveness of living environments for walking should be considered and then be operationalized in measures that are tested and validated based on relevant external criteria.

In addition, the exact nature of the relationship between objective neighborhood walkability and walking trips, as well as how walkability affects activity-travel behavior among different age groups, is unclear. Previous studies offered evidence of existence of associations between walkability, outdoor activities, and short distance destinations (Sallis et al., 2009; Van Holle et al., 2015). But these studies did not address the more general question of how the relationship between walkability and frequency of walking trips is caused. It is, therefore, not clear whether high walkability neighborhoods stimulate primarily activity choice (more outdoor activities), destination choice (more short-distance trips), mode choice (more often walking mode), or combinations of those. Moreover, empirical studies pointed out that the association between walking and walkability may be different between age groups. Children and the elderly, in particular, can react differently to features of the built environment in this regard (Buck et al., 2015; De Vries et al., 2010; Giles-Corti et al., 2009; Timperio et al., 2004). Children, for example, may not be triggered to walk often in neighborhoods that are characterized by high urban and intersection densities that in existing measures increase walkability, as such environments provide few opportunities for children to play (Buck et al., 2015). As for elderly, walkability has been found to be linked to walking for transportation but not to recreational outdoor activities (Van Holle et al., 2014). Therefore, it is important to recognize that the relationships between walkability, activity choice, destination choice, and mode choice may not be the same for different age groups.

Furthermore, many studies provide evidence that residential self-selection plays a role in the relationship between neighborhood environment and walking behavior (Cao et al., 2006; Cao et al., 2007, 2009). Residential self-selection in this context refers to the phenomenon that people who prefer walking may choose to live in a high walkability neighborhood and thus walk more (Cao et al., 2006; Handy et al., 2006). It is not clear, however, what the relative importance of residential self-selection is. Although the impact of residential self-selection on walkability has received attention, a more integrated approach is needed to analyze the interdependency relationships between walkability reasons for the residential location, walking attitude, walkability (perceived), and walking behavior, to shed light on these questions.

Moreover, the use of virtual reality techniques in a conjoint experiment to measure individual's perceptions of neighborhood walkability has received only limited attention. Empirical studies that use stated preference applied traditional static representations of attributes to describe alternative neighborhood designs, which often provides only a rudimentary impression of the environment the researcher intends to present (Shr et al., 2019). The use of virtual reality technology could result in greater external validity, as it allows to present the spatial environments in a dynamic and detailed way such that users can experience the environments (Birenboim et al., 2019). A few studies considered virtual walking environments in a conjoint experiment. However, these studies paid less attention to the relationship between emotions and walking experiences. Empirical studies clearly pointed out that the neighborhood environments also influence the emotions of individuals as well as their individual perceptions of the walkability in neighborhoods (Ettema et al., 2015). In addition, there are different modes of VR possible ranging from fully immersive to just a video mode (Shr et al., 2019). However, the question whether different VR representation modes result in different experiences and preferences of individuals is still unanswered.

1.2 Research objective and questions

The objective of this dissertation is focused on the effect of walkability on individuals' walking behavior and walking experience in neighborhoods, given the above-mentioned research gaps. The intention is to fill these gaps by answering the following research questions:

1. (a) How can an objective measure of walkability using a wide range of potentially relevant environmental variables be derived and tested? To what extent do existing theory-based measures account for the factors identified and explain walking behavior? (b) How does walkability influence walking behavior and what are the relative contributions of activity choice, destination choice and mode choice? How does walkability influence the activity-travel behavior of different age groups?

2. What are the roles of (walkability reasons for) residential location choice and walking attitude in generating the relationship between (perceived) walkability and walking behavior?

3. How do walkability attributes of a neighborhood affect individuals' walking experience? How can individuals' perception of walkability be measured by using virtual reality techniques in a conjoint experiment? To what extent do different VR representation modes result in different experiences and preferences of individuals?

1.3 Contributions

Walkability indices that are widely used in walkability research are generally derived based on just conceptual considerations. Empirical validation of the theory-based measures has not received much attention in the literature. Some studies have focused on the empirical estimation of the weights of variables (Grasser et al., 2016; Habibian et al., 2018), but they considered only a limited number of variables to measure walkability. This dissertation intends to improve the conceptualization and measurement of walkability based on an extensive database of neighborhoods and travel behavior in terms of variable selection and weighting of the variables. In so doing, this dissertation will test the assumptions of existing walkability indices regarding the selection of variables and weighting of the variables used and evaluate the extent to which the measures are able to explain differences in walking behavior across environments. The results should help urban planners and designers to understand better which factors are key for creating walkable neighborhoods and to what extent they contribute to walkability. Furthermore, by analyzing the relationships between walkability, on the one hand, and the shares of outdoor activities, short-distance destinations, and walking mode in daily trip diaries of individuals, this dissertation intends to shed light on how walkability influences the activity-travel behavior of different age groups. The results increase the understanding of the relationships between walkability and different types of walking trips among different age groups. This information can help urban planners and designers to address the specific needs of vulnerable groups (children and elderly).

Furthermore, to predict the effects of neighborhood environment on walking behavior, the relationships between walkability, and walking behavior must be established. In addition, this thesis investigates the links between walkability reasons for residential location, walking attitude, walkability, and walking behavior in the context of a more comprehensive casual model. This should provide more insight in the relationship between walkability, residential location choice, walking attitude and walking behavior.

To obtain more in-depth insight in factors influencing walkability and walking experience, this dissertation will design and conduct a conjoint experiment combined with virtual reality techniques. This will shed light on how people perceive and experience walkability, how it contributes to positive feelings during walking, and the extent to which this differs between groups. Furthermore, by repeating the experiment using different representation modes – a video of virtual environment mode and an immersive VR mode -, the study will further answer the question whether using the more convenient mode (a video of virtual environment) gives the same measurement results as the immersive VR mode that requires special equipment and a lab environment. By addressing this question, the validity of the video-mode, which is less costly and, hence, allows larger samples, is evaluated.

1.4 Research design

In this section, first the conceptual framework used for the research of this dissertation is discussed. Then the research approach chosen to achieve the stated research objectives is described.

1.4.1 Conceptual framework for the research

The main objective of this dissertation is to explain the effect of walkability on walking behavior and walking experience of individuals in neighborhoods. Figure 1.1 represents graphically a conceptual framework that indicate the assumed relationships between the spatial, socio-demographic and behavioral variables involved considering individuals as the unit of analysis. The figure indicates the structure of this dissertation corresponding to the three main research questions, which are focused on the relationships between (1) walkability (objective) and walking behavior (with different age groups), (2) walkability (subjective), residential self-selection and walking behavior, and (3) walkability (subjective) and walking experience.

The green links assume that personal characteristics and neighborhood environmental characteristics (including walkability) have effects on walking behavior. The relationships between neighborhood environmental characteristics, walkability, and walking behavior will be examined in Chapter 2 and Chapter 3, taking into account personal characteristics. The purple link indicates that residential self-selection has influence on walkability and walking behavior, which will be discussed in Chapter 4. And the blue links indicate the assumption that personal characteristics, neighborhood environmental characteristics, and walkability are associated with walking experience. In Chapter 5 and Chapter 6, a conjoint experiment will be designed and used to analyze these relationships.

1.4.2 Research approach and data collection

The three main research questions are addressed in the three parts. The first part addresses the first main research question and consists of two studies. The first study of this part develops an approach to measure walkability based on a regression analysis of a large national dataset of neighborhoods and travel behavior. The second study uses the same data set and is based on a path analysis to examine the question whether the increase in walking trips in better walkable neighborhoods are related primarily to trip generation, destination choice, or transport mode choice and whether this differs for different age groups.

The data used for the two studies in this part consist of trip-diary data from the Dutch national travel survey (CBS, 2016) and neighborhood data from the Dutch Bureau of Statistics (CBS, 2017). The relevant trip data from the travel survey are aggregated to a neighborhood level (postcode areas). To obtain sufficient observations for each neighborhood, three years (2014-2016) of this survey are merged. In addition, the socio-demographic and physical neighborhood variables are used from the Dutch Bureau of Statistics.

The second part (walkability, residential location, and walking behavior) includes the third study which is focused on the role of walkability reasons for residential location and walking attitude in the formation of the relationship between walkability and walking behavior. Data used for this analysis is collected via an online survey including 295 respondents from a national consumer panel and social media (e.g., Twitter and Facebook). A structural equation model is formulated and estimated to test the relationships between these variables.

The third part (walkability and walking experience) includes the fourth and fifth study and answers the last research question of this thesis. The studies are based on a factorial experimental design (orthogonal design) defining scenarios of a 3D model with virtual reality technology of a hypothetical neighborhood. The VR-experiment was part of the on-line survey that was also used to collect the data for the third study. For the fourth study a latent class regression model and discrete choice analysis are used to estimate preference parameters and identify groups of individuals that experience walkability differently. Furthermore, the emotions associated with walkability are analyzed. The fifth study uses the same 3D models and scenarios and repeats the

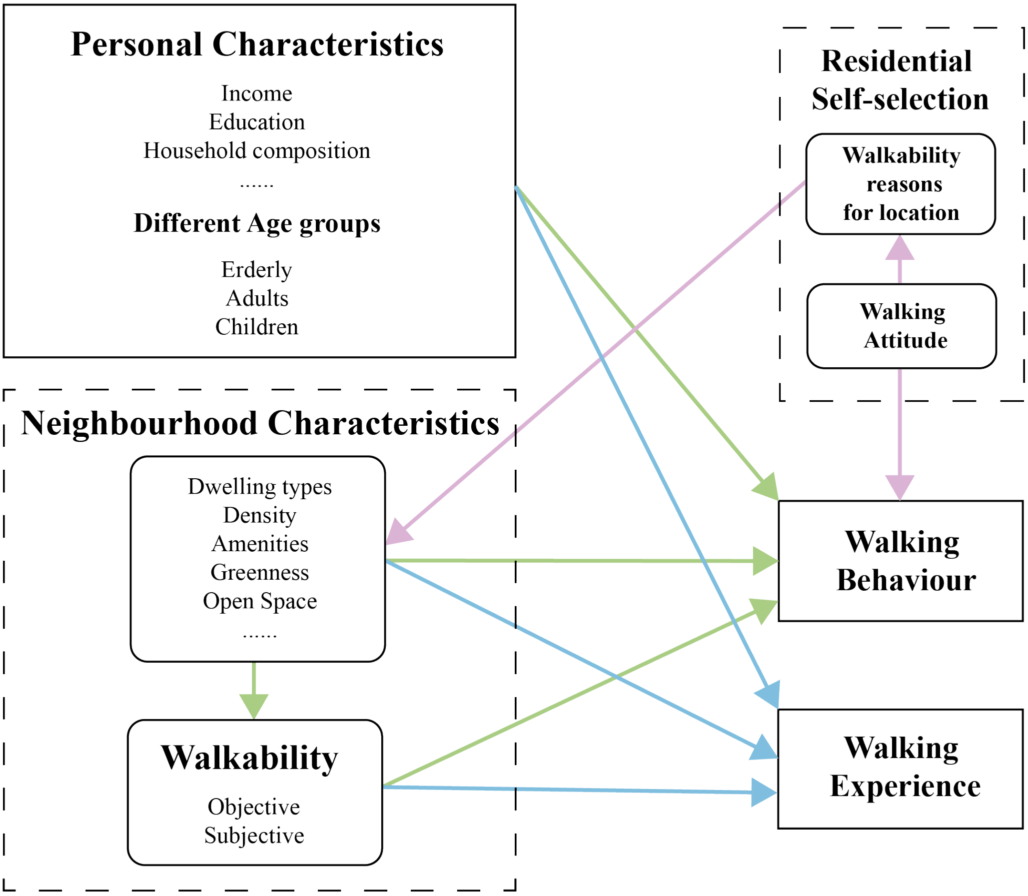

Figure 1.1 Conceptual framework

experiment using different representation modes (videos and immersive VR). The experiment was repeated in the lab where a more immersive VR mode was used (VR glasses). Participants are master students and Ph.D. students who study at Eindhoven University of Technology. In total 47 respondents finished the lab experiment. Since almost all participants are Chinese students, 47 Chinese students are extra recruited to conduct the online survey (the video VR condition) as a control group. A random effects regression model is used to analyze how individuals experience walkability and whether this is affected by representation mode. Table 1.1 provides an overview of the research approach and data collection of each part.

Table 1.1 An overview of each research part

Research part	Research questions	Chapters	Research approach	Data collection
Walkability (objective) and walking behavior	Question (1)	Chapter 2	Regression analysis	The Dutch national travel survey and Dutch Bureau of Statistics neighbourhood data
		Chapter 3	Path analysis	
Walkability (perceived) and walking behavior	Question (2)	Chapter 4	Structural equation model	Dedicated online survey (N=295)
Walkability (perceived) and walking experience	Question (3)	Chapter 5	Latent class regression model, Discrete choice analysis	VR-based conjoint experiment – videos of virtual environments on-line and lab experiment
		Chapter 6	Random effects regression model	

1.5 Outline

The structure of this dissertation is visualized in Figure 1.2. The separate studies are covered in Chapters 2 to 6. Each chapter contains a specific introduction and literature review. The first part includes Chapter 2 and Chapter 3 that jointly address the first main research question. In Chapter 2, a measure of walkability using a wide range of potentially relevant environmental variables is developed. A large number of neighborhood variables are considered in order to determine the set of variables that can best explain differences in walking frequency between neighborhoods, while controlling for differences in socio-demographic characteristics. The resulting regression model and existing walkability indices are compared to evaluate the extent to which existing measures represent the factors that emerge from the analysis.

In Chapter 3, the relationships between walkability, out-of-home activities (activity choice), short-distance trips (destination choice), and walking trips (mode choice) are examined. In the first step, a neighborhood fixed effects regression model is estimated. Subsequently, the estimated fixed effects are used as walkability data for a path analysis to test and analyze hypotheses regarding the relationships with travel-activity choices for different age groups.

To explain the relationships between walkability reasons for residential location, walking attitude, walkability, and walking behavior, Chapter 4 uses a structural equation model based on a causal model to test the hypotheses stated and answer the second research question. Data collected in an on-line survey including a national sample of 295 persons are used to estimate the model.

Based on a conjoint experiment with virtual reality technology, Chapter 5 and Chapter 6 investigate how people perceive and experience walkability in virtual reality environments depending on attributes of walkability. In Chapter 5, the hypothetical virtual environments of the conjoint experiment are presented using 3D virtual reality videos that visualize different street block designs from the viewpoint of a moving pedestrian. Data collected in an on-line survey (the same survey as used in Chapter 4) including 1180 ratings of walking environments from 295 respondents are used. Chapter 6 represents results of the same conjoint experiment using two types of virtual reality representation modes (videos of virtual environments and the immersive VR) conducted to analyze the effect of virtual reality representation mode on experiences and preferences. The data is collected through an online survey and a lab experiment. In the final dataset, 560 evaluations of walking environments are collected from 140 respondents.

Finally, Chapter 7 concludes the dissertation by discussing the main findings, the theoretical and practical implications, and possible directions of future research.

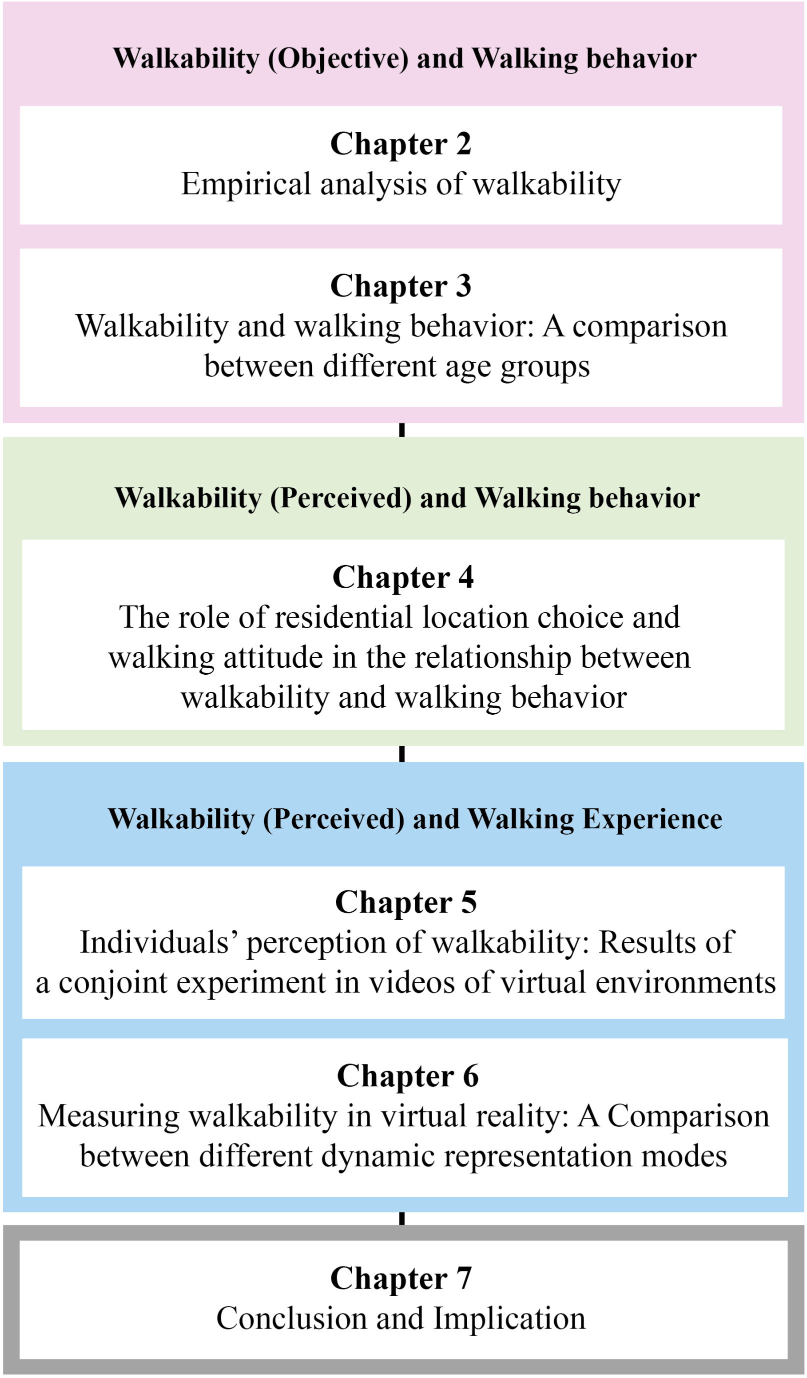

Figure 1.2 Structure and overview of chapters

PART 1

WALKABILITY (OBJECTIVE) AND WALKING BEHAVIOR

CHAPTER 2

EMPIRICAL ANALYSIS OF WALKABILITY

This chapter is based on:

Liao, B.*, van den Berg, P. E. W., van Wesemael, P. J. V. & Arentze, T. A. (2020).
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2.1 Introduction

Recently, walkability has become an important concept in both urban planning and transportation. It is recognized that walkability is not only related to physical activity; it can also reduce the per capita rate of resource use and greenhouse gas emissions (WHO, 2018), and it contributes to social interaction and therefore potentially to community building (Jacobs, 2002; Whyte, 2012). Therefore, walkability is an essential enabler of sustainable urban development, contributing to both the people and the environment.

To measure walkability, objective methods are receiving increasing attention in empirical studies. Despite the progress that has been made, existing objective walkability indices still have some limitations. The selection of variables and the weights of variables used in these indices are commonly based on theoretical considerations. However, conclusive evidence that these methods accurately represent the influences of characteristics of the built environment on walkability is lacking. For example, the walkability index of Frank et al. (2010) is the most commonly used method in studies. This index includes two land use measures that are strongly correlated (Vale et al., 2016). Not taking into account the correlation leads to over- or underestimation of the separate or pure effects of these characteristics on walkability. In addition to theory-driven approaches, also data-driven approaches to derive walkability measures have received attention. For example, the walkability index of Habibian et al. (2018), which draws on the work of Frank et al. (2005), is an empirically derived measure. However, in the regression analysis conducted to derive a measure, only a limited number of variables were considered, and socio-demographic variables were not (sufficiently) controlled for.

The objective of this chapter is to test the assumptions of existing walkability indices regarding the selection of variables and weighting of the variables used. Using regression analysis and data from the Netherlands, we identify the variables of the built environment that can explain observed differences in walking frequency of individuals within neighborhoods. We try to avoid the limitations of earlier models by considering a large set of physical neighborhood characteristics as potentially influential factors (a data-driven approach), by controlling for a wide range of socio-demographics and by suing the neighborhood as the unit of analysis. The resulting regression model offers a benchmark against which predicted theory-based indices can be evaluated. We address the question to what extent existing indices accurately predict the empirically derived walkability (predictive validity) and whether physical neighborhood variables that appear significant for explaining walkability are represented in existing concepts (construct validity). The empirical validation, thus, sheds light on the validity of existing indices and ways in which the models could be improved if they fall short. In the present study, we focus on the walkability indices of Frank et al. (2010) and Grasser et al. (2016) which are the indices that are most commonly used. Although the empirically derived walkability measure relates to a specific geographic region, namely the Netherlands, the analysis does indicate to which extent the theory-based indices are generalizable.

To derive a measure of walkability and test the validity of existing concepts, the remainder of this chapter is structured as follows. In the next section, the theoretical concept of walkability and existing work on the measurement of walkability are reviewed. In Section 2.3, we explain the proposed approach and describe the results of the regression analysis to derive a measure of walkability using data from the Netherlands. In Section 2.4, we compare the measure of walkability obtained to existing walkability indices to test the predictive and construct validity of the latter constructs. Finally, in Section 2.5, we summarize the major conclusions and discussion.

2.2 Literature review

2.2.1 Theoretical concepts of walkability

Walkability is an measurement takes into account built environment characteristics, and is defined as a measure of how friendly an area is to walking (Adkins et al., 2017; Vale et al., 2015). Cervero and Kockelman (1997) identify three urban-space constituents of walkability analysis: density (household and job density), diversity (land-use mix) and design (intersection and street density), which was later expanded to also include destination (job accessibility) and distance (to transit) (Ewing et al., 2009; Ewing & Cervero, 2001; Manaugh et al., 2011). Since then other authors have expanded this scheme to also include other environmental aspects, like residential density and retail floor area ratio (Booth et al., 2001; Moudon et al., 2002; Wellar, 2002; Frank et al., 2003; Frank et al., 2005; Ewing et al., 2009; Greenwald 2009; Ewing & Cervero, 2010). In transportation and urban planning, these theoretical concepts of walkability are used to better understand the relationship between the built environment and walking behavior (Grasser et al., 2013; Sallis, 2009).

In transportation and urban planning studies, the concept of walkability is specifically related to the associations between the built environment, travel patterns and physical activities (Vale et al., 2015). For instance, Leslie et al. (2006, 2007) and Frank et al. (2010) used the concept of walkability to explain the association between the built environment and the use of active transport modes. Other studies considered walkability as an essential component of transit-oriented development (TOD) and used the indices to assess pedestrian friendliness of the environment typically within a half-mile radius from hubs of transportation (Canepa, 2007). Furthermore, on the neighborhood level, the importance of walkability for creating good neighborhood (or community) designs is stressed by several authors, including Kwon et al. (2017) and Moura et al. (2017).

2.2.2 Subjective measurement of walkability

Subjective approaches to measuring walkability have received attention in the literature. These approaches use individuals' perception of the degree of walkability of their environment as a starting point, usually measured through a questionnaire. Scales have been developed to measure the perceptions. The Neighborhood Environment Walkability Scale (NEWS), a 68-item questionnaire, is the most commonly used method to evaluate walkability (Saelens et al., 2003).

Later, Cerin et al. (2006) developed a simplified version of NEWS (NEWS-A). The NEWS methods consider the following environmental characteristics: a) residential density; b) proximity to nonresidential land uses; c) ease of access to nonresidential uses (land use mix-access); d) street connectivity; e) walking/cycling facilities; f) aesthetics; g) pedestrian traffic safety and h) crime safety (Cerin et al., 2006).

2.2.3 Objective measurement of walkability

Several empirical studies have used objective approaches to measure of walkability (Ewing et al., 2009; Forsyth et al., 2007; Talen et al., 2013; Vale et al., 2016). In these approaches, the built environment is described by a number of variables (e.g., land use mix, intersection density), which are then combined into an index of walkability (Vale et al., 2015). Frank et al. (2003) and Frumkin et al. (2004) argue that walkability has two aspects: density and connectivity. Frumkin et al. (2004) state that density can be measured by the quantity of people, households, or jobs distributed over an area unit. They argue that, since land use mix is a measure of how many land-use types are located in a given area, this variable can be seen as a density variable as well. Connectivity is defined as the street linkages among destinations and, thus, represents the directness of pathways between residences, shops, and places of employment (Frumkin et al., 2004; Leslie et al., 2007; Sallis, 2009). Objective methods generally involve a linear combination of a selection of environmental variables to compute a walkability score. With respect to the development of the measures, data-driven and theory-driven approaches can be distinguished.

2.2.4 Theory-driven approaches

In theory-driven approaches, the selection, operationalization, and weighing of environmental factors are fully based on a conceptual definition of walkability. The most common measure in this approach is the Walkability Index, proposed by Frank et al. (2005, 2010) in the American context. In the original measure (Frank et al., 2005), a walkability score is calculated by summing the normalized scores across factors that are identified based on a definition of the concept of walkability. The original measure was further developed in Frank et al. (2010) to extend the application field of the index. This index uses land use mix, residential density, retail floor area ratio, and intersection density as variables to measure walkability. In subsequent work, the selection of variables and weights of variables of this index was adapted to suit different study regions. Grasser et al. (2016) pointed out that European cities differ in many respects from American cities. Urban areas in the US are characterized by low population density, a low degree of land-use mix, and low connectivity compared to European cities. To obtain an index that better fits the context of European cities, Grasser et al. (2016) proposed an adaptation of the selection of variables and weights of variables of Frank's Walkability Index. They used population density, household density, an entropy index for land-use mix and three-way intersection density to construct the so-called Graz Walkability Index as an alternative walkability measure (Grasser et al., 2016).

In addition, also other theory-driven methods have been proposed. Weiss et al. (2010) constructed the Objective Walkability Index (OWI), which is a translation of the variables included in NEWS to measure walkability objectively. OWI includes street connectivity, land use mix, pedestrian safety, neighborhood aesthetics, neighborhood safety, and neighborhood infrastructure. Burden et al. (2011) developed Walk Score as a patented tool to measure walkability of neighborhoods. Walk Score calculates a score by determining the walking distance to amenities in nine different amenity categories (such as grocery stores and restaurants). The Google AJAX Search application program interface (API) provides data for the Walk Score. This API identifies the nearest locations of amenities and calculates a score of walkability (Duncan et al., 2011).

Typically, the theory-based measures are validated by comparing computed scores to walking frequencies observed in a sample (Manaugh et al., 2011, Hajna et al., 2013, Ruiz-Padillo et al., 2018, and Hall et al., 2018). Although this provides a test of face-validity, it does not provide convincing empirical evidence that the selection and weighting of the factors are accurate. A more data-driven approach, where a measure is derived from regressing walking behavior on physical factors of the local environment, has therefore received attention as an alternative approach.

2.2.5 Data-driven approaches

Several researchers have recognized the lack of empirical validation and proposed alternative methods based on analysis of walking behavior (Hall & Ram, 2018). Glazier et al. (2012) used a list of candidate variables and then selected from this list the variables for which suitable data sources were readily available in the setting they considered (Glazier et al., 2012). The authors used factor analysis to identify factors of the built environment that are statistically uncorrelated with each other. Based on their factor analysis results, dwelling density, population density, retail stores, street connectivity, and services available within a 10-minute walk were selected as variables to create the Urban Walkability Index (Glazier et al., 2012).

In addition, regression analysis has been used to estimate the relationships between environmental factors and walking frequency to determine the selection and weighting of variables. Habibian et al. (2018) used regression analysis to derive an improved formula for Frank's Walkability Index. They constructed four variables based on the theory of Frank's Walkability Index and explored a number of different measurement methods for each variable. Using regional data in Iran, they employed linear regression analysis to estimate the models and identified the model specification that offered the highest goodness of fit (Habibian et al., 2018).

In the studies reviewed above several alternative walking indices were developed. The approaches vary with respect to the question of whether data analysis or a theoretical framework is used as the basis for determining the specification of the index. Table 2.1 provides an overview of the walkability indices reviewed in this section. The theory-driven approaches result in measures that potentially are better generalizable as they are not fitted on specific characteristics of a country or region as the data-driven measures are. Empirical validation testing of existing theory-based measures has, however, not often been conducted using data on walking behavior from a large, representative sample. Glazier et al. (2012) and Habibian et al. (2018), in different ways, both focused on the empirical estimation of the weights of variables. However, they considered only a limited number of variables to measure walkability (see Table 2.1). In that sense, their work used the theoretical assumptions rather than putting them to a test. For example, Weiss et al. (2010) and Burden et al. (2011) pointed out that environmental attributes like neighborhood safety and neighborhood facilities, which were not considered, are also potentially important. In the present study, the aim, therefore, is to derive a measure of walkability using a data-driven approach considering a wide range of potentially relevant location variables and to use the measure as a basis for testing the validity of existing concepts.

2.3 Methodology

2.3.1 Approach

The conceptual model shown in Figure 2.1 indicates the relationships between walkability variables, socio-demographic characteristics, and walking frequency. As implied by this mod-

Table 2.1 Existing objective methods of walkability in the literature (chronological order)

Objective methods	Authors	Variables	Operationalization ways	Formula
Methods based on a theory-driven approach				
Frank's Walkability Index	Frank et al., (2005); Frank et al., (2010)	■ Net residential / Population density ■ Retail floor area ratio ■ Intersection density ■ Land use mix	Z-score	Walkability = (2 × Z-intersection density) + (Z-net residential density) + (Z-retail floor area ratio) + (Z-land use mix)
Objective Walkability Index	Weiss et al., (2010)	■ Intersection density ■ Land use mix ■ Neighborhood infrastructure ■ Neighborhood aesthetic ■ Neighborhood safety ■ Pedestrian safety	Scale rating system	Summing the score of each point of each scale (point score value from 1 to -1) to get the walkability score
Walk Score	Burden et al., (2011)	■ Walking distance to amenities ■ Intersection density metrics ■ Average block length	Distance decay function	The algorithm is patented-protected
Graz Walkability Index	Grasser et al. (2017)	■ Net residential / Population density ■ Intersection density ■ Land use mix	Z-score	Walkability = (Z-intersection density) + (Z-net residential density) + (Z-land use mix)
Methods based on a data-driven approach				
Urban Walkability Index	Glazier et al. (2012)	■ Dwelling density ■ Population density ■ Availability of all retail and services ■ Street connectivity	Factor analysis; Principal components analysis	Walkability = l_1(Dwelling density) + l_2(Population density) + l_3(Street connectivity) + l_4(Availability of all retail and services) [l is the value of factor loading]
Habibian's Walkability Index	Habibian et al., (2018)	■ Design indices ■ Diversity indices ■ Density indices ■ Destination accessibility indices	Linear regression; Correlation analysis; Principal components analysis; Z-score	Walkability = $\beta_1 Z_{1j} + \beta_2 Z_{2j} + \beta_3 Z_{3j} + \beta_4 Z_{4j}$

el, the influence of walkability variables can be identified in a regression analysis that uses walking frequency as the dependent variable and socio-demographic and walkability variables as independent variables. Having controlled for socio-demographic variables, the estimated coefficients for walkability variables indicate the separate influence of physical neighborhood characteristics on the tendency of residents to walk in their neighborhood. Hence, using state-of-the-art methods for model selection in regression analysis, the best set of walkability variables can be identified together with their weights. We consider walkability as a characteristic of the neighborhood. As a consequence, the unit for this analysis is the neighborhood. Therefore, in the regression model, the socio-demographic variables are related to the socio-demographic composition of the neighborhood and walking frequency concerns the average walking frequency across individuals residing in the neighborhood. We argue that walking frequency is a better indicator than walking share (proportion of walking trips) because the latter is not sensitive to absolute differences in walking intensity. In addition, walking distance is neither an optimal option for the dependent variable, because walking distance is rather sensitive to trip purpose,[1] and long-distance walking trips, even if they would occur infrequently, will have a strong influence on the measure. In sum, as implied by the model shown in Figure 2.1, we operationally define walkability as a property that can explain differences in walking frequencies between neighborhoods that can be attributed to physical characteristics of the neighborhood. The regression analysis results in a measure of walkability of neighborhoods as basis to compare theoretical walkability indices with (in the next section below).

It should be noted that the regression analysis of cross-sectional data cannot account for a possible (residential) self-selection effect. Self-selection occurs when people who prefer walking choose to live in neighborhoods that have high walkability (X. J. Cao, 2015; X. Cao et al., 2009; Zang et al., 2019). Moreover, regression analysis does not allow identification of causality. This is an inherent limitation of cross-section data analysis that should be taken into account here as well (B. Liao et al., 2020).

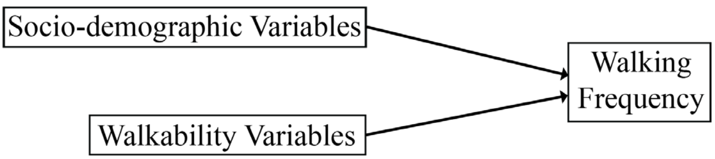


Figure 2.1 A conceptual model of the relationship between walkability variables, socio-demographic characteristics, and walking frequency

[1] For example, individuals tend to walk much longer distances for recreation and shorter distances for other purposes (Yong Yang & Diez-Roux, 2012).

2.3.2 Data and variables

We consider all of the Netherlands as the study area. Different data sources are used to retrieve data for the different categories of variables. First, as a source of walking frequency data, we use the Dutch national travel survey (CBS, 2016). This travel survey provides one-day trip-diary data of a large nationwide sample of individuals, in which all days of the week are covered. The neighborhood of each individual can be identified based on the postcode of the home address, which is available in the survey data on a 4-digit level. By computing the average number of walking trips (on the observed day) across individuals within (4-digit) postcode areas, the relevant trip data are aggregated to the postcode area level. We only counted the trips that started from the home of the individual to make sure that walking trips are related to the home location. To obtain sufficient observations for each postcode area, three years (2014-2016) of this survey are merged. Thus, trip data of 97,552 individuals in total (from 4053 postcode areas) are used for the present analysis.

In addition, we use neighborhood data from the Dutch Central Bureau of Statistics (CBS, 2017) as a source for socio-demographic and physical neighborhood variables. The socio-demographic variables that are used as control variables include gender, age, income status, work status, household status, and migration background. A description of the control variables is provided in Tables 2.2 and 2.3. The physical neighborhood variables used for the analysis are listed in Table 2.2. The variables of this section are divided into four parts: density variables, facilities variables, green space variables, and land use mix variables. The density variables include population density, intersection density, and business property density. The facilities variables include for a range of facilities the distance to the nearest facility (average distance from the center of the neighborhood) and the number of facilities available within a 1 km radius (from the center of the neighborhood). The green space variables include the total area of different types of open green space and recreational space. As a measure of land-use mix, entropy was first tried, but this did not lead to a better fitting model. Therefore, the separate lower-level land-use variables in the form of a percentage of the total land covered by the land-use were used instead. All walkability variables were derived from the Esri-open postcode plane and the CBS data. The postcode area data from the travel survey does not completely match the neighborhoods of the CBS data. The (4-digit) postcode areas represent a higher level of spatial aggregation. Therefore, to obtain the final database for the analysis, the CBS neighborhood data were aggregated to the postcode area level. The final dataset consists of seven sections of variables, as shown in Table 2.3.

2.3.3 Data analysis

Multiple linear regression analysis was carried out to estimate the relationships between walkability variables, socio-demographic characteristics, and walking frequency. In order to obtain a meaningful walking frequency average per postcode area, a minimum number of respondents (from the Dutch national travel survey) per postcode area is needed. The choice of the minimum should not be set too high, because then the variation in physical characteristics of postcode areas will be reduced. Therefore, the minimum was set to 15 respondents. To determine the robustness of the model for variation in this setting, the model estimation (using the stepwise method) was repeated for both a lower minimum of 10 respondents and a higher minimum of 20 respondents. In all cases, the stepwise method is used for model selection where the significance level for variable selection is set to an alpha of 10%.

The results are shown in Table 2.4. Although there are some differences in estimated values and selection of variables between the models, the differences mostly occur on the level of the socio-demographic control variables. In other words, with respect to the walkability variables, which are of interest here, the results are rather robust for the choice of the minimum number of respondents per postcode area. With the minimum of 15 respondents, the dataset includes 1982 postcode areas out of a total of 4053 postcode areas in the Netherlands.

2.3.4 Measuring walkability based on the local data

Since the socio-demographic characteristics are included as control variables, the regression analysis results on the level of the walkability variables are relevant for defining the measure of walkability. The standardized coefficients and standardized scores of the walkability variables are used to define a measure that is independent of the measurement unit of each variable. In the formula, the measure of walkability is given by:

$$Walkability = \sum_{i=1}^{n} \beta_i \cdot Z_{X_i}$$

where β_i is the standardized regression coefficient of the *i*-th walkability variable and Z_{Xi} is the standardized value (*Z*-score) of the i-th walkability variable. Since the model is estimated based on postcode-area (neighborhood) data, all walkability variables, X_i, relate to characteristics of neighborhoods. Comparing the variables, X_i, and weights, β_i, obtained by our analysis with those used in existing indices allows us to assess the (construct) validity of existing indices, at least, for the Dutch context.

In the next step, to assess predictive validity, the formula obtained will be used to compute walkability scores for the postcode areas in the Netherlands. Comparison of these computed scores with the scores that are based on some existing walkability indices then indicates the extent to which these existing indices agree with empirically derived walkability scores. In this step, the mutual correlations between estimated (measured) walkability, the existing walkability indices, and walking frequency will be determined. To determine whether any discrepancies found follow primarily from the assumed selection of variables or values of the weights, we furthermore compare the goodness-of-fit of several regression models in which the selection of the variables is based on existing walkability indices.

Table 2.2 The list of candidate variables

Variables	Description of variables
Dependent variable	
Walking frequency	The average number of walking trips (in 1 day) per person in the neighborhood;
Socio-demographic variables	
Gender	The percentage of men and women in each neighborhood;
Age of population	The percentage of each age class of each neighborhood: 0 to 15 years, 15 to 25 years, 25 to 45 years, 45 to 65 years, older than 65 years;
Average income per inhabitant	The average personal income per person based on the total population of private households;
Households with a low income	The percentage of households income that is less than 9249 euro in each neighborhood;
Employed persons	The percentage of persons aged 15-75 years who have a job;
Unemployed persons	The percentage of persons receiving benefits from the Unemployment Insurance Act in each neighborhood;
Household status	The percentage of each household type: single-person, household with children, household without children;
Migration background	The percentage of people with a western migration background and with a non-western migration background;

Variables	Description of variables
Density variables	
Population Density	Population density per km^2 ;
Business Density	Business density per km^2 ;
Intersection Density	The ratio between the number of intersections (3 or more legs) and the land area of the postcode group in acres;
Facilities variables	
Facilities distance	The average distance from the center of the neighborhood to the near-daily and non-daily facilities, e.g., supermarket, daily goods stores, and fitness, etc.;
The number of facilities	The number of daily and non-daily facilities within 1 kilometer by road for all residents of an area;
Green space variables	
Open green space	The percentage of the area of different types of open green space: green park space, forest, and open nature space, and inland water area;
Recreational space	The percentage of the area of different types of recreational space: sports space and daily recreational space;
Neighborhoods Crime	
Theft	It contains figures on property crimes registered by the police per type of crime expressed in number per 1000 inhabitants. The figures are broken down by commune, district, and neighborhoods.
Crime against public order	
Violence and sexual offenses	
Other environmental variables	
Land use mix	The percentage of each area: living building areas, traffic building areas, service building areas, and recreational building areas, etc.;
Urban density	Five level density from high to low: very high urban density, high urban density, middle urban density, low urban density, and very low urban density.

Table 2.3 The descriptive analysis of the final candidate variables dataset

	Mean	Sd	Min	Max	Unit
Dependent Variable					
Walking frequency	0.16	0.09	0.00	0.60	times
Socio-demographic variables					
Men	49.59	1.79	40.89	74.07	%
Women	50.41	1.79	25.93	59.11	%
People age under 15	16.01	3.72	2.44	38.00	%
People age 15 to 25	12.01	3.78	4.45	60.33	%
People age 25 to 45	23.54	5.74	9.00	53.00	%
People age 45 to 65	28.86	4.50	7.00	45.05	%
People age 65 older	19.58	6.63	3.00	56.00	%
Average income per inhabitant	24.98	4.73	12.83	57.87	× 1,000 euro
Households with a low income	7.04	4.64	0.80	63.70	%
Employed person	58.43	5.97	26.20	77.50	%
Unemployed person	2.27	0.61	0.00	5.9	%
Single-person households	34.21	11.86	8.44	87.00	%
Households without children	30.96	5.69	8.00	55.00	%
Households with children	34.83	9.30	3.00	71.00	%
Western migration background	9.28	4.96	0.67	58.00	%
Non-Western migration background	9.48	10.87	0.00	85.50	%
Daily facilities					
Supermarket distance	0.94	0.63	0.20	6.70	km
Number of supermarkets within 1km	1.60	1.46	0.00	13.50	number
Daily goods store distance	0.81	0.63	0.10	10.15	km
Number of daily goods stores within 1km	7.26	10.49	0.00	99.40	number
Café distance	1.23	1.08	0.10	9.80	km
Number of cafés within 1km	3.83	9.07	0.00	94.70	number
Cafeteria distance	0.88	0.82	0.10	8.00	km
Number of cafeterias within 1km	5.37	9.82	0.00	108.70	number
Restaurant distance	0.88	0.69	0.05	9.10	km
Number of restaurants within 1km	6.91	15.68	0.00	234.50	number
Hotel distance	2.61	2.06	0.10	13.30	km
Non-daily facilities					
Daycare distance	0.92	0.82	0.1	9.85	km
Children-care out of school distance	0.89	0.74	0.1	9.85	km

	Mean	Sd	Min	Max	Unit
Number of children-care out of school within1km	1.82	1.53	0	10.8	number
Primary education distance	0.77	0.44	0.2	7.85	km
Number of primary education within 1km	1.78	1.18	0	11.35	number
Secondary education distance	2.77	2.56	0.3	18.1	km
Vmbo distance*	2.96	2.63	0.3	18.1	km
Havo vwo distance*	3.56	3.25	0.3	34	km
Train station distance	5.47	6.24	0.4	58.53	km
Transfer station distance	11.47	9.38	0.58	62.05	km
Cinema distance	6.96	5.99	0.25	38	km
Green space variables					
Park and green space	0.06	0.07	0.00	1.24	%
Sports field	0.03	0.05	0.00	0.54	%
Day recreational terrain	0.01	0.02	0.00	0.47	%
Forest and open natural terrain	0.12	0.98	0.00	37.24	%
Inland water	0.08	0.59	0.00	18.62	%
Neighborhood Crime					
Theft	4.44	2.82	0	23.55	Number per 1000 persons
Crime against public order	5.59	3.84	0	40.75	Number per 1000 persons
Violence and sexual offenses	5.12	6.5	0	110.5	Number per 1000 persons
Density Variables					
Population density	4073.22	3201.99	26.00	23062.00	number/km^2
Business density	2.98	3.64	0.04	50.50	number/km^2
Intersection density	297.42	153.75	32.00	917.00	number/km^2
Land use mix					
Land use for traffic	5.15	3.32	0	28.1	%
Land use for service buildings	39.82	30.97	0	100	%
Land use for residential buildings	2.78	5.91	0	75.19	%
Land use for agriculture	37.28	33.61	0	97.88	%
Land use for recreation	7.62	8.5	0	66.67	%
Urban Density					
Very high urban density	0.14	0.35	0	1	/
High urban density	0.24	0.43	0	1	/
Middle urban density	0.15	0.36	0	1	/
Low urban density	0.16	0.36	0	1	/
Very low urban density	0.31	0.46	0	1	/

"*" means: "Vmbo" and "Havo vwo" are secondary professional education in the Netherlands.

Table 2.4 Robustness tests for the choice of the minimum respondents in each postcode area

	Respondents ≥ 10		Respondents ≥ 15		Respondents ≥ 20	
Number of postcodes	**2307**		**1982**		**1742**	
	Estimate		Estimate		Estimate	
(Intercept)	-0.0942	.	**-0.1250**	*	-0.0968	.
Socio-demographic variables						
People age 15 to 25	0.0016	*	**0.0018**	**	0.0017	*
People age 45 to 65	0.0019	***	**0.0023**	***	0.0021	***
People age older than 65	0.0025	***	**0.0026**	***	0.0022	***
Average income per inhabitant	0.0011	**	**-0.0011**	*	0.0007	.
Employed person	0.0012	*	**0.0014**	**	0.0011	*
Single person households	0.0011	***	**0.0010**	***	0.0010	***
Western migration background	0.0017	***	**0.0017**	***	0.0019	***
Non Western migration background	0.0029	***	**0.0030**	***	0.0030	***
Daily Facilities Variables						
Supermarket distance	-0.0079	***	**-0.0092**	**	-0.0084	*
Number of daily good stores within 1km	0.0014	***	**0.0014**	***	0.0012	**
Number of cafeteria within 1km	0.0011	**	**0.0011**	**	0.0013	**
Neighborhood Green-space Variables						
Total inland water			**0.0065**	*	0.0068	**
Land use mix						
Land use for residential buildings	0.0006	*	**0.0006**	*	0.0005	.
Urban Density						
Very high urban density	0.0150	*	**0.0159**	*	0.0138	*
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1						
Multiple R-squared:	0.3931		**0.4162**		0.4455	
Adjusted R-squared:	0.3897		**0.4121**		0.4410	

* Variables with the boldfaced letter are chosen as selected variables of the new index of walkability.

Table 2.5 Standardized coefficients of the walkability variables

Supermarket distance	**Number of daily goods store within 1 km**	**Number of cafeterias within 1km**
-0.0509	0.1408	0.1433
Total inland water	**Land use for residential buildings**	**Very high urban density**
0.0472	0.0336	0.0554

2.4 Results

2.4.1 Associations between walkability variables and walking frequency

The results of the regression analysis of the final model (respondents ≥ 15) using the stepwise method are shown in Table 4. The results are largely in line with expectations given the existing literature as reviewed above. The walkability variables that emerge from our analysis can be divided into four sections: availability and accessibility of daily facilities, availability of neighborhood green space, land use mix, and urban density (see Table 2.4).

Regarding availability and accessibility of daily facilities, we find an association between retail facilities and walking behavior. In our estimation, distance to a supermarket emerges as a relevant variable and shows a negative relationship with walking frequency. This means that the shorter the distance to the supermarket in a neighborhood, the more people walk in that neighborhood (keeping everything else constant). The number of daily goods stores within 1 km and the number of cafeterias within 1 km also emerge as relevant variables, indicating that in neighborhoods where these numbers are larger, the average walking frequency is higher. These results are in line with the findings of Duncan et al. (2011).

Regarding land-use, we find that the shares of the area covered by inland water and residential land use have positive relationships with walking frequency. This suggests that people prefer to walk in places where there is surface water such as ponds and narrow streets along canals and where dwellings make up a large percentage of the built-up area. Furthermore, high urban density turns out to be a relevant variable; in neighborhoods with high urban density, the walking frequency is higher. This suggests that high-density areas are more attractive for walking, maybe because walking distances are shorter in these areas due to the compactness of the built-up area. These results are in line with some empirical studies, as well as theory-based walkability indices, which found that high residential density is associated with more walking in the neighborhood (Duncan et al., 2012; Huang et al., 2019).

In summary, distance to a supermarket, number of daily goods stores within 1 km, number of cafeterias within 1 km, total surface of inland water, land used for residential buildings, and very high urban density turn out to be the relevant variables in this analysis. The standardized coefficients of these variables are shown in Table 2.5. The (absolute) size of the standardized coefficient indicates the importance of the variable as explanatory variable of walkability. The numbers of facilities within a 1 km radius (daily goods stores or cafeterias) are by far the most important variables – their effect is roughly three times as high as the effects of other variables. The unstandardized coefficients of these two most important variables (Table 3.4) indicate that btain the following equation to measure walkability:

$$
\begin{aligned}
\textit{Walkability} = {} & (-0.0509)\times Z\text{-}_{\textit{Supermarket distance}} + \\
& (0.1408)\times Z\text{-}_{\textit{Number of daily goods store within 1 km}} + \\
& (0.1433)\times Z\text{-}_{\textit{Number of cafeterias within 1 km}} + \\
& (0.0472)\times Z\text{-}_{\textit{Total inland water}} + \\
& (0.0336)\times Z\text{-}_{\textit{Land use for residential buildings}} + \\
& (0.0554)\times Z\text{-}_{\textit{Very high urban density}}
\end{aligned}
$$

2.4.2 Comparison of the measured walkability and existing walkability indices

The measure of walkability presented here is related to walking frequency. By controlling for socio-demographic differences between neighborhoods, the measure should capture the separate influence of the physical characteristics. Furthermore, compared to existing data-driven methods, we considered a larger set of variables, used the neighborhood as a unit of analysis, and included a large nationwide sample. In addition, compared to theory-based indices, the issue of collinearity between variables is solved by using (multiple) regression analysis so that the weights found represent separate (pure) effects of the variables.

As explained in the method section above, to assess the agreement between this empirically derived measure of walkability and several theory-based measures described in the literature the following analyses were conducted:

1. Determining the mutual correlations between the measure of walkability, some existing walkability indices, and walking frequency.

2. Comparison of the goodness of fit of regression models to predict walking frequency where the selection of the variables is based on (1) the current measure of walkability and (2) several existing walkability indices.

As existing walkability indices, Frank's walkability index and Graz walkability index were considered, as these measures appear to be most important in applications in European cities (Grasser et al., 2017). The first analysis offers an indication of predictive validity of the existing indices. The second analysis offers an indication of construct validity.

Figure 2.2 shows the correlation coefficients between the three sets of walkability scores and walking frequency across the Dutch postcode areas. The correlation coefficients between walking frequency, on the one hand, and the walkability score based on the current measure, Frank's walkability score, and Graz walkability score, on the other, are 0.58, 0.48, and 0.45, respectively. This indicates that the existing indices considered (Frank's and Graz) are only to a limited extent able to predict walking frequencies observed in the neighborhoods. In that sense, predictive validity is poor. However, considering the fact that physical characteristics of neighborhoods are not the only factors influencing walking frequencies (also socio-economic differences do) comparison with the correlation achieved by the current measure of walkability (i.e., 0.58) is more informative. The physical neighborhood characteristics (walkability) can explain around 33% (= 0.58^2) of the variance in walking frequency. The existing measures explain between 20% (= 0.45^2) and 23% (= 0.48^2). This is substantially lower, leading to the conclusion that the existing measures miss some important factors that at least for the Dutch context have an influence on walkability either in terms of the selection or the weighting of the variables.

The second step is to compare the goodness-of-fit of three regression models that result from regression analysis of walking frequency based respectively on the current selection of variables and the selections of the variables in Frank's and Graz's indices. Thus, we re-estimate the current regression model on our dataset two times where we replace the current selection of walkability variables with the variables of Frank's walkability index and Graz walkability index. The adjusted R-square values for the models are 0.41, 0.39 and 0.38 for the current model, Frank's walkability index, and Graz walkability index, respectively. This indicates that the empirical measure of walkability offers a somewhat better goodness of fit than the linear regression models based on the selections of variables used in the other two walkability indices re-estimated on the Dutch data. Although the goodness-of-fit values for the indices are lower compared to the benchmark, the differences are only small. Combined with the previous result this leads to the conclusion that the limitation in predictive validity is primarily attributable to the weighting of the variables as opposed to the selection of variables (identification of factors). Yet, the differences are not completely explained away.

Comparing the model specifications offers insight into the actual differences in variable selection and weights. In the regression analysis, the variables that emerge as significant are distance to daily-good stores, availability of daily good stores and cafeterias, the total inland water, residential land-use, and high urban density. In main lines, this is in agreement with the factors that are used in the existing measures, which also emphasize accessibility to amenities, land-use mix, and urban density (Eom & Cho, 2015; Frank et al., 2010; Grasser et al., 2016). However, a number of variables included in existing indices are not significant in the current analysis. Specifically, land use mix (entropy index), intersection density, and retail floor area ratio appear not to be significant. These variables may exert their influence indirectly through other variables. These findings are in agreement with some other empirical studies. Using data from Hong Kong, Lu (2019) and Lu et al. (2017) also found that land use mix is not significantly associated with recreational green physical activity (walking). In the Latin American context, Reis et al. (2013) and Salvo et al. (2014) found that land use mix (entropy index) and intersection density are negatively associated with moderate-to-vigorous physical activity (walking). On the other hand, there are variables that appear significant in our analysis but do not recur in the existing indices. Specifically, the presence of in-land water appears to be significant but is not included in the existing measures. This variable may capture the effect of presence of natural elements (such as the presence of green and water bodies) on walkability. Natural elements may increase the attractiveness of the environment for walking and this factor may be underestimated in current conceptualizations. Apart from the selection of variables, there are differences in the relative weights of variables. In the regression model, we find that the weights of distance to and availability of facilities are of the order of magnitude of three times as important as the land-use and urban density variables. In existing measures, on the other hand, land-use mix variables have a relative weight of two times the weights of other variables while the accessibility of amenities (distance and amount) is not included as such. This indicates that in present conceptualizations independent (separate) effects of accessibility of amenities on walkability seem to be underestimated, at least, in the Dutch context.

To summarize, the analysis indicates that both in terms of the selection and weighting of variables the existing indices considered do not fully capture the location factors that influence walkability. The largest part of the mismatch emerges from the assumed weighting of the factors, but there are also striking differences in the selection of variables. This finding stresses the importance of taking collinearity between independent variables into account and points to an underestimation of (urban) landscape factors.

Finally, to illustrate how walkability is spatially distributed across the Netherlands, we used the measure of walkability to draw a walkability score map of the Netherlands. Figure 2.3 shows the resulting map. The highest walkability scores are found in areas with a very high degree of urbanization, such as inner cities of Amsterdam, Rotterdam, Den Haag, and Utrecht. The lowest walkability scores are found in suburban areas.

2.5 Conclusions

In this chapter, we developed an approach to measure walkability based on a regression analysis of a large nationwide database of neighborhoods. A large set of neighborhood variables was considered with the aim to identify the set of variables that can best explain differences in walking frequency between neighborhoods, while accounting for differences in socio-demographic characteristics. We compared the resulting regression model to existing walkability indices, to evaluate the extent to which existing measures represent the factors that emerge from the analysis. The comparison shows that existing walkability indices only partly explain the empirically measured walkability in this case. The most important part of the mismatch relates to the weights assigned to variables indicating that particularly the influence of accessibility variables is underestimated (Vale et al., 2015). However, also differences in the selection of variables appear. We find that the entropy index (land use mix), intersection density, and retail floor area ratio are not significantly related to walking frequency in the Dutch context. This is partly in line with Habibian et al. (2018), Lu (2019), Lu et al. (2017), Reis et al. (2013) and Salvo et al. (2014) who also found that the entropy index for land use mix is not appropriate for describing walkability. On the other hand, other significant variables are not represented in the empirical literature. Our analysis indicates that presence of natural elements of the landscape can contribute to walkability, a factor that is not represented in existing indices. The presence of natural elements may capture differences in the attractiveness of the environment for walking. In sum, the analysis results of this study indicate which factors are key for creating walkable neighborhoods and to what extent they contribute to walkability. The results indicate that both in terms of the selection and weighting of variables existing indices could be improved.

However, this chapter still has several limitations that should be addressed in future research. Firstly, our analysis focused on the Dutch context and considered only two existing indices in detail. It is interesting and necessary to replicate the study using data from other countries or regions and include a wider range of existing conceptualizations. This is in agreement with conclusions from other studies on walkability measurement that also stressed that further work is needed to understand performance and applicability of the methodology in other urban settings (Frank et al., 2010; Glazier, Weyman et al., 2012; Habibian & Hosseinzadeh, 2018). When systematic differences exist between regions, the question arises whether the goal of developing a universally applicable method to measure walkability should be abandoned and replaced by a practice where local estimation and validation of a model is an integral part of the application of walkability analysis.

Second, our analysis did not consider possible differences in responses to neighborhood factors related to the type of walking trips. Especially, walking for transport and walking for leisure may differ in that respect. It is interesting to explore the relationships between the built environment and different types of walking in future research. Third, our test variables did not include variables that are less commonly used in primary (neighborhood) databases but nevertheless may influence walkability as well. One can think, for example, of variables such as lighting, pedestrian safety, and aesthetics variables (Glazier et al., 2012).

Although more research is necessary to understand the performance of this method for application in other areas and regions in the future, this chapter has shown that is useful and meaningful to consider extending in terms of variable selection and weights of the variables to measure walkability.

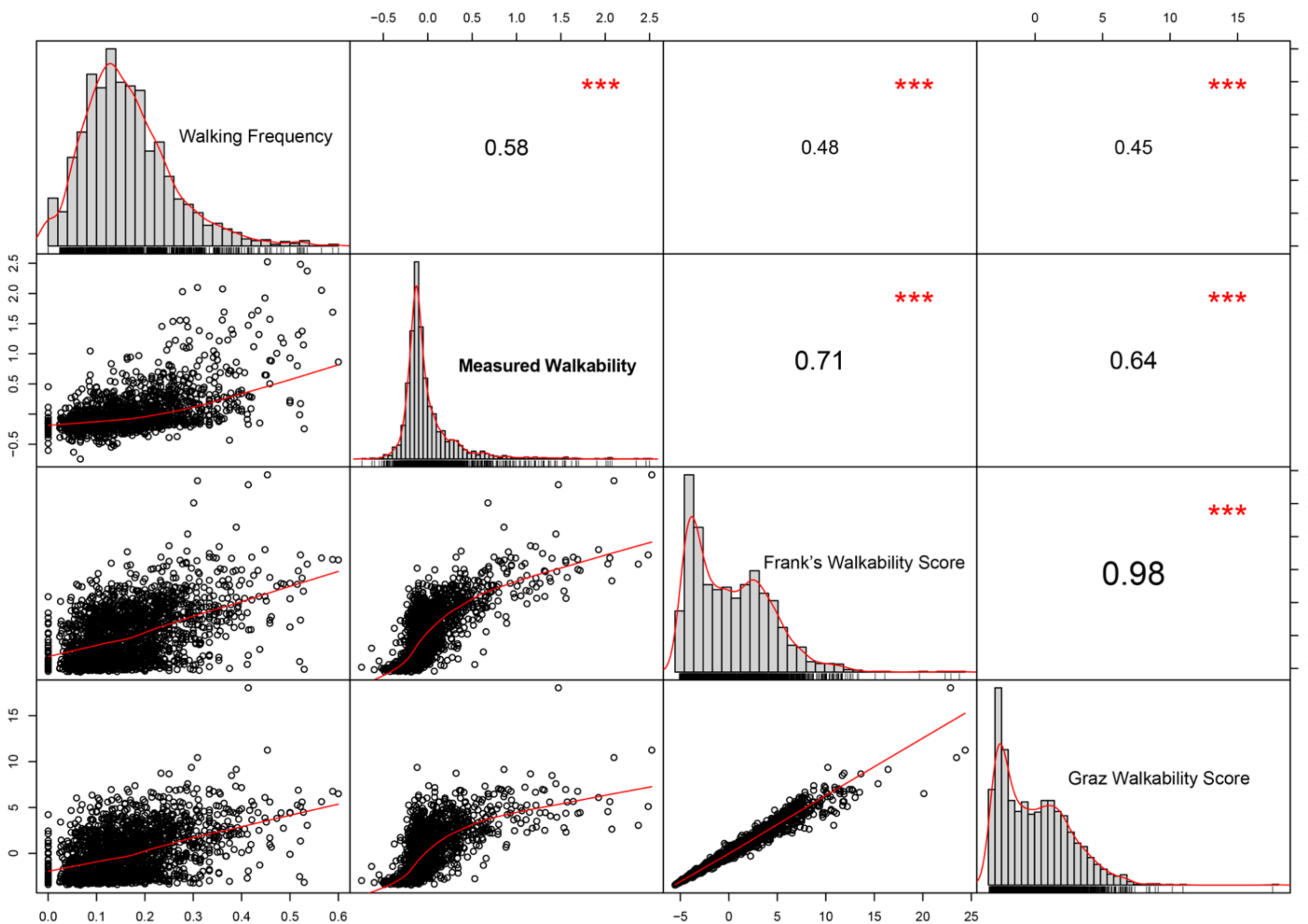


Figure 2.2 The correlation coefficients chart between three walkability scores and walking frequency

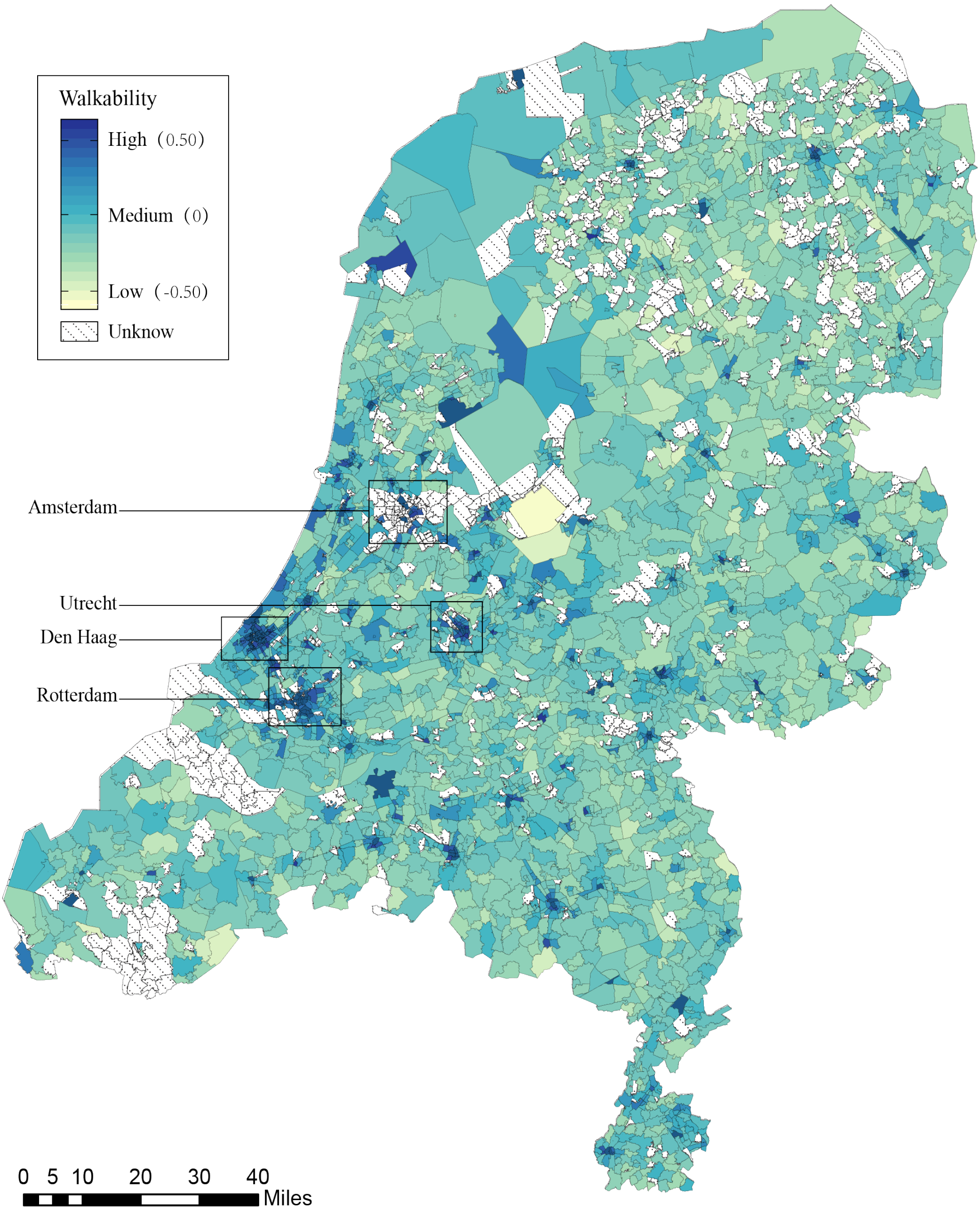


Figure 2.3 A walkability score map in the Netherlands

CHAPTER 3

WALKABILITY AND WALKING BEHAVIOR

--A COMPARISON BETWEEN DIFFERENT AGE GROUPS

This chapter is based on:

Liao, B.*, van den Berg, P. E. W., van Wesemael, P. J. V. & Arentze, T. A. (2020).
How does walkability change behavior? A comparison between different age groups
in the Netherlands,
International Journal of Environmental Research and Public Health.
DOI: 10.3390/ijerph17020540.

3.1 Introduction

Empirical research has shown that the design of the built environment has a significant influence on the extent to which individuals walk which is an important element of a healthy lifestyle (Howell et al., 2017; Neville Owen et al., 2004; Brian E Saelens et al., 2003; J.F. Sallis et al., 2016). Commonly, this influence is captured in the notion of walkability which represents the extent to which the built environment is conducive to walking. An important theoretical basis for measuring walkability is provided by Cervero et al. (2010) who distinguish six built-environment dimensions, i.e., density, diversity, design, distance, destination, and demand management (Reid Ewing & Cervero, 2010). Using this framework, indices of walkability have been developed to predict levels of inhabitants' walking activity and active travel in the neighborhood (Frank et al., 2006; Sallis et al., 2004; Wang & Yang, 2019). These existing measures consider neighborhood features, such as dwelling density, presence of local amenities (schools, shops, etc.), and street connectivity, as determining factors of walkability. These neighborhood features correlate with the extent to which individuals are inclined to walk in their direct environment for transport or recreational purposes (Howell et al., 2017; Owen et al., 2004; Saelens et al., 2003; Cerin, et al., 2016). Neighborhood studies have shown that, in neighborhoods with higher walkability, individuals make more walking trips (Canepa, 2007; Frank et al., 2006, 2005; Maghelal & Capp, 2011).

However, it is not clear what the exact nature is of the relationship between neighborhood walkability and walking trips, since logically a higher walking frequency can be triggered in different ways: (1) choice of activity—individuals conduct more outdoor activities and, therefore, make more walking trips; (2) choice of destination—individuals choose more often short distance destinations for their trips and, consequently, walk more; (3) choice of transport mode—individuals choose walking more often as transport mode. In other words, walkability could lead to more walking trips through an activity choice, a destination choice, or a mode choice effect.

Previous studies emphasized the relationships between walkability, outdoor activities, and short distance destinations (King et al., 2011; Portegijs, Keskinen et al., 2017; Sallis et al., 2018; Van Holle et al., 2014). However, little literature has focused on the question of how the relationship between walkability and frequency of walking trips is caused. Hence, it is not clear whether high walkability neighborhoods stimulate primarily outdoor activities, short-distance destinations, walking mode, or combinations of those. Moreover, there is empirical evidence that the association between walking and walkability may be different among age groups. Especially, children and the elderly may respond differently to features of the built environment in that respect (Buck et al., 2015; D'Haese et al., 2014; De Vries et al., 2010; Giles-Corti et al., 2009; Timperio et al., 2004). For example, children might not have a high walking frequency in neighborhoods that score high on walkability indices, as those neighborhoods are characterized by high building and population densities that offer few places, such as green yards, where children prefer to play (Buck et al., 2015). For the elderly, walkability has been found to be positively associated with walking for transportation and unrelated to outdoor activities (Van Holle et al., 2014). Therefore, it is important to acknowledge that the relationships between walkability, outdoor activities, short-distance destinations, and walking mode may not be the same for different age groups. The purpose of the present study is to analyze these relationships to obtain a better understanding of how walkability influences activity–travel behavior of different age groups (i.e., children, adults, and elderly). This study used data from the Netherlands (CBS, 2017) and path analysis to answer this research question.

The remainder of the paper is organized as follows. In the next section, the existing literature is reviewed and the hypotheses and causal model that is the basis for a path analysis are outlined. Section 3.3 describes the data used for path analysis. The modeling results are presented in Section 3.4. The final section summarizes the results and discusses the implications of the findings for urban planning and neighborhood design.

3.2 Literature review and hypotheses

3.2.1 The influence of walkability on walking behavior and activity

Empirical studies have examined the relationship between walkability and walking behavior, and found different correlates between built environment factors and walking for transport, recreation, and exercise (Heath et al., 2006; Humphrey, 2005; Owen et al., 2007). From the perspective of urban planning and transportation research, ease of pedestrian access to nearby destinations is related to walking behavior. In the public health literature, studies showed that some components of neighborhood walkability (e.g., access to recreation facilities and aesthetics) are related to recreational physical activity and walking. Correlations are found between walkability, destination choice, and mode choice. For example, residents who live in more walkable neighborhoods tend to make more frequent walking trips to nearby destinations (e.g. the neighborhood grocery store) (Owen et al., 2007).

However, less research has examined the association between walkability and destination choice of pedestrians and whether, indeed, walkability leads to higher walking frequencies through enabling people to choose more often short distance destinations for their trips. Some studies indicated that with more short-distance destinations available, people would walk more often. Similarly, Cao et al. (2006) found that in neighborhoods with stores within walking distance residents' frequency of walking to the stores is larger. Furthermore, Sugiyama et al. (2010) found that short distance to some destinations (e.g. attractive open spaces) was associated with more recreational walking. For example, a high-quality park within walking distance of one's home promotes walking for recreation (Sugiyama et al., 2010). Likewise, Chikaraishi et al. (2015) found that residents are more likely to choose walking for short-distance trips in a high walkability neighborhood (CHIKARAISHI et al., 2015; Millward et al., 2013). Although these studies established the existence of associations between walkability and destination choice, other components were left out of consideration. In addition, neighborhood walkability is also related to residents' outdoor activities. Several studies found that walkability is one of the environmental factors exerting a strong influence on out-of-home activity levels (Rodriguez et al., 2009; Van Cauwenberg et al., 2011; WHO, 2011; Zandieh et al., 2017).

In addition, a number of studies indicated that the association between walkability and outdoor activities differ between different age groups. Particularly, children and the elderly display specific behavior (Buck et al., 2015; D'Haese et al., 2014; De Vries et al., 2010; Giles-Corti et al., 2009; Timperio et al., 2004). These studies used walkability variables (e.g., residential density, land-use mix, and intersection density) to evaluate walkability and to explain further how the neighborhood environment affects children and older adults' walking frequency. For instance, positive relations have been reported between neighborhood walkability and older adults' transport-related walking while no clear relations between neighborhood walkability and children's walking activities were found in Belgium (D'Haese et al., 2014). Furthermore, several studies have also considered the relationship between some social characteristics and out-of-home activities, and the role of neighborhood walkability. People with low socioeconomic status are more likely to have less outdoor activities than their higher status counterparts (Kamphuis et al., 2009).

This brief review of the existing literature suggests that neighborhood walkability plays an important role in trip generation, destination choice, and transport mode choice. Although the links between them have been discussed, it is still not clear to what extent high walkability neighborhoods stimulate trip generation, destination choice, transport mode choice, or combinations of those. It is also important to clarify whether the relationships between them are the same in different age groups. The goal of the present paper is therefore to analyze the relationships between neighborhood walkability, trip generation, destination choice, and transport mode choice in different age groups in an integrated fashion.

3.2.2 Hypotheses and causal model

As the brief review above indicates, the different components – activity, destination, and mode choice – have all received attention as elements of behavior that are possibly influenced by walkability. However, a systematic analysis of the relationship between walkability and walking tendency in terms of the question of whether it is primarily mediated by activity, destination or mode choice is lacking. The purpose of the present study is to provide this analysis so as to increase our understanding of the relationships between walkability and behavior.

Figure 3.1 shows the causal model that we use in a path analysis to test the possible relationships. In the model, neighborhood walkability has direct associations with out-of-home activities, the share of walking trips, and the share of short-distance trips as well as indirect associations. The indirect relationships run through the relationships between out-of-home activities and the share of short-distance trips and between the share of short-distance trips and share of walking trips. These latter vertical relationships in the figure represent well-known relationships between activity generation, trip distance, and mode choice. We are especially interested in the direct relationships between walkability and the behavioral measured variables. The hypotheses we test can be formulated as follows:

Hypothesis 1 (H1). Neighborhood walkability has a direct relationship with the number of out-of-home activities, i.e., the higher the walkability the higher the number of out-of-home activities (an activity choice effect).

Hypothesis 2 (H2). Neighborhood walkability has a direct relationship with the share of short-distance trips, i.e., the higher the walkability the higher the share of short-distance trips after controlling for the number of out-of-home trips (a destination choice effect).

Hypothesis 3 (H3). Neighborhood walkability has a direct relationship with the share of walking trips, i.e., the higher the walkability the higher the share of walking trips after controlling for the number of out-of-home activities and the share of short-distance trips (a mode choice effect).

Hypothesis 4 (H4). The relationships between neighborhood walkability, out-of-home activities, the share of short-distance trips, and the share of walking trips differ between age groups.

The findings of this study will provide a better understanding of the relationships between neighborhood walkability, out-of-home activities, short-distance destinations, and walking trips. Since we use cross-sectional data, our analysis does not allow us to identify causality.

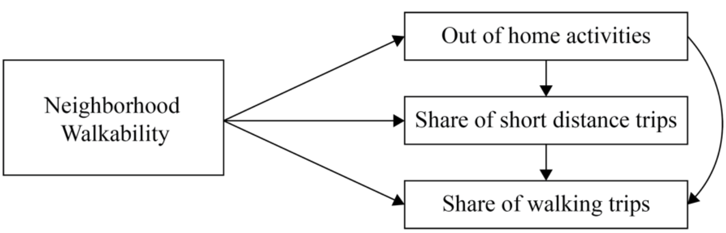


Figure 3.1 A causal model of neighborhood walkability and activity choice, destination choice, and mode choice

3.3 Methods and materials

In this section, we introduce the approaches used to measure neighborhood walkability and to analyze the relationships between neighborhood walkability, trip generation, destination choice, and transport mode choice for different age groups. For the analysis, we used data from the national travel survey in The Netherlands.

3.3.1 Approach

The analysis of the relationships between neighborhood walkability, out-of-home activities, short-distance trips, and walking trips, requires data on each of these components on the level of neighborhoods. Firstly, data on neighborhood walkability should be obtained. An obvious way to obtain walkability data would be to calculate walkability scores by using some existing walkability index, such as the well-known Walkability Index (Frank et al., 2010). This index uses land use mix, residential density, retail floor area ratio, and intersection density to derive a measure walkability. However, this would not be the best way, as the scores calculated based on a walkability index do not include measurement error due to unobserved neighborhood attributes. To obtain a more complete measure taking into account observed as well as unobserved attributes, we propose to use a separate regression analysis to derive walkability values of neighborhoods as follows.

The regression analysis to derive neighborhood walkability values uses individuals' observed walking frequency as dependent variable and socio-demographic characteristics and neighborhood dummy variables (fixed effects) as independent variables. Figure 3.2 shows a conceptual model that represents the relationships between walkability, socio-demographic characteristics, and walking frequency (B. Liao et al., 2019). As implied by this model, the total influence of walkability variables can be identified in this regression analysis as the fixed effects of neighborhoods on walking frequency after controlling for socio-demographic characteristics of individuals. The socio-demographic variables available in the survey and included in the model include gender, age, income, household composition, education, and migration background. When controlled for these socio-demographic variables, the fixed neighborhood effects in the regression model should represent the component of physical characteristics which we identify as the degree of the walkability of each neighborhood. Note that individuals are the unit of analysis in this regression analysis, to eventually obtain neighborhood-level values (the fixed effects).

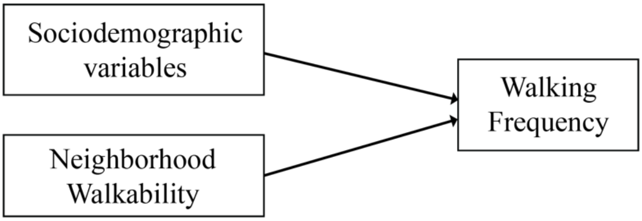


Figure 3.2 A conceptual model of the relationship between walkability variables, sociodemographic characteristics, and walking frequency (B. Liao et al., 2019)

In statistics, a fixed effects model refers to a regression model in which the group means are fixed (non-random) by the sample from a population (Schafer, 2002). The specification of the fixed-effects model, in this case, can be written as follows:

$$Y_{ij} = X_{ij}\beta \ + \ \alpha_j \ + \ \mu_{ij} \quad \text{for} \ \ j = 1, \dots \dots, J \ and \ i = 1, \dots \dots, N \tag{1}$$

where Y_{ij} is the observed frequency of walking trips of an individual i at neighborhood j, X_{ij} is a vector of socio-demographic characteristics of that individual in that neighborhood and β is the related vector of coefficients, α_j is an unobserved neighborhood effect and μ_{it} is an error term.

The estimated values of the fixed effects, represent the neighborhood walkability values. They will be used as walkability data for the path analysis based on the causal model (Figure 3.1) to test the hypotheses stated. Several limitations of this way of measurement should be mentioned. First, it should be noted that the fixed effects may also capture the collective preferences of individuals living in the same neighborhood. In this case, collective preferences may arise due to a self-selection effect where people who prefer walking choose to live in neighborhoods that have high walkability. Thus, a common attitude will be captured by the fixed-effect term as well making that a causal interpretation of the relationship between walkability and walking frequency is problematic. This is an inherent limitation of the cross-sectional data analysis. Furthermore, it is noted that the accuracy of this method depends on the extent to which the selection of socio-demographic variables, , covers the population characteristics that have an influence on activity and travel preferences. When important socio-demographics are missing the fixed-effect term may also capture differences in walking frequency that are related to differences in population composition of neighborhoods rather than just walkability. Therefore, we include a complete set of socio-demographic variables that are known to be influential and that (for that reason) are available generally in travel surveys.

3.3.2 Data and variables

For the regression analysis and path analysis, we use national travel survey data from The Netherlands (OViN) (CBS, 2017). This travel survey provides for a large nation-wide sample trip-diary data for a random day where all days of the week are covered. The neighborhood of each individual can be identified based on the postcode of the home address, which is available in the survey data on a 4-digit level. To increase the number of observations, four years (2013-2016) of this survey are merged for the present analysis. In the Netherlands, as in other developed countries, possible changes in physical neighborhood characteristics such as infrastructure, land-use and accessibility to facilities, which have an influence on walkability, in a period of four years will be only minor. So it is expected that the error caused by not taken possible changes into account will be neglectable. Hence, the data of 125,934 individuals in total are used for estimating the fixed effects model as well as the path model. As said, the socio-demographic variables used in the analysis include age, gender, income, household situation, employment situation, and migration background. The description of the variables and descriptive statistics are shown in Table 3.1 and Table 3.2.

The second step is to estimate the causal model and test the stated hypotheses by path analysis. Path analysis is a special case of structural equation modeling (SEM) that does not deal with latent variables but only with measured variables (van den Berg et al., 2013). Using the same travel survey data, the number of out-of-home activities, the share of short-distance trips and the share of walking trips can be derived from the trip data for each individual on the observed day. To determine the share of short-distance trips, we used 1000 m as a cut-off-point. Thus, the ratio of the number of trips shorter than 1000 m and the total number of trips from home is calculated for each person in the database. Next, the data of the travel mode was used to calculate the share of trips made on foot. This yields data on out-of-home activities, short distance trips and walking trips on an individual level. However, the unit of analysis of the path analysis is the neighborhood. By computing averages of the variables (number of out-of-home activities, the share of short-distance trips and share of walking trips) across individuals within (4-digit) postcode areas, the relevant trip data are aggregated to the postcode area level. To test hypothesis H1-H4, a path analysis is conducted for each of the three age groups (children group, adult group, and elderly group) separately, as well as all age groups together. The children group includes respondents who are aged under 18, the adult group includes respondents who are aged between 19 to 65, and the elderly group includes respondents who are aged 65 or older. To obtain neighborhood data, the aggregation from individuals to neighborhoods (postcode areas) was conducted for each of the three age groups separately as well as all age groups together. The description and descriptive statistics of the variables are shown in Table 3.3 and Table 3.4.

Table 3.1 Description of variables

Variables	Description of variables
Walking frequency	The total number of walking trips (in 1 day) per person;
Gender	A binary variable: male and female;
Age	Three categories for individuals: age under 18, age 19 to 65, and age older than 65;
Income situation	Three categories for individuals: households with a low income (less than € 20,000), households with a medium-income (€ 20,000 - € 50,000), and households with a high income (more than € 50,000);
Households situation	Three categories for individuals: single persons, couples without children, and couples with children;
Employed situation	A binary category variable: employed and unemployed;
Migration background	Three categories for individuals: people are indigenous, people with a western migration background, and with a non-western migration background.

Table 3.2 Descriptive analysis of variables

	Mean	Sd	Min	Max	Unit
Walking frequency	0.58	1.14	0.00	13.00	times
Men	0.49	0.50	0.00	1.00	/
Women	0.51	0.50	0.00	1.00	/
Persons age under 18	0.26	0.44	0.00	1.00	/
Persons age between 19 to 65	0.50	0.50	0.00	1.00	/
Persons age older than 65	0.23	0.42	0.00	1.00	/
Households has a low income	0.12	0.32	0.00	1.00	/
Households has a medium income	0.57	0.50	0.00	1.00	/
Households has a high income	0.43	0.50	0.00	1.00	/
Employed persons	0.46	0.50	0.00	1.00	/
Unemployed persons	0.54	0.50	0.00	1.00	/
Single persons	0.14	0.34	0.00	1.00	/
Couples without children	0.28	0.45	0.00	1.00	/
Couples with children	0.58	0.49	0.00	1.00	/
Indigenous	0.84	0.37	0.00	1.00	/
Western migration background	0.07	0.27	0.00	1.00	/
Non-Western migration background	0.08	0.27	0.00	1.00	/
	N = 125,934 persons				

Table 3.3 Description of measured variables

Variables	Description of variables
Out-of-home activities	The average number of out-of-home activities of respondents in each postcode;
Share of short-distance trips	The average percentage of short-distance trips (less than 1000 m) of respondents in each postcode;
Share of walking trips	The average percentage of walking trips of respondents in each post-code.

Table 3.4 Descriptive analysis of measured variables in different age groups

Variables	Mean	Sd	Min	Max	Unit
All age groups					
Walkability fixed score	0.06	0.07	-0.11	0.46	/
Out-of-home activities	3.50	0.43	0.00	5.32	times
Share of short distance trips	14.91	5.90	0.00	43.86	%
Share of walking trips	15.98	6.40	0.00	58.76	%
	N = 2354 postcode areas (Persons ≥ 15)				
Children group					
Walkability fixed score	0.06	0.06	-0.06	0.46	/
Out-of-home activities (Children)	3.49	0.50	0.00	5.18	times
Share of short distance trips (Children)	21.69	8.86	0.00	58.49	%
Share of walking trips (Children)	18.71	9.09	0.00	55.56	%
	N = 800 postcode areas (Persons ≥ 15)				
Adults group					
Walkability fixed score	0.07	0.06	-0.09	0.35	/
Out-of-home activities (Adults)	3.68	0.55	0.00	5.71	times
Share of short distance trips (Adults)	11.65	5.91	0.00	33.98	%
Share of walking trips (Adults)	13.55	6.32	0.00	41.13	%
	N = 1662 postcode areas (Persons ≥ 15)				
Elderly group					
Walkability fixed score	0.06	0.05	-0.05	0.29	/
Out-of-home activities (Elderly)	3.23	0.45	1.35	4.76	times
Share of short distance trips (Elderly)	14.22	7.77	0.00	53.49	%
Share of walking trips (Elderly)	19.67	8.64	0.00	51.79	%
	N = 677 postcode areas (Persons ≥ 15)				

3.4 Results and discussion

This section presents the results of the path analysis. The results of the path analysis are shown in Figures 3.3-3.5 and Table 3.5 for all age groups together and the three age groups (children, adults, and elderly) separately, respectively.

3.4.1 The relationship between neighborhood walkability and behavior variables—all groups

Regarding the relationship between neighborhood walkability and behavior variables of all age groups together, the results of the path analysis (Figure 3.3 and Table 3.6 – All age groups) show a positive relationship between walkability and the number of out-of-home activities that people conduct, a positive and relatively strong relationship between walkability and share of short-distance trips (keeping number of activities constant) and a positive and relatively strong relationship between walkability and the share of walking trips (keeping the number of out-of-home activities and share of short-distance trips constant). These results provide support for hypotheses H1, H2 and H3, i.e., that the relationship between walkability and walking frequency originates from an activity choice effect (people choose more out-of-home activities), a destination choice effect (people choose shorter distance destinations more often) and a transport mode effect (people choose to walk more often also for farther away destinations).

Looking at the size of the path coefficients, the transport mode effect appears to be much stronger than the activity choice effect and destination choice effect (0.84 versus 0.15 and 0.47). The internal relationships between the activity-trip variables are as expected: the number of out-of-home activities has a positive association with short distance trips (0.06), and in turn short distance trips have a positive association with the share of walking trips (0.16). Due to the latter relationship, the relationship between walkability and the frequency of walking trips is strengthened by an indirect relationship that runs through destination choice.

3.4.2 Differences between age groups

Comparing the estimated path models between the different age groups (Figures 3.4-3.6 and Table 3.6), we see that the relationships between walkability and behavior variables are quite different for children, adult, and the elderly. In all three groups, the relationships between walkability, the share of short-distance trips, and the share of walking trips are positive and significant and roughly of the same order of magnitude (although the mode choice effect is smaller for children and elderly compared to adults). In terms of the relationship between walkability and number of out-of-home activities, there is however a difference. In the children group and the elderly group, there are no links between walkability and number of out-of-home activities indicating that higher walkability is does not lead to more out-of-home activities for children and the elderly. In the adult group, there is a small positive association (0.18) between walkability and number of out-of-home activities. In conclusion, hypothesis H4 is partially confirmed by the results – there are differences between age groups in terms of behavior related to walkability, although all age groups make more short-distance trips and (controlling for distance) choose walking mode more often in higher walkability neighborhoods.

The line of argumentation is similar in terms of the internal relationships between the behavior variables: all age groups show a relatively strong positive (direct) association between the share of short-distance trips and share of walking trips. This means that for all age groups, the relationship between walkability and walking frequency is enhanced by an indirect relationship that runs through destination choice. The relationship between the number of out-of-home activities and the share of short-distance trips is small (adults and elderly) or absent (children). Furthermore, there is no (direct) association between the number of out-of-home activities and the choice of walking mode in any one of the age groups.

3.4.3 Discussion of results

The absence of a relationship between walkability and out-of-home activities in the children group and the elderly group is the most striking finding. A possible explanation for this finding may be different for children and elderly. For children, it could be related to outdoor play where children prefer to have outdoor activities in spacious and vegetated yards rather than in places with high building density and high population density, which are typical for high walkability. For elderly, it may be related to parks where the elderly prefers to have outdoor activities. Those places are also not typical for high walkability (Corseuil et al., 2011). If these explanations are valid, it means that what walkability is to children and elderly is not exactly the same as what walkability is to the adult group. For children and elderly, the conditions that contribute to walkability may differ when it comes to favoring outdoor activities. This does not hold for destination choice and transport mode choice – the conditions that support short-distance destinations and the choice of walking mode work out for children and elderly in the same way as for the adult group. It is generally held that highly walkable neighborhoods invite people to make walking trips just for recreation. Our analysis shows that people in high walkable neighborhoods do not or only modestly, dependent on age group, perform more activities outdoor. A much stronger relationship is that, in high walkable neighborhoods, people more often choose short-distance destinations and walking for their activities. In terms of the strength of the relationships, the mode choice effect appears to be somewhat larger than the destination choice effect.

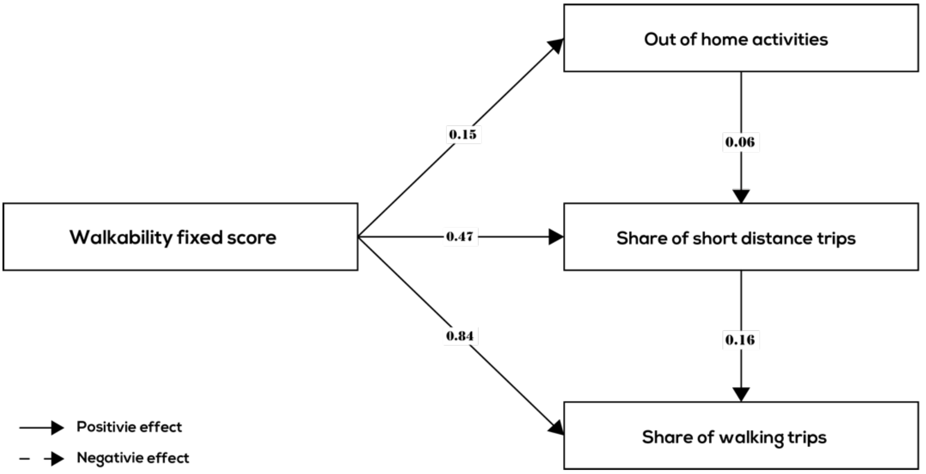


Figure 3.3 Significant relationships between walkability and behavior variables (all age groups)

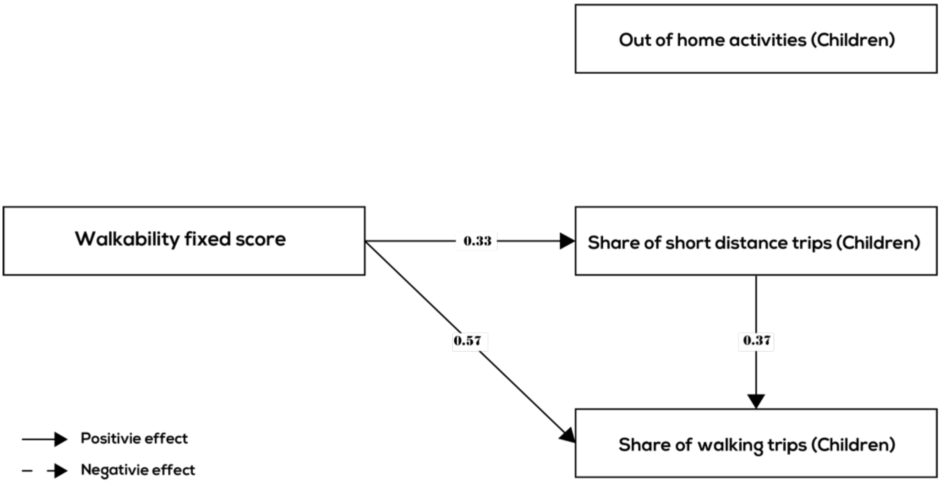


Figure 3.4 Significant relationships between walkability and behavior variables (children group)

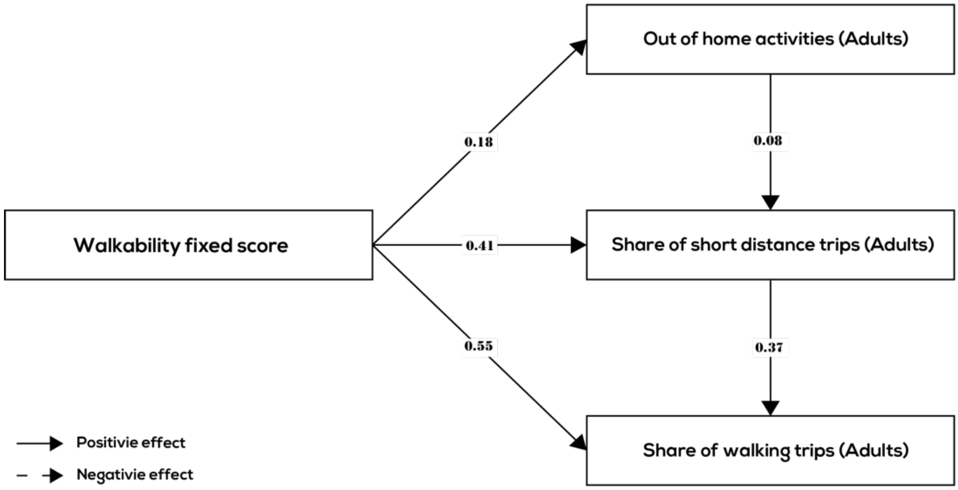


Figure 3.5 Significant relationships between walkability and behavior variables (adult group)

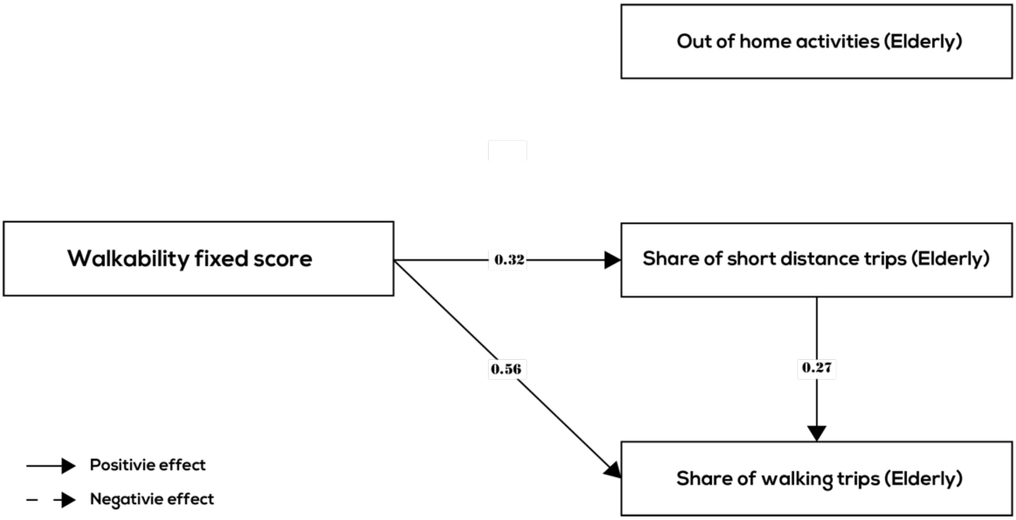


Figure 3.6 Significant relationships between walkability and behavior variables (elderly group)

Table 3.5 Path analysis model standardized estimates

To From	Out-of-home activities	Share of short-distance trips	Share of walking trips
All age groups			
Walkability	0.154***	0.467***	0.839***
Out-of-home activities		0.059***	-0.054
Share of short-distance trips			0.160***
Children group			
Walkability (Children)	0.031	0.334**	0.572***
Out-of-home activities (Children)		0.024	-0.062
Share of short-distance trips (Children)			0.374***
Adults group			
Walkability (Adults)	0.180***	0.411***	0.551***
Out-of-home activities (Adults)		0.077***	-0.058
Share of short-distance trips (Adults)			0.370***
Elderly group			
Walkability (Elderly)	0.044	0.317***	0.556***
Out-of-home activities (Elderly)		0.005	-0.047
Share of short-distance trips (Elderly)			0.274***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

3.5 Conclusions

This chapter has aimed to increase our understanding of the relationships between neighborhood walkability, out-of-home activities (activity choice), short-distance trips (destination choice) and walking trips (mode choice). Based on data from a large national travel survey on socio–demography and trips, walkability scores were derived, and a path analysis was conducted to estimate the relationships between these variables in a causal model using the neighborhood as the unit of analysis. Since behavior may differ between age groups, the path analysis was conducted for different age groups separately.

The findings indicate that there are positive relationships between neighborhood walkability, short-distance trips, and walking trips. At the same time, neighborhood walkability has a weak association with number of out-of-home activities only in the adult group. The relationships between neighborhood walkability and number of out-of-home activities are absent in the children group and the elderly group. We conclude, therefore, that relationships between walkability, out-of-home activities, short-distance trips, and walking trips are different between age groups. People in highly walkable neighborhoods do only modestly (adults) or not at all (elderly and children) perform more outdoor activities. All age groups do, however, more often have short-distance destinations (keeping all else constant) and choose walking as transport mode (keeping all else constant). A possible explanation for the absence of an activity choice effect for children and elderly is that children and elderly may prefer specific leisure spaces (e.g., spacious playground, and parks) for recreational activities which are not typically related to high walkability (e.g., shopping center or cinema). Therefore, these findings suggest that to extend the use for a wider group of people, a measure of neighborhood walkability should also consider specific demands of children and the elderly regarding walkable neighborhood design related to outdoor activities, such as green spaces and spacious playgrounds.

Although the findings shed light on the relationships between walkability and activity-travel behavior, we should also mention some limitations of this study. Firstly, since we used cross-sectional data we cannot account for possible residential self-selection. Residential self-selection means that people who prefer to walk may choose to live in a neighborhood that allows them to walk. Due to selection effects causal interpretation of the relationships found is problematic: the causal direction is reversed when the preference to walk already existed before one lived in the neighborhood. In a recent study, Ettema and Nieuwenhuis empirically tested the relationship between people's preference for travel mode and residential location choice, to assess the extent to which residential self-selection plays a role. Based on a survey among households who had recently moved, they found only a weak relationship between travel attitude and residential location choice. They conclude that "the association between travel attitude and travel as a factor in location choice is moderate at best".

This evidence suggests that, at least in the Dutch context, residential self-selection plays only a minor role as factor in explaining travel mode choice. Nevertheless, establishing the direction of causal relationships is important when the purpose is to predict the effects of interventions in the built environment for example to improve walkability. To quantify the (pure) built environment effects propensity-scoring or sample selection methods could be used, as reviewed in Mokhtarian and Van Herick (Mokhtarian & van Herick, 2016). Furthermore, the collection of longitudinal data that enables one to determine the time order in which changes in behavior and changes in built environment occur would offer a more fundamental basis to identify causality.

The purpose of the present study was to analyze the relationships between walking behavior and walkability using path analysis. For future research it is interesting to use either one of these approaches to increase insight in the causal directions of the relationships assumed in the path model.

Secondly, the assumption that walkability can be identified as the residual term of a regression model that predicts walking frequency based on socio-demographic variables, which was used in this study, is valid to the extent that the socio-demographic variables included effectively capture differences unrelated to physical characteristics (walkability). Therefore, care was taken to include a complete set of relevant socio-demographic variables to make sure that the influence of differences in population characteristics between neighborhoods is eliminated. However, when a collective preference of individuals within a neighborhood exists that is not related to walkability variables and neither to socio-demographics then the value of the estimated fixed effect will over- or underestimate walkability. For example, a culture pro or con walking may have emerged in a neighborhood that can neither be explained by observed population variables and neither be attributed to walkability characteristics of the neighborhood. This introduces a source of measurement error - in some cases overestimating walkability and other cases underestimating it. For future research it is worthwhile to collect in addition to socio-demographic data also data on attitudes on walking preferences. Attitudes will be correlated to socio-demographics as well as to physical (walkability) characteristics, but a remaining part of variation will exist that make correction for unobserved variables possible and increase the power of the analysis. The attitudinal data will at the same time provide a means to account for residential self-selection in the analysis.

Thirdly, we do not see an association or only a small association between walkability and outdoor activities. Hence, it is interesting to further investigate the relationship between walkability and outdoor activities in the future. Addressing these issues will increase our understanding of walkability and ways to design neighborhoods and plan daily urban systems to stimulate walking.

PART 2

WALKABILITY (PERCEIVED) AND WALKING BEHAVIOR

CHAPTER 4

THE ROLE OF RESIDENTIAL LOCATION CHOICE AND WALKING ATTITUDE IN THE RELATIONSHIP BETWEEN WALKABILITY AND WALKING BEHAVIOR

This chapter is based on:

Liao, B.*, van den Berg, P. E. W., van Wesemael, P. J. V. & Arentze, T. A. (2021).
The role of residential location choice and walking attitude in the relationship between walkability and walking behavior, Under review

4.1 Introduction

As high walkability is related to more walking and thereby to a more active healthy lifestyle of residents (Villanueva et al., 2014), walkability is becoming a more important concept in neighborhood planning and design (Yin et al., 2020; Zhang et al., 2020). Empirical research has shown how neighborhood characteristics influence walkability, and further offers evidence that walking behavior is affected by the way people perceive the walkability (Sung & Lee, 2015).

Existing research has established correlations between neighborhood characteristics and walking behavior (Cao et al., 2007; Owen et al., 2007), and correlations between neighborhood walkability and walking behavior (Cerin et al., 2007; McCormack et al., 2008). However, correlation does not necessarily mean causality. Specifically, many studies provide evidence that residential self-selection has influence on the relationship between neighborhood characteristics and walking behavior (Cao et al., 2014; Cao, 2010; Cao et al., 2006; Cao et al., 2007; Cao et al., 2009; Handy et al., 2006; Owen et al., 2007; Yu & Zhu, 2015). In this context, residential self-selection indicates that people who enjoy walking may choose to live in a location that encourages them to walk (Cao et al., 2006, 2007). Establishing the relationships between self-selection, neighborhood walkability, and walking behavior is important when it comes to predicting the influence of neighborhood environment on walking behavior. Furthermore, measuring walking attitude is a common way to control for the effects of residential self-selection on walkability based on the reasoning that walking attitude is a more stable personal characteristic that may influence residential location choice (Yu & Zhu, 2016). However, since, to the best of our understanding, there are no reports that directly controlled residential self-selection, it is not clear what exactly the relationships are between residential location choice, walking attitude, neighborhood walkability, and walking behavior.

The goal of this study is to explain the relationships between these variables, in order to gain a better understanding of association between walkability and walking behavior. Data is collected based on an online survey among a large sample of residents in the Netherlands to measure the variables of interest including walkability reasons for residential location and walking attitude. A structural equation model is then used to measure the constructs and estimate the relationships in an integrated way.

The rest of this chapter is structured as follows. In the Section 4.2, we review the literature on the relationships between neighborhood walkability and walking behavior, and the relationships between self-selection and walking behavior. The hypotheses and the conceptual framework that is the basis for the structural equation model are also outlined in this section. The third section explains data collection and analysis methods. Section 4.4 presents result of the analysis and discussion. In the 4.5 section, we highlight some key findings and policy implications for neighborhood design.

4.2 Literature review

This section briefly reviews the literature on the association between walkability, self-selection, and walking behavior separately. Based on the review, we then introduce our hypotheses and causal model.

4.2.1 The relationship between walkability and walking behavior

A positive correlation between neighborhood walkability and walking behavior has been documented in many empirical studies (Lawrence D Frank, 2010). Owen et al. (2007) indicated that (perceived) walkability and walking for transport were positively associated. Similarly, Van Dyck et al. (2012) and Sundquist et al., (2011) reported a positive link between neighborhood walkability and transport-related walking. In addition to walking for transport, neighborhood walkability is also related to walking for recreation. McCormack et al. (2008) found that neighborhood walkability attributes were associated with walking for recreation. Also, Rosenberg et al. (2009) pointed out that walking trips of teenagers were related to neighborhood walkability in American neighborhoods. Villanueva et al. (2014) indicated that walkability had effect on the recreational walking of older adults, even at the larger neighborhoods.

4.2.2 The relationship between residential self-selection and walking behavior

Existing research has provided empirical evidence for the effects of residential self-selection on walking activity in the neighborhood environment. Cao et al. (2006) and Handy et al. (2006) explained the effects of self-selection on walking behavior, namely that individuals who like to walk may deliberately choose to live in a location where they can benefit from walking, and thus walk more. Later, Owen et al. (2007) confirmed in a study that residential self-selection is significantly related to walking for transport. Other similar studies, including Rhodes et al. (2007), Cao et al. (2009), Norman et al. (2013), Schoner & Cao (2014), Van Dyck et al. (2011), and Yu & Zhu (2015), used questionnaires to quantitatively examine the influence of residential self-selection of individuals on walking behavior, and found correlations between self-selection, walking for transport, recreation and exercise. However, these studies used walking attitude as a proxy and did not measure self-selection explicitly. In other studies, that did include walkability reasons for residential location as a variable, walking attitude as a possible explanatory variable for both self-selection and walking behavior was left out of consideration. Therefore, existing studies did not explain the relationships between (walkability reasons for) residential location choice, walking attitude, neighborhood walkability, and walking behavior in an integrated fashion.

The short review of current studies indicates that perceived walkability and self-selection play important roles in walking behavior. While the relations between them have been addressed, it is still not clear to what extent walkability reasons for location and walking attitude influence walking behavior and what their separate contributions are. Therefore, two relevant research questions have not been addressed, namely: (1) To what extent is walkability of the neighborhood where one lives the consequence of residential location choice? (2) What is the relative importance of walkability compared to walking attitude in determining walking behavior? Insights in these questions help us to understand the association between walkability and walking behavior better. Therefore, the objective of this study is to clarify the relationships between walking reasons for location, walking attitude, walkability, and walking behavior in a more comprehensive model.

4.2.3 Hypotheses and causal model

We propose a causal model as the basis for a structural equation model (SEM) to test the assumed relationships and answer the research questions, as shown in Figure 4.1. In the model, walking attitude has a direct association with both walkability reasons for location (a walking-oriented person chooses to live in a location with high walkability) and walking behavior (given the walkability of the location, a walking-oriented person will walk more often), walkability reasons for location has a direct association with walkability (a logical relationship implied by the meaning of self-selection), and walkability has a direct association with walking behavior. Thus, according to this model, walking reasons for location at least partly explains differences in walkability at the place where one lives and, with that, differences in walking behavior. More formally, we formulate the hypotheses that can be tested as follows:

Hypothesis 1 (H1). *Walkability reasons for location partly explains variance in walkability.*

Hypothesis 2 (H2). *There is a relationship between walking attitude and walking behavior after controlling for walkability.*

The findings of this research could provide deeper insights into the relationships between walkability, residential location choice, walking attitude, and walking behavior.

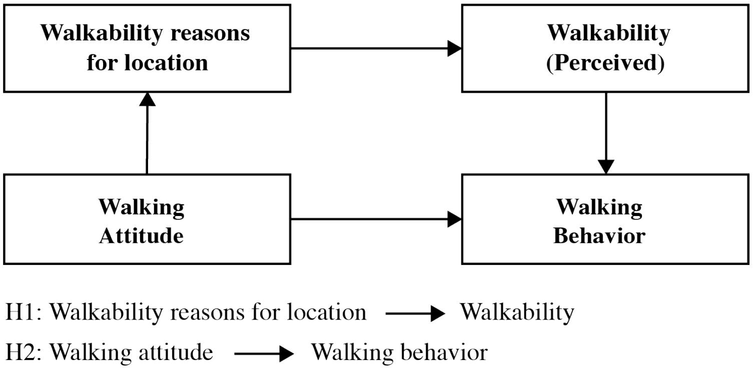


Figure 4.1 A causal model of walkability reasons for location, walking attitude, walkability, and walking behavior

4.3 Methodology

This section introduces the approach used to collect and analyze the data. As shown in Figure 4.1, we hypothesize that walkability reasons for location has an influence on walkability and walking attitude has an influence on walking behavior. Therefore, we use structural equation modelling (SEM) to test our hypotheses. In the SEM model, we consider walking reasons for location, walking attitude, and walkability as latent constructs, and use different measurement items to measure each latent construct in the model. For walking behavior, we distinguish two types of walking trips, namely walk for transport and walk for recreation. In the model, the socio-demographic characteristics are included as control variables to identify the separate influence of walking attitude on different types of walking behavior.

4.3.1 Data and variables

In this research, we collect subjective data to examine the associations between walkability (as perceived), walking reasons for location, walking attitude, and walking behavior, as described in the proposed model. For this, we designed an online survey. The survey focuses on how respondents perceive their neighborhood (defined as the area within approximately one kilometer of their home or that they could walk to in 10 minutes). To measure the perceived walkability, 11 sub-set items from the Neighborhood Environment Walkability Scale (NEWS) (Cerin et al., 2006), a worldwide assessment tool to measure the walkability, are used. To measure walking attitude, we use two items, as follows: (1) "I like walking"; and (2) "If possible, I rather walk than drive". Each item uses a 5-point Likert scale that varies from strongly disagree to strongly agree. To measure walkability reasons for location, we asked to what extent the following factors had affected the person's choice where they live: (1) "There are shops within walking distance"; (2) "There are schools within walking distance"; and (3) "The residential environment is pedestrian friendly". Each item uses a 5-point Likert scale that varies from "not at all" to "very much". The questions related to walking behavior are about the walking frequency of respondents, as follows: (1) "How often do you walk for transport?"; and (2) "How often do you walk for recreation, health or fitness?". The respondents had to indicate each question on a 7-point scale ranging from "never" to "almost everyday".

Moreover, empirical research indicates that socio-demographic characteristics have direct relationships with walking behavior (walking frequency) (Liao et al., 2020). Cao et al. (2006), for instance, used socio-demographic characteristics as controlling variables to estimate the influence of walkability reasons for location on walking behavior, and Dewulf et al. (2012) also controlled socio-demographic characteristics to evaluate the relationship between walkability and walking behavior. Therefore, we use socio-demographic characteristics as control variables only for walking behavior but not for residential self-selection variables and walkability in the data analysis. The socio-demographic variables considered include age, gender, education, work status, travel time for work, income, ethnic background, household type, dwelling type, and dwelling ownership, as shown in Table 4.1.

We recruited respondents from a national consumer panel in the Netherlands and through social media (Twitter, LinkedIn and Facebook). In total, 308 respondents completed the online survey, 272 from the consumer panel and 36 from social media. To ensure sufficient data quality, we removed respondents who provided the same ratings to each question. After data cleaning, 295 respondents remained for the analysis.

4.3.2 Analysis approach

To estimate the relationships in the SEM model, the first step is to confirm the measurement of the latent constructs in the SEM model. It follows from the foregoing, that the model uses 11 walkability items to indicate the latent walkability (as perceived), 2 items to measure walking attitude and 3 items to measure walkability reasons for location in the SEM model. Table 4.2 shows the descriptive analysis for the measurement variables.

We do a confirmatory factor analysis to generate the latent variables and test whether measured items and data fit a hypothesized measurement model (Kline, 2015). Then, the reliability of the measurement item of each latent variable (walkability, walking attitude, and walkability reasons for location) has been tested by the Cronbach's alpha analysis. A Cronbach's alpha > 0.70 is considered an acceptable reliability (George & Mallery, 2003). For the SEM model as a whole, various measures of goodness of fit of the estimated model are used. These include the Goodness-of-Fit Index (GFI), the Root Mean Square Error of Approximation (RMSEA), and the Standardized Root Mean Squared Residual (SRMR) (Cerin et al., 2008; Kline, 2015). Acceptable model fit values are > 0.90 for GFI, and < 0.08 for both RMSEA and SRMR (Jun & Hur, 2015).

Table 4.1 Socio-demographic characteristics of the respondents

Variables	Levels	
Age (years)	/	43.64 (years)
Gender	Male	44.4%
	Female	55.6%
Education	Primary	2.70%
	Medium	45.1%
	High (BSc or higher)	52.2%
Work status	Full time work	39.7%
	Part-time work (high, 21-37 hours)	22.7%
	Part time work (low, 1-21 hours)	8.80%
	No paid work	28.8%
Travel time for work	Short commute time	46.8%
	Medium commute time	19.6%
	Long commute time	5.10%
	Others	28.5%
Gross income (per year)	Low income level	24.7%
	Middle income level	36.3%
	High income level	26.1%
	Others (I don't want to answer)	12.9%
Ethnic background	Dutch	94.9%
	Non-Dutch	5.10%
Household type	Single	24.1%
	Couple without child(ren)	34.6%
	Family with Children	30.8%
	Others	10.5%
Dwelling type	Detached house	15.6%
	Semidetached or terraced house	54.3%
	Apartment	25.4%
	Others	4.70%
House owner situation	Own dwelling	66.8%
	Rent dwelling	33.2%
	N = 295 respondents	

Table 4.2 The descriptive analysis of measured items and variables for the SEM analysis

	Mean	Sd	Min	Max
Walking behavior				
Walk for transport	5.15	1.79	1.00	7.00
Walk for recreation	5.41	1.73	1.00	7.00
Walkability items				
Shopping in local stores	3.98	0.93	1.00	5.00
Walk to transit stop	3.97	2.96	1.00	5.00
Stores are within walking distance	3.81	1.15	1.00	5.00
Sidewalks are well maintained	3.67	0.88	1.00	5.00
Safe to walk in neighborhood	4.05	0.71	1.00	5.00
Many interesting things to look at	3.52	0.94	1.00	5.00
Speed of traffic is slow	3.39	0.89	1.00	5.00
Neighborhood is well lit at night	3.86	0.69	1.00	5.00
Seeing and speaking to other people	3.51	0.93	1.00	5.00
Attractive buildings/homes	3.04	0.98	1.00	5.00
Neighborhoods are understandable and recognizable	3.75	0.81	1.00	5.00
Walkability reasons for location items				
Walking distance to shops	3.03	1.40	1.00	5.00
Walking distance to schools	2.51	1.50	1.00	5.00
Environment is pedestrian friendly	3.12	1.31	1.00	5.00
Walking attitudes items				
I like walking	3.91	0.83	1.00	5.00
I rather walk than drive	3.49	0.98	1.00	5.00
	N = 295 respondents			

4.4 Results and discussion

In this section, we present the results of the confirmatory factor analysis (CFA), Crobanch's alpha analysis, and estimation of the structural equation model (SEM). The results of latent variables are shown in Table 4.3-4.4, the estimation results of the SEM model are shown in Figure 4.2 and Table 4.5-4.6.

4.4.1 The results of the structural equation modeling

Table 4.3 shows the results of the Cronbach's alpha analysis for three latent variables. All measurement items of Cronbach's alpha values are larger than 0.70, which indicates a reliable measurement for each latent variable (George & Mallery, 2003). As for goodness of fit of the SEM model (Table 4.5), the RMSEA is 0.077 and the SRMR is 0.079, which indicates that the model fit is sufficient. A GFI of 0.914 also indicates a good model fit. Figure 4.2 shows the estimated measurement and path coefficients of the SEM model. Since socio-demographic characteristics are control variables for walking behavior and consist of many items, the estimated values on that level are not shown for clarity of presentation. The latter relationships are shown in Table 4.5.

Table 4.4 shows the relationships between latent variables and measurement items. For the latent variable walkability reasons for location, the item “Environment is pedestrian friendly” has the largest coefficient while the item “Walking distance to schools” has the smallest coefficient, with values of 0.84 and 0.48 respectively. For the latent variable walking attitude, the item “I like walking” (0.83) has a larger value than the item “I rather walk than drive” (0.64). For the latent variable walkability (perceived), the item “Safe to walk in neighborhood”, the item “Sidewalks are well maintained”, and the item “Neighborhood is well lit at night” appear to be stronger indictors than other items, with estimated values of 0.65, 0.63, and 0.57 respectively. This indicates that walking safety is particularly important for (perceived) walkability in neighborhoods. The item “Seeing and speaking to other people” appears to be a weaker indicator than other items (0.17), which means that the meaning of social interaction with other people for perceived walkability is relatively weak.

The estimation results of the SEM model (Figure 4.2 and Table 4.5) show that, as expected, walking attitude has direct associations with walkability reasons for location, walking for transport, and walking for recreation; and that walkability has a direct association with walking for transport, but no direct relationship with walking for recreation. Looking at the sizes of the standardized coefficients, we see that walking attitude has relatively strong relationships with walking for transport and recreation with values of 0.50 and 0.59 respectively. This means that people who are more walking oriented are more likely to walk more for their transportation and recreation after controlling for walkability. Besides, walking attitude has a significant relationship with walking reasons for location (0.23). This indicates that people who are more walking oriented are more likely to choose a place to live that offers a walking friendly environment. These findings are partly in line with Handy et al. (2006), Schoner et al. (2014), and Van Dyck et al. (2011), who also found significant relationships between walking attitude and walking behavior.

For the indirect relationships in the SEM model (Table 4.5), the results indicate that the indirect relationship between walking attitude and walkability (via walkability reasons for location) is significant, which means that people who are more walking-oriented are more likely to choose an environment with high walkability to live. Moreover, the indirect relationships between walkability reasons for location and walking behavior (walk for transport via walkability) is very low (0.017). This means that the effect of individuals choosing to live in a place with high walkability on making walking trips for transportation more often is only very small (and practically not significant). In addition, socio-demographic characteristics have significant relationships with walking behavior. Individuals who have medium education level and do not own but rent the house use walking more often for transport, while individuals who have medium and high education level and couples without children use walking more often for recreation.

In conclusion, the assumed relationships in the causal model are supported by the results of the SEM estimation results —walking attitude has direct relationships with walkability reasons for location and walking behavior (both for transport and recreation), and walkability reasons for location has a direct relationship with walkability. Furthermore, walkability has a direct relationship with walking for transport.

Table 4.3 The Cronbach's alpha for measurement items of latent variables

	Cronbach's alpha
Walkability items	
Shopping in local stores	0.722
Walk to transit stop	0.730
Stores are within walking distance	0.727
Sidewalks are well maintained	0.721
Safe to walk in neighborhood	0.723
Many interesting things to look at	0.727
Speed of traffic is slow	0.731
Neighborhood is well lit at night	0.726
I can see and speak to other people	0.743
Attractive buildings/homes	0.723
My neighborhood is understandable and recognizable	0.735
Walkability reasons for location items	
Walking distance to shops	0.717
Walking distance to schools	0.744
Environment is pedestrian friendly	0.713

Walking attitudes items	
I like walking	0.728
I rather walk than drive	0.734

Table 4.4 Latent variables standardized estimates of the SEM model

To From	Walking attitudes	Walkability reasons for location	Perceived walkability
I like walking	0.833***		
I rather walk than drive	0.635***		
Walking distance to shops		0.612***	
Walking distance to schools		0.480***	
Environment is pedestrian friendly		0.839***	
Shopping in local stores			0.426***
Walk to transit stop			0.409***
Stores are within walking distance			0.373***
Sidewalks are well maintained			0.634***
Safe to walk in neighborhood			0.651***
Many interesting things to look at			0.344***
Speed of traffic is slow			0.414***
Neighborhood is well lit at night			0.565**
I can see and speak to other people			0.242***
Attractive buildings/homes			0.383***
My neighborhood is understandable and recognizable			0.330***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

Table 4.5 Regressions standardized estimates of the SEM model

To From	Walkability reasons for location	Walkability (perceived)	Walk for transport	Walk for recreation
Walkability (perceived)			0.172*	
Walking attitude	0.325**		0.504***	0.591***
Walkability reasons for location		0.424***		
High education level				0.404**
Medium education level			0.338*	0.482**
Couple without children				0.152**

To From	Walkability reasons for location	Walkability (perceived)	Walk for transport	Walk for recreation
Dwelling is rented			0.151**	
Goodness of fit of the model:	GFI = 0.914; RMSEA = 0.077; SRMR = 0.079.			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

Table 4.6 Explained variances of main (independent) variables

To From	Walkability (perceived)	Walk for transport	Walk for recreation
Walkability reasons for location	18.1%		
Walkability (perceived)		13.8%	
Walking attitude		13.9%	28.0%

4.4.2 Discussion of results

The estimation results of the SEM model above, allow us to answer the research questions, i.e., (1) To what extent is walkability of the neighborhood where one lives the consequence of residential location choice? (2) What is the relative importance of walkability compared to walking attitude in determining walking behavior?

For the first question, the estimation results (see Table 4.6) indicate that walkability reasons for location explains around 18.1% of the variance in walkability. This indicates that in line with hypothesis 1 that differences in walkability are only partly explained by walkability reasons for location.

Regarding the second question, the estimation results (see Table 4.6) indicate that walkability can explain around 13.8 % of the variance in walk for transport and nothing of the variance in walk for recreation. In comparison, walking attitude explains a larger part of the variance in walking behavior, i.e., around 13.9% of the variance in walk for transport, and around 28% of the variance in walk for recreation (the direct associations with walking attitude). Hypothesis H2, stating that walking attitude has effect on walking behavior after controlling for walkability is supported by these analysis results and walking attitude appears to play a more important role than walkability in explaining differences in walking behavior. This supports the idea of Cao et al. (2009) who indicated that a walking-oriented citizen in a walking friendly place will walk more.

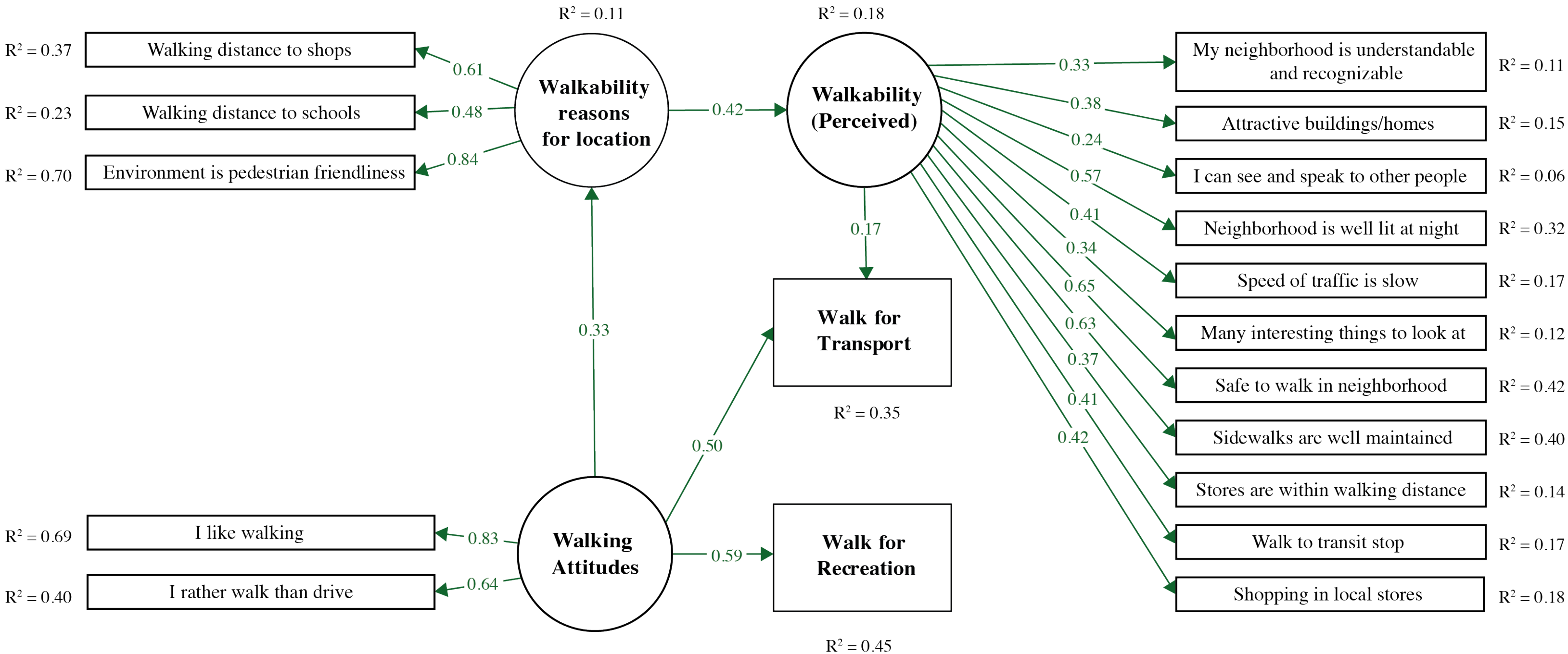


Figure 4.2 Significant relationship between walkability reasons for location, walking attitudes, walkability, and walking behavior in the SEM model

4.5 Conclusion

This chapter examined the role of walkability reasons for residential location and walking attitude in the establishment of the relationship between walkability and walking behavior. To estimate the separate effects of walkability reasons for location and walking attitude, we controlled for the relationships between socio-demographic variables and other person characteristics on walking behavior. Based on data from an online survey, a structural equation model was estimated to measure the strength and direction of the relationships.

The findings point out that walking attitude has a direct relation with walking behavior (for transport and for recreation), and an indirect association with perceived walkability via walkability reasons for location. Walkability reasons for location only partly explains variance in walkability (a direct association with walkability). Looking at the size of explained variance of walking behavior, we find that walking attitude is a stronger predictor of walking behavior than walkability. Thereby, the role of walkability is confined to only walking for transportation (as opposed to walking for recreation). These findings indicate that walking-oriented persons more often choose to live in a high walkability neighborhood and, given the degree of walkability, also choose to walk more often. We conclude, therefore, that walking attitude is, as expected, an important predictor of walking behavior, but does not completely explain away the effects of walkability. Given the walking attitude, walkability does not have a relationship with walking for recreation but does have a relationship with walking for transportation. Among the indicators of walkability used, walking safety appears to be the most important item and social interaction (safety to walk in neighborhood) the least important.

For policy making, these findings imply that improvements of walkability primarily have an effect on walking behavior and, furthermore, that the effects will be confined to walking for transport. This holds for people's perception of walkability which is most strongly influenced by considerations of safety. Therefore, it will be useful to consider road safety (e.g., traffic speed limit), service facilities (e.g., shops, lighting, and landmarks), transportation facilities (e.g., bus stations) and walking facilities (e.g., good pavement and wider pedestrian size) in a walkable neighborhood design. In addition, it is also useful to consider stimulating walking attitude for a walkable neighborhood design, for example, starting from a young aged people by stimulating walking to school, maybe through gamification.

Although this chapter increased insights on the relationships between walkability reasons for residential location, walking attitude, walkability, and walking behavior, there are several limitations of this study that could be addressed in future research. Firstly, our analysis focused on the Netherlands. It would be interesting to reproduce this analysis by using data from other countries or areas. Secondly, we cannot explain whether a change in neighborhoods environment leads to a change in perception of people because of the cross-sectional data. Therefore, a stated preference experiment could be considered as an alternative approach. In that approach, individuals are asked to indicate their preference for hypothetical alternatives where neighborhood characteristics can be varied independently of each other so that the separate effects can be measured. Since walking behavior of residents involves direct, dynamic interaction with the physical environment, it is interesting to use new visualizing technologies to represent the neighborhood environment (e.g., virtual reality technology) in these experiments. Confirmative evidence through such alternative approaches would strengthen the external validity of the findings.

WALK ABILITY

PART 3

WALKABILITY (PERCEIVED) AND WALKING EXPERIENCE

CHAPTER 5
INDIVIDUALS' PERCEPTION OF WALKABILITY

--RESULTS OF A CONJOINT EXPERIMENT IN VIDEOS OF VIRTUAL ENVIRONMENTS

This chapter is based on:

Liao, B.*, van den Berg, P. E. W., van Wesemael, P. J. V. & Arentze, T. A. (2021). Individuals' perception of walkability: Results of a conjoint experiment in videos of virtual environments, Under review.

5.1 Introduction

Research on how physical activity and lifestyle are influenced by the built environment and social context has received increased attention in recent years. Previous studies have shown that the design of the built environment has a significant influence on the extent to which individuals walk (Koschinsky et al., 2017), which is an important element of the active lifestyle of people in the neighborhood (Liao et al., 2020). Empirical research further points out that walking behavior is affected by the way people perceive the walking environment (Koschinsky & Talen, 2015; Sung & Lee, 2015).

The majority of existing research uses subjective measurement to understand individuals' perception of walkability on the neighborhood level. In many cases, studies in this line of research use questionnaires where respondents are asked to rate various aspects of the walking environment of neighborhoods they live in by rating scales (Cerin et al., 2006). The conjoint experiment has also received attention as a method to identify effects of built-environment attributes on how people perceive walkability of neighborhoods (Kasraian et al., 2020). In a conjoint experiment, generally, respondents are asked to indicate their preferences in specific hypothetical situations. Commonly, these hypothetical situations are constructed based on attribute profiles that are varied by an experimental design. Traditionally, the attribute profiles are presented either verbally (text) or by using visualizations such as photos, and images. These are by definition static and are only rudimentary representations, which forces respondents to stretch their imagination, and thereby introduce inevitable imagination bias. Compared to these traditional methods of representation, a virtual reality environment could provide a more dynamic and integral impression of the environment and, hence, avoid this pitfall (Birenboim et al., 2019). The use of virtual reality technology in a conjoint experiment will help respondents to perceive the walkability in neighborhood environments more directly by experiencing it in a more integral and dynamic way. However, despite these potentials of VR, research on how to combine virtual reality technology with a conjoint experiment has until now received less attention.

The objective of the present study is, therefore, to design a conjoint experiment to measure individuals' perception of walkability using VR environment (videos of virtual environments) to simulate the neighborhood environments seen from the eye-level of pedestrians. Considering the level of scale, we use the street-block. The street block has been described as the fundamental and appropriate unit to map the urban structure (Bochow et al., 2010). Using the smaller scale level of the street-block then the neighborhood allows for the construction of a 3D model of the environment that provides sufficient spatial and social detail. The data of the conjoint experiment is collected through an online survey. This survey uses a dynamic VR video (pre-recorded) to visualize different street block designs from the viewpoint of a moving pedestrian. The set-up of the present study also aims to identify groups that differ with regard to their perception of walkability. The results should, thus, contribute to a better understanding of individuals' perception of walkability and the development of tools to connect design theory and design practice through for instance streetscape design guidelines.

The remainder of this chapter is structured as follows. The next section discusses the literature about the relationship between neighborhood characteristics and perceived walkability, and the use of virtual reality techniques in conjoint experiments. In Section 5.3, we explain the experimental design, the data collection, and analysis methods. The results of the analysis and discussion are presented in Section 5.4. In the 5.5 section, the key findings and policy implications are highlighted.

5.2 Literature review

5.2.1 The relationship between neighborhood characteristics and perceived walkability

Various assessment tools to understand how neighborhood characteristics affect the way people perceive the walkability of neighborhoods have been developed for empirical studies (Talen & Koschinsky, 2013). These include the Neighborhood Environment Walkability Scale (NEWS), NEWS-A (Simplified Version), NEWS-Y (Youth), International Physical Activity Questionnaire Environmental module (IPAQ-E), Active for Life, and Perceptions of Local Environment (Cerin et al., 2006; Foster et al., 2004; Hagströmer et al., 2006; Rosenberg et al., 2009; Spittaels et al., 2009, 2010; Wallmann et al., 2012). These tools are based on questionnaires asking subjects to rate characteristics of the built environment that are considered important for walkability. Items often recurring in the questionnaires used are: (a) residential density; (b) proximity to nonresidential land uses (land use mix-diversity); (c) ease of access to nonresidential uses (land use mix-access); (d) street connectivity; (e) walking/cycling facilities; (f) aesthetics; (g) pedestrian traffic safety; (h) crime safety; and (i) overall environment (Cerin et al., 2006; Foster et al., 2004; Hagströmer et al., 2006; Harrison et al., 2007; Inoue et al., 2009; Liao et al., 2020; Meusel et al., 2007; Rosenberg et al., 2009; Wang et al., 2019)..

Application of the different assessment tools in studies has led to mixed findings regarding the associations between built environment characteristics and perceived walkability. Rosenberg et al. (2009) examined the relationship between the neighbourhood environment and adolescents' perception of walkability in the US using NEWS-Y. Traffic safety, aesthetics, walking/cycling facilities, land use mix, and overall environment were found to be associated with perceived walkability. In China, Cerin et al. (2007, 2010, and 2013) used NEWS and NEWS-A to investigate effects of the built environment on perceived walkability of Hong Kong elderly. They found that two attributes (access to services and human and motorized traffic) were both significantly associated with the perceived walkability. Cerin et al. (2013) analysed the measurement results of NEWS and NEWS-A across twelve countries around the world. They found that land use mix, street connectivity, walking/cycling facilities, aesthetics, and safety have an influence on perception of people of walkability in all twelve countries.

In addition to NEWS, NWES-A, and NEWS-Y, also studies using IPAQ-E have contributed to a growing body of evidence in this area. Inoue et al. (2009) tested the reliability of IPAQ-E in Japan and found that for Japanese adults' residential density, access to shops, access to public transport, and presence of sidewalks are associated with perceived walkability. However, when used in Germany, the results from the IPAQ-E were different than in Japan. In Germany, the IPAQ-E was used by Wallmann et al. (2012) to explain the association between perceived walkability and walking environment. They observed positive associations between perceived walkability and good access to destinations, well-maintained sidewalks, higher residential density, and neighbourhood safety. Other environmental assessment tools, including Active for Life and Perceptions of Local Environment, have also been used to analyse the way people perceive the walkability. Foster et al. (2004) reported A4L investigation results in the United Kingdom, which indicated that street safety, public spaces, and green spaces contributed positively to perceived walkability. Results of the PLE survey in the United Kingdom pointed out that neighbourhood safety and access to leisure facilities had positive effects on the perceived walkability (Harrison et al., 2007).

In the studies reviewed above, divergence in findings originates from differences between the tools as well as the diversity of regions. However, some neighborhood characteristics were commonly found to contribute to perceived walkability, namely land use mix-diversity, safety, and walking facilities. Although these studies provide perspectives to better understand the interaction between neighborhood characteristics and perceived walkability, they all relied on revealed preference data making it hard to identify the separate effects of attributes because of the existence of strong correlations. Also, these studies did not involve and explain the relationship between emotions and walking experiences (perceived walkability). While empirical studies clearly have pointed out that the neighbourhood environment also influences emotions of individuals, colouring their individual perceptions of the walkability in neighbourhoods. For example, Ettema et al. (2015) found that in the Netherlands pedestrian experience of individuals was associated with sense of happiness. Furthermore, Birenboim (2018) indicated that sense of comfort and sense of security are associated with walking through experiences in urban environments. And, Resch et al. (2020) found relationships between the walkability and senses of stress and relaxation. Besides, a few studies have reported the association between walking experiences and sense of annoyance in neighborhood environments (Birenboim, 2018; Paunović et al., 2009; Ulrich et al., 1991).

A conjoint experiment to understand respondents’ subjective judgment of the neighborhood environment, where neighborhood characteristics can be varied independently, has therefore been considered as an alternative approach (stated preference data). In a conjoint experiment, respondents are asked to answer questions for hypothetical alternatives, which usually involves a choice, ranking, or rating task (Hensher et al., 2005). Recent studies that have used the conjoint experiment to analyze walkability or walking preferences of individuals are: Adkins et al., 2012; Borst et al., 2008; Kaparias et al., 2012; Kasraian et al., 2020; Kelly et al., 2011; Kim et al., 2011; Lusk et al., 2018; Perdomo et al., 2014. Specifically, these studies considered the relationship between the characteristics of a neighborhood or a street and how it is experienced by individuals who use it. Borst et al. (2008), Kaparias et al. (2012), Kasraian et al. (2020), Kelly et al. (2011), and Kim et al. (2011) found that pavement cleanliness, wider sidewalks, and good connectivity are generally preferred by individuals. Lusk et al. (2018) and Kasraian et al. (2020) found that, in addition, the presence of trees increases preference to walk. These studies show that a conjoint experiment is especially useful to get quantitative insight in the weighting of individual attributes in judgments of preference or perceived walkability. Furthermore, a conjoint experiment involves the experience of individuals and therefore could also be used to analyze the relationship between emotions and perceived walkability.

5.2.2 Virtual reality techniques in conjoint experiments

In a conjoint experiment, attributes of the alternatives are varied based on a statistical design such that the separate effects of the attributes can be determined by analyzing the choice or preference data. Normally, text is used to describe the attributes (Caulfield et al., 2012). For example, Brown et al. (2009) used textual representations in a stated preference survey to investigate walking preferences of older adults in the United States. However, textual representations cannot always adequately convey the essence and complexity of certain decision contexts (Verhoeven et al., 2017). To circumvent this problem, the use of visual representations such as photos and images to present hypothetical situations instead of textual representations has been proposed (Shr et al., 2019). For instance, Tilt (2010) presented photos in a conjoint experiment to investigate walking preferences. Although visual representation may help the respondent to create more vivid imaginations of a presented environment, it still only provides a static and often rudimentary impression of the environment the researcher intends to present (Shr et al., 2019a). Since the behavior of residents involves direct, dynamic interaction with the surrounding physical and social environment, Birenboim et al. (2019) pointed out that the incorporation of virtual reality (VR) techniques could result in greater external validity compared to traditional representation methods in choice experiments. The main merit of VR technology lies in its potential "to address the long-standing trade-off problem between mundane realism and experimental control that is encountered in many experiments on human perceptions and behaviors" (Birenboim et al., 2019).

Bishop et al. (2001) used VR techniques in a choice experiment to examine how respondents perceive a virtual landscape of a specific area. In the experiment, respondents were asked to use mouse actions to choose paths and watch viewpoints. Later, Bishop and Rohrma (2003) improved their approach by using dynamic 3D videos simulating a real outdoor environment via VR techniques in a conjoint experiment. Similarly, Kort et al. (2003) simulated an indoor environment and invited respondents to watch the VR environment (videos of virtual environments) in their laboratory. Perdomo et al. (2014) simulated a small real environment by representing 3D videos to investigate preferences of pedestrians. Rid et al. (2018) and Vliet et al. (2021) constructed virtual alternatives by augmented-reality 3D rendering techniques and allowed respondents to watch and choose their virtual environment in an online survey. Similar to Perdomo et al. (2014), Kasraian et al. (2020) investigated pedestrians' perceptions of walkability by using a dynamic 3D representation (videos of virtual environments) of various hypothetical street designs in Toronto.

Furthermore, several studies focused on how to present immersive virtual reality of the built environment to respondents via new equipment. For example, VR glasses, which is a head-mounted device that provides immersive virtual reality for the wearer, allows one to dynamically display the built environment that enables a direct coupling between the respondents' motor actions and the simulation (Birenboim et al., 2019). Studying environmental preferences, Maffei et al. (2016), Higuera-Trujillo et al. (2017), Farooq et al. (2018), Abd-Alhamid et al. (2019), Atwa et al. (2019), Birenboim et al. (2019), Gao et al. (2019), and Zhu et al. (2020) have also applied VR glasses in conjoint experiments. Furthermore, Birenboim et al. (2019) and Zhu et al. (2020) compared the participants' stated preferences under immersive virtual reality and conventional representations. In their experiments, they asked respondents both to use a VR headset and to watch traditional representations (images) on a computer screen. Maffei et al. (2016), Higuera-Trujillo et al. (2017), Abd-Alhamid et al. (2019), and Gao et al. (2019) simulated real environments in the laboratory and used VR headsets to present them. Then they recorded preferences of respondents when environmental elements of the VR environments were changed.

To summarize, in the conjoint experiments, the reviewed studies include two modes of representation of virtual reality environments: (1) videos of virtual environments (watching videos to experience the virtual environments), and (2) more immersive VR (using VR glasses to experience the virtual environments). These two representation modes are based on 3D models (using software such as Unity, SketchUp, and Twinmotion) to simulate environments realistically, and then ask respondents to experience them using different modes. Therefore, both methods rely on virtual reality technologies, but apply different modes of representation. In the immersive VR mode, respondents can access virtual reality environments immersive with VR glasses and create watching routes by themselves. But this mode has as a downside that it limits the feasible sample size, as individuals have to come to the laboratory to experience the immersive virtual reality. Compared to the immersive VR mode, the video of virtual environment mode fixes the watching route and cannot provide full immersive experience to respondents. On the other hand, the video-based mode allows the use of a large sample size as it can be implemented in an on-line survey and does not require special equipment from the respondent to engage in the experiment. For example, Kasraian et al. (2020) collected data of 600 respondents via an online survey, which is a much larger sample than can be achieved in studies using the immersive VR mode to collect data in the laboratory (less than 100 participants regularly). Table 5.1 provides an overview of the virtual reality techniques in the conjoint experiments reviewed in this section.

It follows from this brief review that a conjoint experiment combined with VR technology to analyze perceived walkability has received only limited attention. Furthermore, a full-fledged experimental design would allow the identification of weights of individual attributes, but only a few reviewed studies considered an orthogonal design or a full factorial design in their experiment, as shown in Table 5.1. In the present study, the aim, therefore, is to combine a full-fledged experimental design (orthogonal design) with virtual reality environment (videos of virtual environments in multiple scenarios) to analyze perceived walkability in a more rigorous way. In this study, we use videos of virtual environments to present the virtual reality environments. Given our goal to identify groups that differ in these perceptions, we aim at a large sample and, therefore, use an online survey to collect data. A potential downside of using VR or, more generally, visual representations of alternatives in a conjoint experiment should also be mentioned, which is that arbitrary elements in a visualization may have an influence on how an alternative is perceived and evaluated. We tried to circumvent this potential problem in two ways: (1) we use street-block designs that are representative of the situation in the Netherlands in which the experiment is conducted, and (2) we use abstract representations and exclude as much as possible arbitrary details.

5.3 Methodology

In this section, we introduce the method to design a conjoint experiment using virtual reality environment in this study. We also introduce the approach used to collect and analyze the data.

5.3.1 Design of the experiment

The design process of our conjoint experiment using virtual reality environment includes three steps, as follows: (1) define attributes and attributes levels, (2) design the virtual reality environment, and (3) design the on-line questionnaire.

Table 5.1 Virtual reality techniques in the conjoint experiments (chronological order)

Authors	Environments	Representation ways	Views	Tools/Software	Experimental places	Choices/ Scenarios	Statistic design	Sample sizes
Bishop et al. (2001)	River valley landscape	2D maps; 3D Static images	Eye-level pedestrians	UNIX; IRIS	Laboratory	3 choices	/	25 participants
Bishop & Rohrma (2003)	Suburban area	3D video	Oblique aerial view	Alias/Wavefront Advanced Visu-alizer	Real environ-ment; Laboratory	2 scenarios	/	10 groups
Kort et al. (2003)	L-shape indoor space	3D navigation	Eye-level pedestrians	dvMockup	Laboratory	4 scenarios	/	101 participants
Perdomo et al. (2014)	Pedestrian zone	3D video	Oblique aerial view	PTV VISSIM	Online	2 scenarios	/	501 participants
Maffei et al. (2016)	Limited traffic zone	VR headset	Eye-level pedestrians	SketchUp pro; Worldviz Vizard v4.0	Laboratory	2 scenarios	/	32 participants
Higuera-Trujillo et al. (2017)	Shop indoor	Photos; VR headset	Eye-level pedestrians; Oblique aerial view	Unity; SketchUp 2015; Panoramic real photos	Laboratory	1 scenario	/	100 participants
Farooq et al. (2018)	Autonomous vehicles on urban roads	VR headset	Eye-level pedestrians	Unity	Laboratory	2 scenarios	/	42 participants
Rid et al. (2018)	Neighbourhood housing	3D video	Oblique aerial view	3D Studio Max; Dreamweaver 8.0	Online survey	18 choices	Full factorial design	402 participants
Abd-Alhamid et al. (2019)	Panoramic indoor	VR headset	Eye-level pedestrians	Panoramic real photos	Laboratory	2 scenarios	/	20 participants

Authors	Environments	Representation ways	Views	Tools/Software	Experimental places	Choices/ Scenarios	Statistic design	Sample sizes
Atwa et al. (2019)	Green business park	VR headset	Oblique aerial view	Auto CAD; SketchUp	Laboratory	3 scenarios	/	28 participants
Birenboim et al. (2019)	Cycling environment	VR headset	Eye-level cycling	3D Studio Max	Laboratory	8 scenarios	Full factorial design	86 participants
Gao et al. (2019)	Green parks	Photos; VR headset	Eye-level pedestrians	Panoramic real photos	Laboratory	9 scenarios	/	179 participants
Kasraian et al. (2020)	Street segments	3D video	Eye-level pedestrians	Unity	Online survey	3 scenarios	Full factorial design	600 participants
Zhu et al. (2020)	Real world street	VR headset	Eye-level pedestrians	Sketch Up pro; Unity	Laboratory	14 choices	Orthogonal design	48 participants
Vliet et al. (2021)	Green parks	3D video	Eye-level pedestrians	Twinmotion	Online survey	16 alternatives	Orthogonal design	697 participants

The first step is to define the attributes and attribute levels of the choice alternatives used in the experiment. Existing empirical research has already identified the neighborhood characteristics that have an influence on walking behavior (Sallis, 2009). For the present experiment, we use the street-block as spatial scale level. Because a street block is part of a neighborhood, street block characteristics are similar to neighborhood characteristics regarding their effects on walking behavior. Compared with the neighborhood, the street block has a smaller size that is suitable to generate detailed 3D models in the VR environment and that allows respondents to perceive features of the built environment more directly within short walkable distances.

As for the selection of attributes, as reviewed in Section 5.2, land use mix-diversity, walking facilities, sidewalks, and trees are important factors influencing walking behavior. Besides, in earlier work, we found that connectivity and open space are significantly associated with walking behavior in the Netherlands. Therefore, for the experiment we select the above mentioned five characteristics of neighborhoods as street block design attributes. To limit the size of the experimental design, we considered two levels for each attribute to create alternatives, as follows: (1) land use mix has the levels only residential area and residential mixed with commercial area, (2) block connectivity has the levels high and low connectivity (number of intersection points), (3) road size the levels two lanes with narrow pedestrian zone and one lane with wide pedestrian zone, (4) open space the levels does and does not have open space in the block, and (5) green has the levels does have and does not have trees in the block. Table 5.2 shows an overview of the attributes and the levels of the attributes that were varied.

Table 5.2 Attributes and levels of the attributes

Attributes	Levels
Land use mix	(1) Residential land-use
	(2) Mixed with commercial area
Block connectivity	(1) High connectivity
	(2) Low connectivity
***Road siz*e**	(1) Two lanes with narrow pedestrian zone
	(2) One lane with wide pedestrian zone
***Open spa*ce**	(1) Has open space in the block
	(2) Does not have open space in the block
***Gre*en**	(1) Has trees in the block
	(2) Does not have trees in the block

Given this specification, 32 (2^5) combinations of attributes are possible. However, it is possible to reduce the number of combinations and still avoid any correlations between attributes. The number of combinations is reduced by taking a fraction of a full-factorial design that has the known properties of preserving orthogonality and allows us to estimate the main effects of the attributes. Orthogonality is a mathematical constraint requiring that all attributes are statistically independent of one another so that their effects can be identified through statistical analysis (Hensher et al., 2005). In this case, the full factorial design can be reduced to an orthogonal design consisting of eight attribute profiles (combinations of attribute levels). This orthogonal fraction of the full-factorial design allows us to identify the main effects of the attributes (and main effects only) and is shown in Table 5.3.

In the next step, the eight combinations were converted to eight virtual reality environments. We built a typical Dutch street block as a basic 3D model in SketchUp Pro 2019. In the street block, the experiment area is 300 meters in length and 240 meters in width. The eight 3D sketch models correspond to the attribute profiles of the orthogonal design, as shown in Figure 5.1. Keeping the road width constant, we varied the type of road: (1) two lanes for cars with a narrow size of the pedestrian sidewalk, and (2) one lane for cars with wide space for pedestrians, as shown in Figure 5.2. For the land use mix attribute, we created an all-residential street block as the first level, and mixed with some commercial buildings (e.g., shops and supermarket) in the middle of the residential area to create the second level. For the connectivity attribute, we varied the number of intersection points in the street block. As for open space, we varied between presence and absence of open space. Regarding green, we varied the presence of street trees. Based on the 3D sketch models and different levels of the attributes, we generated eight virtual reality environments, which were then all eight imported to the Twinmotion 2019 (Epic Games, 2019) — a quick real 3D rendering software. In Twinmotion 2019, we added materials, trees, traffic, facilities, and people to all 3D sketch models, as shown in Table 5.4.

Next, we set a walking perspective and exported all virtual reality environment as movies. To keep consistency, all movies of virtual reality environment had the same walking route, watching direction, geographical location, sunlight time, and weather. The length of each video is 1 minute and 30 seconds.

The questionnaire is designed into two parts. The first part is about the individual's perception of his/her existing neighborhood and personal characteristics, and the second part contains the virtual reality environment consisting of movies and related questions to retrieve perceptions of the virtual reality environments. The questionnaire in the virtual reality environments part is about how the participant experiences the virtual reality environments when he or she walks through the virtual environment. Considering the length of the questionnaire, we randomly show 4 out of 8 dynamic 3D videos of the virtual reality environment to each respondent. We use two sections to ask participants about their perception of each virtual reality environment. The first section includes two questions about the quality of the environment, as follows: (1) "How satisfied are you with the overall quality of this virtual environment?"; and (2) "How satisfied are you with the walking friendliness of this virtual environment?". Each question uses a 7-point Likert scale ranging from not at all satisfied to fully satisfied. The questions of the second section are about the emotions the virtual environment evoked. Four dimensions of emotions were associated with the perceived walkability (walking through experience), as follows: happiness, comfort, annoyance, and security. Hereby, we ask participants to indicate to what extent they experienced each of these four emotions. The questions are framed as statements, namely "I felt happy / comfortable / annoyed / secure", and for each item the respondent answered on a 7-point Likert scale ranging from completely disagree (1) to completely agree (7), as shown in Table 5.5. The second section includes questions concerning the benefits that are perceived from the virtual environment.

5.3.2 Data collection and analysis approach

Respondents are recruited from a national consumer panel in the Netherlands and through social media (Twitter, LinkedIn and Facebook). For the virtual reality environments, we introduced to respondents that scenarios are presented of a neighborhood in virtual reality that represent a typical Dutch street block (pre-recorded videos). Then we asked respondents to indicate the overall quality of virtual scenarios, the walking friendliness of virtual scenarios, and how they are feeling about the virtual scenarios when they watch the scenarios. In total 308 persons completed the on-line questionnaire, 272 from the consumer panel, and 36 from social media. To ensure sufficient data quality, respondents who provided the same answer to each question or took less than 8 minutes for the VR part were removed. After data cleaning, 295 respondents remained in the sample. All respondents watched 4 videos (3D-videos) so that 1180 ratings on each item were recorded for the analysis. The socio-demographic characteristics of the sample are shown in Table 5.6.

Table 5.3 An orthogonal design of eight attribute profiles

		Profile 1	*Profile 2*	*Profile 3*	*Profile 4*	*Profile 5*	*Profile 6*	*Profile 7*	*Profile 8*
Land use mix	Residential land-use	*	*	*	*				
	Mixed with commercial area					*	*	*	*
Block connectivity	High connectivity	*	*			*	*		
	Low connectivity			*	*			*	*
Road size	Two lanes with narrow pedestrian zone	*	*					*	*
	One lane with wide pedestrian zone			*	*	*	*		
Open space	Has open space in the block	*		*		*		*	
	Does not have open space in the block		*		*		*		*
Green	Has trees in the block	*			*		*	*	
	Does not have trees in the block		*	*		*			*

* note that the combination includes the attribute level

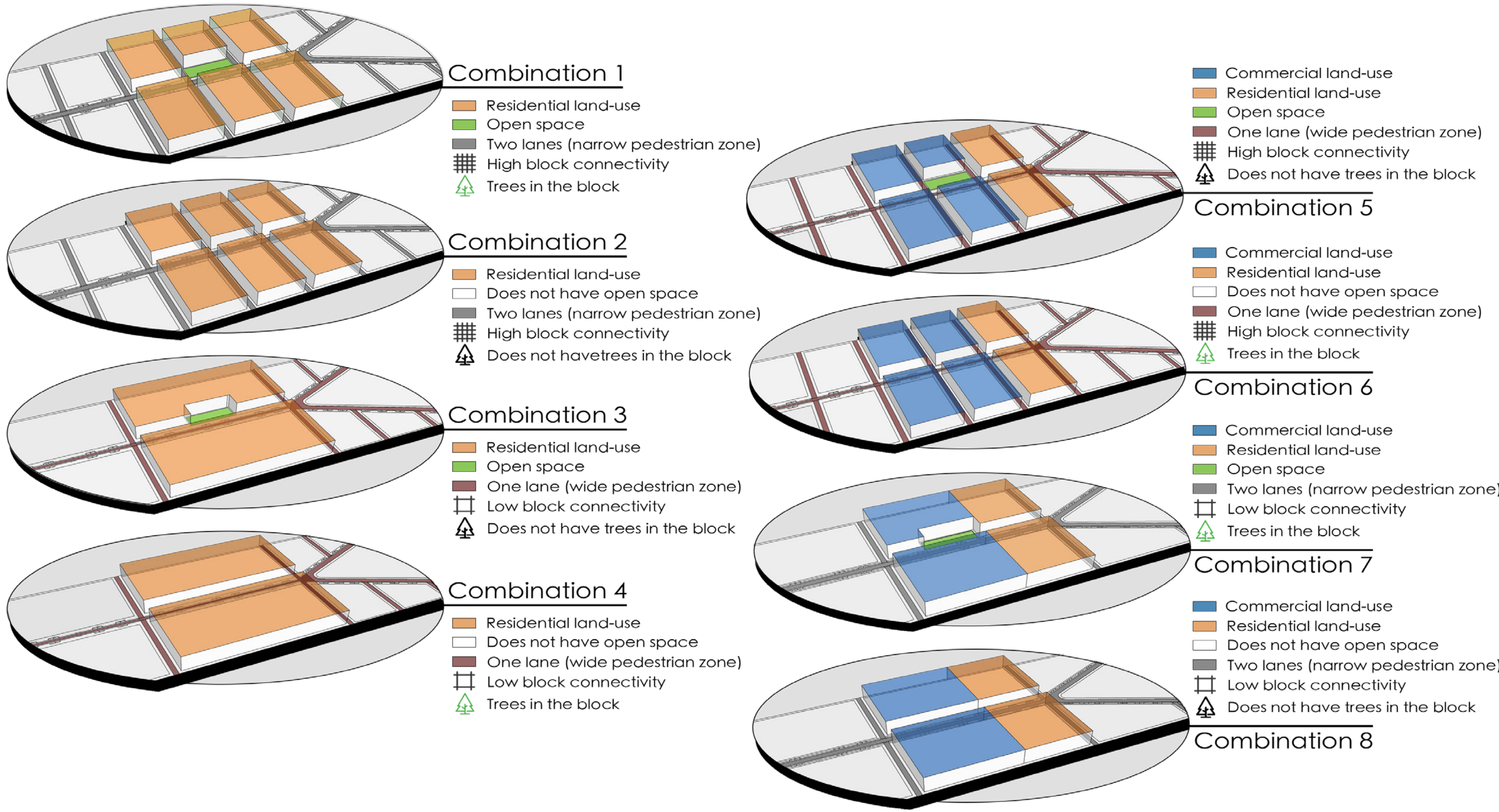


Figure 5.1 The design combinations of street block

a. Two lanes with narrow pedestrian zone

b. One lane with wide pedestrian zone

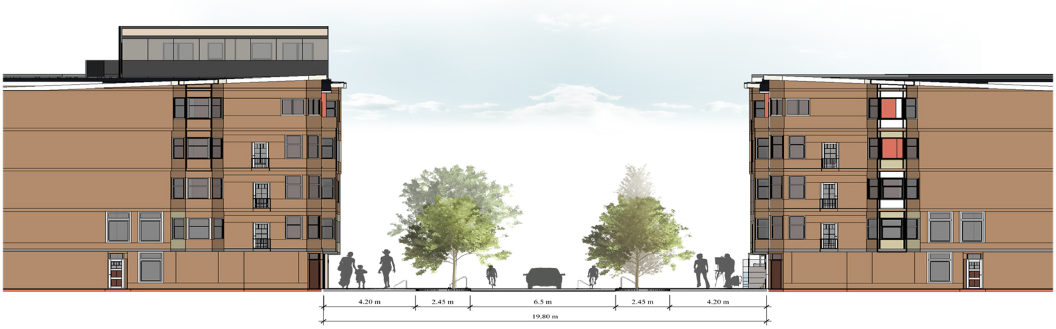


Figure 5.2 The design road size of street block

Table 5.4 The virtual design environments of street blocks

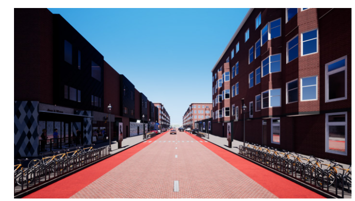
Profile 1	*Profile 2*	*Profile 3*	*Profile 4*
			
• Residential land-use • High connectivity • Two lanes with narrow pedestrian zone • Has open space in the block • Has trees in the block	• Residential land-use • High connectivity • Two lanes with narrow pedestrian zone • Does not have open space in the block • Does not have trees in the block	• Residential land-use • Low connectivity • One lane with wide pedestrian zone • Has open space in the block • Does not have trees in the block	• Residential land-use • Low connectivity • One lane with wide pedestrian zone • Does not have open space in the block • Has trees in the block
Profile 5	***Profile 6***	***Profile 7***	***Profile 8***
			
• Mixed with commercial area • High connectivity • One lane with wide pedestrian zone • Has open space in the block • Does not have trees in the block	• Mixed with commercial area • High connectivity • One lane with wide pedestrian zone • Does not have open space in the block • Has trees in the block	• Mixed with commercial area • Low connectivity • Two lanes with narrow pedestrian zone • Has open space in the block • Has trees in the block	• Mixed with commercial area • Low connectivity • Two lanes with narrow pedestrian zone • Does not have open space in the block • Does not have trees in the block

Table 5.5 Questions and answers rating for the VR environment

Questions	Likert Scale (rat. 1-7)
Quality of the environment	
(1) How satisfied are you with the overall quality of this virtual environment?	Not at all satisfied (1) - Fully satisfied (7)
(2) How satisfied are you with the walking friendliness of this virtual environment?	Not at all satisfied (1) - Fully satisfied (7)
Emotions the virtual environments evoked	
(1) I felt happy	Completely disagree (1) - / Completely agree (7)
(2) I felt comfortable	Completely disagree (1) - / Completely agree (7)
(3) I felt annoyed	Completely disagree (1) - / Completely agree (7)
(4) I felt secure	Completely disagree (1) - / Completely agree (7)

In the final data set, we have observations for each respondent for 4 virtual walking trips. We use regression analysis as the basic method to analyse the data assuming that the dependent variable is approximately of interval level (7-point rating scales). We use the latent class regression model to take the panel structure of the data (repeated observation) into account and identify groups. Two regression analyses are performed: 1) regressing the perceived walkability on attributes of the environment and 2) regressing the perception of walkability on feelings (emotions) evoked by the environment. In the second regression analysis, each emotion variable indicates one dimension of individuals' feelings separately. Therefore, these four emotion variables are manifest variables that are included as independent variables in the regression model. Application of the latent-class regression model offers class membership data. In a next step, the membership data are analyzed using a discrete choice model to identify the relationships between socio-demographic characteristics and class membership of individuals.

The latent class model assumes that individuals are implicitly sorted into a set of classes and considers the finite mixture model with classes of the form (Leisch, 2004):

$$h(y|x,\psi) = \sum_{n=1}^{N} \pi_n f(y|x,\theta_n) \quad (1)$$

$$\pi_n \geq 0, \sum_{n=1}^{N} \pi_n = 1$$

where y is a dependent variable with conditional density h, x is a vector of independent variables, π_n is the prior probability of class n, θ_n is the class-specific parameter vector for the density function f, and $\psi=\pi_1,\ldots,\pi_N,\theta_1,\ldots,\theta_N$, is the vector of all parameters. In the model, f is a univariate normal density with class-specific mean $\beta_{n'x}$ and variance σ_n^2. Then, we have $\theta_n = (\beta_n', \sigma_n^2)'$ and Equation (1) describes a latent class regression model (DeSarbo & Cron, 1988; Leisch, 2004). The posterior probability that observation (x,y) belongs to class j is given by (Leisch, 2004):

$$P(j|x,y,\psi) = \frac{\pi_j f(y|x,\theta_j)}{\sum_n \pi_n f(y|x,\theta_n)} \tag{2}$$

The latent class parameters are estimated by the maximum likelihood method, and the goodness of fit of the estimated model can be indicated by the McFadden's Rho-square *(ρ^2=1-LLB/LLO)* (McFadden et al., 1973). The number of classes N is set by the user. To find the best number of classes, we run the model estimation several times for different values of N and use the Akaike information criterion *(AIC=-2(LLB-P))* and Bayesian information criterion *(BIC=-LLB+[(P2)*ln(N)])* to identify the optimal number of classes.

To analyze the relationships between socio-demographic characteristics and class membership, in the second step, we use the basic multinomial logit model. The posterior probabilities (Eq. 2) are used to assign each individual to the class with maximum posterior probability (Leisch, 2004). Since there are two regression models (walking friendliness regressed on attributes and emotions, respectively), there are two class solutions for each individual that result from this analysis.

Table 5.6 Socio-demographic characteristics of the respondents

Variables	Levels	
Age (years)	/	43.64 (years)
Gender	Male	44.4%
	Female	55.6%
Education	Primary	2.70%
	Medium	45.1%
	High (BSc or higher)	52.2%
Work status	Full time work	39.7%
	Part-time work (high, 21-37 hours)	22.7%
	Part time work (low, 1-21 hours)	8.80%
	No paid work	28.8%
Travel time for work	Low commute time	46.8%

Variables	Levels	
	Medium commute time	19.6%
	Long commute time	5.10%
	Others	28.5%
Gross income (per year)	Low income level	24.7%
	Middle income level	36.3%
	High income level	26.1%
	Others	12.9%
Ethnic background	Dutch	94.9%
	Non-Dutch	5.10%
Household type	Single	24.1%
	Couple without child(ren)	34.6%
	Parents	30.8%
	Others	10.5%
Dwelling type	Detached house	15.6%
	Semidetached or terraced house	54.3%
	Apartment	25.4%
	Others	4.70%
House owner situation	Own	66.8%
	Rent	33.2%
	***N* = 295 respondents**	

5.4 Results and discussion

5.4.1 Results of the relationship between the perceived walkability and attributes

In this section we discuss the results of the analysis concerning the regression of walkability on attributes varied in the experiment. Table 5.7 shows for the latent class regression model the statistics of different estimations under different settings of number of classes *N*. The results of the latent class regression model show that the AIC values decrease when the number of classes increases from 1 to 4 classes, while it increases when the number of classes increases to 5. Therefore, we identified the optimum number of classes as equal to 4 for the first regression model (walking friendliness regressed on attributes).

Regarding the effects of attributes on the perceived walkability, Table 5.8 shows the estimation results for the one class model and the model with four latent classes. The estimation results for the ordinary linear regression (one class) model are included for comparison. The value of the adjusted

McFadden Rho square of the latent class model is considerably higher compared to the ordinary linear regression (one class) model indicating that there are strong differences between classes.

Looking at the estimation results in Table 5.8, the one-class model shows that residential land-use, wide pedestrian road, presence of open space and greenness are associated with walking friendliness. This result is in line with many empirical studies (Kasraian et al., 2020; Liao et al., 2020; Rosenberg et al., 2009; Sung & Lee, 2015). However, the one-class model does not fit the observations well as indicated by the low value of the adjusted McFadden Rho square (0.043). Compared with the one-class model, the four-class model shows an increase of the adjusted McFadden Rho square to 0.134. In the four-class model, the first class is labeled as *walking space oriented* (25.9 percent). This class considers more space for walking and presence of open spaces to be important for walkability. The second class is named *liveable space oriented* (47.8 percent). This group of individuals, in accordance with theories from empirical studies, considers a full range of attributes to be all relevant for walkability, i.e. residential land-use (not mixed with commercial), high connectivity, wide pedestrian road, presence of open space and greenness. The third class is labelled *open space oriented* (19.5 percent). The individuals in this class consider open space as the most important attribute for walkability followed by residential land-use. These findings are in line with many empirical studies which indicate that the perceived walkability was associated with residential density and open space (Bahrainy & Khosravi, 2013; Boakye-Dankwa et al., 2019; Hajna et al., 2015; Marquet et al., 2015). The fourth and last class is labelled *road size oriented* (6.8 percent). For this group, a wide pedestrian zone is important for walking friendliness. This finding is in line with Giles-Corti et al. (2005), Rastogi et al. (2011), and Yang et al. (2019), who found that wide pedestrian zone increased walking behaviour and walking time of people.

Table 5.9 shows the results of the estimation of the MNL model to predict class membership based on socio-demographic variables. The first class – Walking space oriented – is taken as the base category. Individuals of the *liveable space oriented* group are more likely to have high socioeconomic status because they are more likely to have middle or long commute time and high income, and they more often live in semi-detached or terraced houses and they are less likely to be immigration. The *open space oriented group* consists of individuals who are more likely to be female, more often have middle commute time, are more likely to live in semi-detached or terraced houses, and less likely to be parent. In addition, the *road size oriented* group has more wealthy people who more likely have high income and long commute time, and more likely live in detached, semi-detached or terraced houses. Since these three groups both include fewer middle income people and fewer homeowners, individuals of the *walking space oriented* group are more likely to be middle income people and homeowners. These findings are partly in line with Leslie et al. (2010) who pointed out that socioeconomic status was associated with the perceived walkability.

5.4.2 Results of the relationship between the perceived walkability and emotions

In this section, we consider the results of the analysis regarding the relationship between perceived walkability and emotions evoked by the environment. Table 5.10 shows that the AIC and BIC values decrease when the number of classes increases from 1 to 3 classes and increase when the number of classes increases from 3 to 4 classes. Hence, the optimal number of classes is equal to 3 for this second regression model (walking friendliness regressed on emotions). In Table 5.11, the detailed estimation results of the three-class model. The table also shows the results of the one-class model for comparison. The one-class model indicates that all four emotions are significantly associated with walkability across all groups. The latent class model identifies three groups and shows an increase in adjusted McFadden Rho square from 0.204 to 0.271. The first class is labelled *happy feeling* (33.9 percent). This class associates walkability mainly with feelings of happiness. This finding is in line with Ettema et al. (2015) and Weijs-Perrée et al. (2020) who also found an association between sense of happiness and walking. Furthermore, feeling secure also plays a role in this group. The second class is labeled as *secure feeling* (44.3 percent). This group mainly associates walkability with feelings of security and secondly with comfort. The third class is named *comfortable feeling* (21.8 percent). This group associates walkability more strongly with feelings of comfort and less strongly with security. These findings are in line with Birenboim (2018) who found that the sense of security and comfort are significantly influenced by the walking environment. All in all, these results indicate that there is quite some heterogeneity on the level of affective experiences that individuals associate with walkability. Feeling secure and comfortable are common emotions shared by almost all groups. For a large segment of the people (approximately one-third) walkability in addition is related to feelings of happiness and reduces annoyance, whereas comfort does not play a role.

Table 5.12 shows the estimation results of the MNL model to predict class membership, the first class – *happy feeling* – is used as reference group in this model. Individuals of the *secure feeling* group are more likely to be high-earning workers due to the fact that they are more often highly educated, more likely to have middle and long commute time, more likely to live in apartments, and more likely to own their dwelling. The *comfortable feeling* group individuals who are more likely to be female, more likely to have middle or long commute time, more likely to live in apartments, and less likely to be single. The *secure feeling* group and the *comfortable feeling* group are both more likely to have middle or long commute time workers, more likely to live in apartment, and less likely to be full time workers. This indicates that part-time workers, who spend more time in the commute and live in an apartment, more likely to associate walkability with feelings of security and comfort. We can derive, therefore, that individuals of the *happy feeling* group are more likely to be full-time workers, more likely to have low commute time, and less likely to live in an apartment.

All in all, differences in socio-demographic characteristics between emotion groups are very clear. The *happy feeling* group includes more full-time workers living close to their home. The *secure feeling* group contains more high-income workers with longer commute time and the *comfortable feeling* group includes more females and apartment residents.

Table 5.7 Statistics for latent class regression models (attributes)

No. of class	Parameters	Log likelihood function	AIC	BIC
1	7	-2011.19	4036.37	4071.89
2	15	-1956.75	3943.49	4019.59
3	23	-1938.63	3923.25	4039.94
4	**31**	**-1931.31**	**3918.76**	**4076.89**
5	39	-1925.19	3928.38	4126.24

Note: AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 5.8 Results for latent class regression models (attributes)

		Four latent classes model			
	One-class model	**Walking space oriented**	**Livable space oriented**	**Open space oriented**	**Road size oriented**
	Estimate	Estimate	Estimate	Estimate	Estimate
Residential land-use	0.466***	0.069	0.414***	0.182*	-0.125
High block connectivity	-0.103	0.104	0.233**	0.032	0.252
Two lanes with narrow pedestrian zone	-0.221**	-0.174**	-0.386***	-0.146	-0.566**
Has open space in the block	0.414***	0.171*	0.541***	0.549***	0.177
Has trees in the block	0.189**	0.084	0.259**	0.157	0.117
Share of the individuals	100%	25.9%	47.8%	19.5%	6.8%
McFadden's Rho-squared:	0.014	0.182			
Adjusted McFadden's Rho-squared:	0.011	0.134			

Note: ***, **, * ==> Significance at 1%, 5%, 10% level.

Table 5.9 Results of the MNL models (attributes)

	Liveable space oriented Coefficients	**Open space oriented** Coefficients	**Road size oriented** Coefficients
Age	0.021***		0.027**
Gender			
Female		0.337*	
Male (reference)			
Work status			
Part time work (low, 1-21 hours)	-0.491**	-1.036***	
No paid work (reference)	/	/	/
Travel time for work			
Middle commute time	0.449**	0.563**	
Long commute time	0.875*		1.941***
Low commute time (reference)	/	/	/
Gross income (per year)			
Low income level	-0.705**		-2.226***
Middle income level	-1.032***	-1.137***	-2.800***
Others (I don't want to answer)	-0.867***	-1.415***	
High income level (reference)	/	/	/
Ethnic background			
Non-Dutch	-0.746**	-1.909***	
Dutch (reference)	/	/	/
Household type			
Parents		-0.722**	
Others (I don't want to answer)	0.705**		
Single (reference)	/	/	/
Dwelling type			
Detached house		-0.729**	1.880***
Semidetached or terraced house	0.636***	0.430*	2.263***
Others dwelling type	-1.160***	-0.951**	2.315***
Apartment (reference)	/	/	/
House owner situation			
Own house	-0.771***	-0.435*	-0.764**
Rent house (reference)	/		/

Note: ***, **, * ==> Significance at 1%, 5%, 10% level.

Table 5.10 Statistics for latent class regression models (emotions)

No. of class	Parameters	Log likelihood function	AIC	BIC
1	6	-2040.03	4084.06	4094.21
2	13	-1986.68	3983.37	4008.73
3	**20**	**-1962.88**	**3941.75**	**3982.34**
4	27	-1962.59	3947.19	4403.01

Note: AIC = Akaike information criterion; BIC = Bayesian information criterion.

Table 5.11 Results for latent class regression models (emotions)

		Three latent classes model		
	One-class model	Happy feeling	Secure feeling	Comfortable feeling
	Estimate	Estimate	Estimate	Estimate
I felt happy	0.075**	0.255***	-0.525	0.005
I felt comfortable	0.312***	0.079	0.271***	0.851***
I felt annoyed	-0.499***	-0.086***	-0.023	-0.002
I felt secure	0.358***	0.186**	0.567***	0.108***
Share of the individuals	100%	33.9%	44.3%	21.8%
McFadden's Rho-squared:	0.207		0.281	
Adjusted McFadden's Rho-squared:	0.204		0.271	

Note: ***, **, * ==> Significance at 1%, 5%, 10% level.

Table 5.12 Results of the MNL models (emotions)

	Secure feeling	Comfortable feeling
	Coefficients	Coefficients
Gender		
Female		0.692***
Male (reference)	/	/
Education		
High education	0.970**	
Primary education (reference)	/	/
Work status		
Full time work	-0.655***	-0.910***
No paid work (reference)	/	/
Travel time for work		
Middle commute time	0.731***	0.678***
Long commute time	0.996***	0.920***
Low commute time (reference)	/	/

	Secure feeling	**Comfortable feeling**
	Coefficients	Coefficients
Household type		
Couple without child(ren)		1.061***
Parents		0.762***
Others household type	-0.780***	1.203***
Single (reference)	/	/
Dwelling type		
Detached house	-1.126***	-1.304***
Semidetached or terraced house	-0.584***	-0.941***
Others dwelling type	-0.939***	-1.445***
Apartment (reference)	/	/
House owner situation		
Own house	0.359***	
Rent house (reference)	/	/
Note: ***, **, * ==> Significance at 1%, 5%, 10% level.		

5.5 Conclusion

In this chapter, we developed an experimental design (orthogonal design) with virtual reality environment to analyze how people perceive and experience walkability. In contrast to the traditional use of static presentations in a conjoint experiment, we used dynamic videos of virtual environments of scenes, which allowed respondents to virtually walk through and experience the hypothetical neighborhoods with more spatial and social detail compared with traditional visualizations or texts. In the design of the experiment, we considered five attributes that are most commonly found to contribute to walking behavior in previous studies. Our results confirmed findings from empirical studies that land use mix, connectivity, road size, open space, and green have an influence on individuals' perception of walkability. However, our findings also indicate substantial differences between groups. For approximately an equally sized group, walkability is determined by just the size of sidewalks and presence of open spaces, whereas land-use, connectivity and green are not considered relevant. The group differences are significantly related to socio-demographic characteristics. In other words, individuals with different socio-demographic characteristics perceive attributes differently for walkability. Therefore, it is useful and meaningful to provide different walkable designs for neighborhoods with different socio-demographic compositions, at least in the Netherlands.

Regarding the relationship between perceived walkability and emotions the environment evokes, we find that perceived walkability is mainly associated with feelings of comfort and feelings of security. However, for a large segment of people walkability means more than just security and comfort. A large group also associates walkability with an increase in happiness and decrease of annoyance during walking. Also, on that level we find significant relationships between socio-demographic characteristics and group membership. So, individuals form different socio-demographic backgrounds experience different emotions in relation to walkability. For example, full-time workers working close to home are more likely to associate walkability with a happy feeling, whereas high-income workers working far from home associate it more often to a secure feeling. Across these dimensions women show a tendency to associate walkability more often to a comfortable feeling.

Although this chapter provides new insights into walkable neighborhood design, it still has several limitations that could be addressed in future research. Firstly, our experiment used an online video representation, but immersive virtual reality technology (using the VR headset and equipment in the lab) could provide a more immersive and real environment for the respondents. Second, our video representation had a fixed route and viewing direction. A more realistic virtual environment would allow respondents to walk around and create a route by themselves. Therefore, to collect complementary data about perceptions and behavior, it is interesting to repeat the experiment developed in this study using full-fledged VR equipment in the lab. This allows respondents to immerse themselves in the environment and walk more randomly and look around in the VR environment. Lastly, our experimental designs are based on the typical Dutch reality environments, and our respondents were also recruited from the Netherlands. Therefore, our findings are more useful and meaningful for the built environment under the Dutch context.

Despite these limitations, this chapter has provided new insights and methods to interconnect theory and design practice and added to the growing experience in the use of VR in combination with conjoint experiment techniques to analyze spatial perceptions and behavior. Our findings have provided insights into differences between groups in how people perceive the walking environment.

CHAPTER 6

MEASURING WALKABILITY IN VIRTUAL REALITY

--A COMPARISON BETWEEN DIFFERENT DYNAMIC REPRESENTATION MODES IN A CONJOINT EXPERIMENT

This chapter is based on:

Liao, B.*, van den Berg, P. E. W., van Wesemael, P. J. V. & Arentze, T. A. (2021).
Measuring walkability in virtual reality: A comparison between different dynamic representation modes in a conjoint experiment, Under review.

6.1 Introduction

The association between walkability, environmental characteristics, and walking behavior has received much attention in built-environment research (Grasser et al., 2013; Liao et al., 2020; Oakes, et al. 2007; Yun et al., 2019). In recent years, empirical studies started using conjoint experiments to identify the effects of characteristics of the built environment on how people experience walkability of neighborhoods (Birenboim et al., 2021; Kasraian et al., 2020). In a conjoint experiment, respondents are asked to reveal their preferences by evaluating carefully constructed hypothetical environments presented to them. To obtain higher-quality responses of participants in these experiments, the use of visual representation techniques such as photos, images, videos of virtual environments (non-immersive virtual reality), and immersive VR environments (via VR headset) have received attention (Zhu et al., 2020). The use of virtual reality techniques in a conjoint experiment is critical because it enables participants to actively engage in the environments and directly experience the variation of environmental design features.

Several empirical studies have found evidence that using virtual reality techniques in this way can provide a more valid way to measure people's preferences (Birenboim et al., 2019; Kasraian et al., 2020). In some cases, researchers have compared different modes of visual representation distinguishing static representation modes (photos and images) and dynamic VR representation modes (either videos of virtual environments or immersive virtual reality) (Birenboim et al., 2019; Ghekiere et al., 2018; Shr et al., 2019; Zhu et al., 2020). They argued that the static representation modes force respondents to stretch their imagination and therefore lead inevitably to imagination bias (Birenboim et al., 2019; Ghekiere et al., 2018). Arguably, compared to the static representation modes, the dynamic representation modes provide a more direct and integral impression of the environment that facilitates an understanding of the impact of changes in certain attributes of the environment on how the environment is experienced (Birenboim et al., 2019). Using videos of a virtual environment is an increasingly used dynamic method to represent alternatives in online experiments. This mode uses a fixed walking route and watching perspective in walk through a virtual environment. In contrast, the immersive VR mode needs to be conducted in a lab and requires the use of special VR devices. In an immersive VR environment, respondents are allowed to walk around and create a route by themselves. It is likely that compared to the video-mode this will create a different experience of the environment and hence different preference measurement results. Despite the fact that the video and immersive VR mode may create different results, there are to the best of our knowledge, no studies which have systematically compared the two VR representation modes. Therefore, it is not clear whether different dynamic VR representation modes of walking environments (the video mode and the immersive VR mode) result in different experiences and preference measurement results.

The purpose of the present study is, therefore, to identify possible effects of VR representation mode (video versus immersive VR) on experiences and preference measurements regarding walkability of walking environments. More specifically, the present study aims to answer the question whether using the video mode, which is less costly and allows larger samples, gives the same results as the immersive VR mode. In earlier work, we created 3D models of environments to simulate different street block designs and used a video mode to present the environments in a conjoint experiment (Authors et al., 2020). In the present study, using the same experimental design and 3D models we compare different VR representation modes: video (fixed watching routes and perspectives, as before) and the immersive VR mode (self-determined walking routes and watching directions) in the lab (via VR devices). Data is collected through an online survey and a lab experiment keeping the experimental conditions the same. The results will reveal whether individuals experience walkability of walking environments differently depending on representation mode.

The remainder of the paper is structured as follows. First, in the following section literature about the use of VR representation technologies in the study of walkability is described. Next, the 6.3 section that follows introduces the VR representation modes, design of the conjoint experiment and methods for data collection and analysis used in this study. The 6.4 section discusses the results of the analysis. The 6.5 section highlights the key findings and discusses the implications of the findings for measuring walkability in virtual reality.

6.2 Literature review

The use of VR representation technologies to present attributes of the walking environments in a conjoint experiment has received increasing attention. In a conjoint experiment, attributes of a walking environment are varied based on a statistical design and respondents are asked to evaluate the alternatives constructed. The two major dynamic VR representation modes used in studies are: (1) a video of the virtual environment (watching a video of a walk through the environment), and (2) immersive VR where the respondent uses VR glasses to walk around and experience the virtual environments. These two modes are both based on 3D VR modeling techniques (using software such as Unity, SketchUp, and Twinmotion) to realistically simulate surroundings and allow respondents to experience them (Birenboim et al., 2021, 2019; Shr et al., 2019; Vliet et al., 2021).

Several studies used 3D modelling software (e.g., 3D studio Max) to generate videos to present hypothetical walking environments on the neighborhood or street level in a conjoint experiment (Kasraian et al., 2020). For example, Yin (2017), Nakamura et al. (2018) and Kasraian et al. (2020) measured walkability of streets based on individuals' walking experience in videos of virtual reality environments. In addition, Jiang et al. (2018) also used videos in a conjoint experiment to investigate how street design influences human experience of the place in an online survey.

Furthermore, a few empirical studies used immersive VR to represent walking environments in a conjoint experiment. For instance, Zhu et al. (2020) used SketchUp and Unity to build 3D-immersive virtual reality environments and asked respondents to walk in the virtual space by wearing a VR headset.

In the context of a conjoint experiment, researchers have also compared the use of static images to the use of dynamic representation modes. Examples are Birenboim et al. (2019) and Zhu et al. (2020). In both studies, firstly, respondents used a VR headset to experience the virtual environments and then answered a questionnaire. After that, the same respondents were asked to watch the same environments through images and then answer the same questionnaire to compare the participants' stated preferences under immersive virtual reality and the conventional representation mode. They found that the VR provides a greater sense of presence than the images (Birenboim et al., 2019; Zhu et al., 2020).

As the brief review above indicates, different ways of representing 3D models of the environment have been applied in conjoint experiments to measure preferences for walking environments. Although the comparison of a static representation mode and the immersive VR mode has received some attention, a systematical comparison of different dynamic representation modes is lacking. Especially, the question arises whether the use of video which can be administered on-line and hence allow larger samples, provides the same measurement results as fully immersive VR which requires special devises and needs to be conducted in the lab. The goal of the present study therefore is to analyze the effects of the use of different VR modes on estimated preferences for attributes of a walking environment considering a video and an immersive VR representation mode. In so doing, our study intends to contribute to the literature by measuring perceived walkability as well in the immersive virtual reality environments. Moreover, the reviewed studies did not consider the influence of virtual reality mode on the relationship between environmental attributes and affective walking experiences (emotions), whereas such relationships have been found to be significant in empirical studies on human-environment interaction. Emotional responses include sense of happiness, sense of comfort, sense of security, and being annoyed (Birenboim, 2018; Ettema et al., 2015; Resch et al., 2020). The present study also intends to contribute to the literature by analyzing the relationships between neighborhood attributes and emotions of individuals depending on VR mode.

6.3 Methodology

In this section, we describe the method used to model and visualize walking environments with different VR representation modes (the video and the immersive VR mode). We also introduce the approaches used to collect and analyze the data.

6.3.1 The visualization of walking environments

In earlier work, we created 3D models of hypothetical walking environments in a conjoint experiment. The attributes that were varied in the experiment concerned spatial factors that are known to influence walkability. Empirical research found that land use mix, walking facilities, sidewalks, and trees are important factors of walkability (Boakye-Dankwa et al., 2019; Ettema et al., 2015; Glazier et al., 2014; Sallis et al., 2016; Cerin, et al., 2016). Furthermore, previous research indicated that connectivity and open space are highly associated with walking behavior in the Netherlands (Liao et al., 2020). Therefore, the attributes that we varied in the experiment are land use mix, block connectivity, road width, open space, and green. To limit the size of the experimental design, two levels were defined for each attribute to create alternatives, as follows: (1) land use mix: only residential area and residential mixed with commercial area, (2) block connectivity: high and low connectivity, (3) road size: two lanes with narrow pedestrian zone and one lane with wide pedestrian zone, (4) open space: the street-block with and without not have open space, and (5) green: the street-block does have and does not have trees. Then, we used an orthogonal fractional factorial design to reduce the number of combinations (profiles) and avoid any correlations between attributes. In this case, the full factorial design could be reduced to an orthogonal design consisting of eight attribute profiles, as shown in Table 6.1.

We created a 3D model of a typical Dutch street block in SketchUp Pro 2019 and implemented eight variants of the 3D model corresponding to the attribute profiles of the orthogonal design, as shown in Table 6.1. The eight virtual reality environments were then all imported into Twinmotion 2019 (Epic Games, 2019) — a quick real 3D rendering software. In Twinmotion, we added materials, trees, traffic, facilities, and people to all 3D sketch models, as shown in Table 6.1.

In the experiment, we compare the video mode and the immersive VR mode of presenting the walking environments. For the videos, we set a walking perspective and walking route and exported all virtual reality environments as 3D videos. To keep consistency, all videos used the same walking route, watching direction, geographical location, sunlight time, and weather. The length of each video is 1 minute and 30 seconds. For the immersive VR case, we use the immersive VR walking mode in Twinmotion 2019. In this walking mode, we set the height of the pedestrian view and use the VR headset and controllers in the lab. This allows respondents to immerse themselves in the environments and walk more randomly and look around freely in the VR environments.

The video format of the conjoint experiment was implemented in an online survey to collect data on how participants experience the walking environments (Authors et al., 2020). In this online survey, we randomly show 4 out of 8 dynamic 3D videos of the virtual walking environments to each respondent and ask respondents to indicate their perceptions for each environment. For consistency, we use the same experimental design and questionnaire for the immersive VR representation mode in the lab.

The survey used three questions to ask participants about their perception of each virtual reality environment. Two questions were asked about the quality of the environment, as follows: (1)

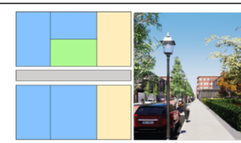
"How satisfied are you with the overall quality of this virtual environment?"; and (2) "How satisfied are you with the walking friendliness of this virtual environment?". Each question uses a 7-point Likert scale ranging from not at all satisfied to fully satisfied. Third, four items were used to measure the emotions the virtual environment evoked for the dimensions: happiness, comfort, annoyance, and security. Hereby, we asked participants to indicate to what extent they experienced each of these four emotions. The questions are framed as statements, namely "I felt happy / comfortable / annoyed / secure", and for each item the respondent answered on a 7-point Likert scale ranging from completely disagree (1) to completely agree (7).

6.3.2 Data collection and analysis approach

To collect data for the immersive VR mode, the lab experiment ran about 3 weeks in October 2020. Participants were master students and Ph.D. students from the Eindhoven University of Technology, and they were invited to come to the lab one by one. Before the formal experiment, each participant received some instruction about the restrictions (such as the walking obstacle surrounding them and the walking area in the lab) that could distract them. During the experiment, participants were asked to walk through and experience the virtual neighborhood environments using the VR headset and a controller. Each participant took part in the experiment by wearing an HTC Vive headset and experiencing the virtual reality environments. The participants navigated in the virtual environment in a pedestrian perspective. In addition, as an auxiliary tool, hand controllers could help participants to correct sight direction and move position. Hence, participants could walk on the ground and use the hand controllers to move (in the VR environments) from one point to another point. In each moving point, participants could walk in a small area and look around in the virtual environment, as shown in Figure 6.1. As in the video case, each respondent received a random selection of 4 out of 8 virtual reality environments, which means that each participant has four trials of a VR walking environment in the lab. After each trial, participants filled out the questionnaire to indicate how they perceived and evaluated the environment with regard to walkability, overall quality and experiences (emotions). In total 47 participants finished the lab experiment, 43 participants are Chinese, and 4 participants are Dutch. The average time the experiment took for each individual is about 45 to 50 minutes in the lab.

For the video condition, the data from a national consumer panel in the Netherlands collected through an online survey is used (Authors 2020). To be able to compare the data with the data from the immersive VR condition, we randomly selected 46 respondents who are young (age $\leq$ 26 years) and highly educated from this national consumer panel sample. Those 46 respondents are all Dutch. Because the sample used in the lab experiment consists almost entirely of Chinese students,

Table 6.1 The design combinations of street blocks

Profile 1	***Profile 2***	***Profile 3***	***Profile 4***
			
• Residential land-use • High connectivity • Two lanes with narrow pedestrian zone • Has open space in the block • Has trees in the block	• Residential land-use • High connectivity • Two lanes with narrow pedestrian zone • Does not have open space in the block • Does not have trees in the block	• Residential land-use • Low connectivity • One lane with wide pedestrian • Has open space in the block • Does not have trees in the block	• Residential land-use • Low connectivity • One lane with wide pedestrian zone • Does not have open space in the block • Has trees in the block
Profile 5	***Profile 6***	***Profile 7***	***Profile 8***
			
• Mixed with commercial area • High connectivity • One lane with wide pedestrian zone • Has open space in the block • Does not have trees in the block	• Mixed with commercial area • High connectivity • One lane with wide pedestrian zone • Does not have open space in the block • Has trees in the block	• Mixed with commercial area • Low connectivity • Two lanes with narrow pedestrian zone • Has open space in the block • Has trees in the block	• Mixed with commercial area • Low connectivity • Two lanes with narrow pedestrian zone • Does not have open space in the block • Does not have trees in the block

Residential land-use | Two lanes with narrow pedestrian zone | Open space
Mixed with commercial area | One lane with wide pedestrian zone

we repeated the on-line video experiment in China for which we recruited 47 Chinese respondents to conduct the online survey (the video VR condition). This latter sample serves as a control group. They are also master students and Ph.D. students who study at Wuhan University in China. Therefore, we have a total sample of 140 participants divided in three approximately equally sized groups (one lab group and two on-line groups) for the analysis. All respondents watched 4 videos (online videos of virtual environments) or experienced 4 immersive virtual environments (lab and immersive VR) so that 560 evaluations of walking environments were recorded for the analysis. The characteristics of the sample are shown per group in the Table 6.2.

Figure 6.1 The participant walks and experiences the virtual reality environments in the lab

Table 6.2 Samples' characteristics

	Online survey in the Netherlands	*Lab experiment*	*Online survey in China*	*Total sample*
Number of respondents	46	47	47	140
Gender (Male)	52.2%	48.9%	68.1%	79
Gender (Female)	47.8%	51.1%	31.9%	61
Nationality (Dutch)	100%	8.5%	0%	51
Nationality (Chinese)	0%	91.5%	100%	89
Living years in their neighbourhood (Mean)	9.1	2.7	5.2	/

In the final dataset, each respondent occurs with 4 evaluations of walking environments. The descriptive analysis of the data is shown in Table 6.3. To take this panel structure of the data into account, we use the random effects regression model to analyze the data. Three regression analyses are performed: (1) regressing the overall quality (overall satisfaction) of environments on attributes of the virtual environment, (2) regressing the perceived walkability (walking friendliness) on attributes of the virtual environments, and (3) regressing the positive feelings. The measure of positive feelings for the latter regression was obtained by determining the sum score across the emotion dimensions after changing the direction of the annoyance scale to indicate the positive emotion. The Cronbach's alpha value of the emotion scale constructed is 0.973, which indicates that the measurement of positive emotions is reliable. To represent the experimental group variable, we add two dummy variables (M1 = online survey in the Netherlands, M2 = lab experiment) using the Chinese-survey group as reference. We incorporate the group identification dummy variables as main and as interaction terms (interactions with attributes) in the analysis. This allows us to estimate a full range of effects of group and, hence, VR representation mode and country on individuals' evaluations.

The random effects regression model allows for individual-level random variation as well as observation-level error (Schall, 1991). The random effects model assumes that the individuals' unobserved heterogeneity is uncorrelated with the independent variables. Formally, the model can be written as (Schall, 1991):

$$Y_{ij} = \alpha + X_{ij}\beta + \mu_{ij}$$

$$\mu_{ij} = \mu_i + V_{ij}$$

where i indicates an individual, j indicates an observation , X_{ij} is a vector of attributes of the walking environment, α is an intercept, β is the vector of effects of X on Y, μ_i is a normally distributed individual-specific error component, and V_{ij} is a usual random noise term which varies across j and i (Schall, 1991; Wooldridge, 2010). The goodness of fit of the estimated models is indicated by the (adjusted) R-square.

Table 6.3 The descriptive analysis of the data

	Mean	*Sd*
Walking satisfaction		
Overall satisfaction	5.18	1.27
Walking friendliness	5.28	1.29
Walkability emotions		
I felt happy	4.82	1.42
I felt comfortable	4.97	1.37
I felt annoyed	3.00	1.60
I felt secure	4.99	1.35
Positive emotion	19.79	4.64
	N = 140 respondents	

6.4 Results and discussion

In this section, we discuss the results of three random effects models concerning the regression respectively of overall satisfaction, walkability (walking friendliness), and positive emotions on attributes of the virtual reality environments.

6.4.1 Results of the random effects models

Table 6.4 shows the estimation results for overall satisfaction. Regarding the effects of attributes on the overall satisfaction, the results show that street blocks with high block connectivity and with trees lead to higher satisfaction, while street blocks with only a residential function (land use mix) result in lower satisfaction. Looking at the size of coefficients, the presence of trees in the street block (0.539) appears to have a stronger effect than the residential land-use (-0.243) and high block connectivity (0.219). Regarding the interaction effects of representation mode (group identification dummy variables) and attributes on the overall satisfaction, the results show some influence of representation mode. For the attribute of open space, the significant positive effect (at the 0.01 level) in the M2 group (lab experiment), implies that participants value open space more in the VR mode compared to the group that received the on-line video in China. Furthermore, open space also has a weak positive effect (at the 0.1 level) in the M1 group (on-line video survey in the Netherlands), indicating that Dutch participants value open space more than Chinese participants in the same mode. The attribute trees shows a significant negative effect (at 0.05 level) in the M1 group, showing that the Dutch participations value green less than Chinese participants (M3 group) in the on-line video mode. Moreover, green has a weak negative impact (at the 0.1 level) in the M2 group, revealing that participants value green less in the VR mode than the comparable Chinese group in the online-video mode.

In addition, Table 6.4 shows the results for the regression model of walkability (walking friendliness) of the virtual reality environments. Regarding the effects of attributes on walkability, the results show that street blocks with open space and with trees are perceived as more walkable, while street blocks with only a residential function (land use mix) and with two lanes with a narrow pedestrian zone are perceived as less walkable. The size of the coefficients for two lanes with a narrow pedestrian zone and street block with only residential function (-0.288 both) appear to be of the same order of magnitude as the coefficients for street blocks with open space (0.246) and street blocks with trees (0.283). These findings are in line with empirical studies which indicated that walkability is associated with land use (residential function), greenness, open space, and pedestrian size (e.g. Hajna et al., 2015). As for the effect of representation mode, the results indicate that individuals value open space differently. In the M1 group (on-line survey in the Netherlands), the presence of open space receives a higher value (at 0.05 significance level) compared to the Chinese counterpart (M3). This indicates that the Dutch participants perceived street blocks with open space to be more walkable than the Chinese group.

Table 6.4 furthermore reports the regression results of the positive emotions of individuals while they are walking through the (virtual) environments. Regarding the effects of attributes on the positive emotions, the results show that individuals have stronger positive emotions in street blocks with high block connectivity while individuals have less strong positive emotions in street blocks with two lanes and a narrow pedestrian zone. Comparing the coefficients' size of these two attributes, high block connectivity (0.876) has an effect that is of similar size as that of street block with two lanes and a narrow pedestrian zone (-0.754). These findings are partly in line with Weijs-Perrée et al. (2020) who found a relationship between positive senses (happiness, secure, and comfort) and quality of urban public space. Turning to the interaction terms, the results show that individuals have stronger positive emotions in the lab experiment (an effect on the constant). In addition, open space has a stronger positive effect on emotion in the lab experiment than in the on-line video mode. This mode effect holds for both the China and Dutch case. Moreover, there is a weak negative effect (at 0.1 level) of M1 group on block connectivity, indicating that block connectivity contributes less to positive emotions in the Dutch group compared to the Chinese group.

6.4.2 Discussion of results

Comparing the on-line video and the immersive VR mode, we do not find significant main effects of the representation mode on overall satisfaction and neither on walkability (walking friendliness). This indicates that there is not a significant effect of representation mode on the base level of evaluations of the environments on these levels. As for positive emotions, we do see a positive effect of the immersive form of VR, which indicates that individuals experience stronger positive emotions in an immersive VR environment.

Furthermore, the results indicate that individuals evaluate attributes somewhat differently dependent on representation mode. In terms of overall satisfaction, respondents assign a higher value to open space in the street-block in the lab experiment compared to on-line video. In our experimental design, this attribute has two levels, namely street block has open space and street block does not have open space. Individuals more strongly experience the variation of this attribute in the immersive VR mode. Also, in the lab experiment, respondents assign a lower value to green (trees), but the effect is weak and significant only at a 0.1 alpha level. When we compare countries within the on-line video mode, we find that Dutch individuals assign a lower value to block connectivity in terms of positive emotions and lower value to green in terms of overall satisfaction, be it that the latter effect is weak and significant only at a 0.1 alpha level. It implies that Dutch individuals assign a lower value to block connectivity for positive emotions and possibly a lower value to green for overall satisfaction than Chinese individuals.

Table 6.4 Regression analysis results

	Overall Satisfaction		Walking Friendliness		Positive Feelings	
	Estimate		Estimate		Estimate	
Residential land-use	**-0.243**	.	**-0.288**	*	-0.484	
High block connectivity	**0.219**	.	0.028		**0.876**	*
Two lanes with narrow pedestrian zone	-0.174		**-0.288**	*	**-0.754**	.
Has open space in the block	0.119		**0.246**	.	0.683	

	Overall Satisfaction		Walking Friendliness		Positive Feelings	
	Estimate		Estimate		Estimate	
Has trees in the block	**0.539**	***	**0.283**	*	0.545	
M1 (Dutch online survey)	0.317		0.241		1.113	
M2 (lab experiment)	0.335		0.077		**1.856**	.
Reference:M3 (China online survey)	/		/		/	
M1:High block connectivity					**-1.157**	.
M1:Has open space in the block	**0.332**	.	**0.417**	*		
M1:Has trees in the block	**-0.373**	*				
M2:Has open space in the block	**0.569**	**			**1.377**	*
M2:Has trees in the block	**-0.312**	.				
Multiple R-square:	0.136		0.109		0.122	
Adjusted R-square:	0.109		0.081		0.095	

Signif. codes: 0 '*** ' 0.001 '** ' 0.01 '*' 0.05 '.' 0.1.

6.5 Conclusion

In this chapter, we compared the video on-line and immersive VR representation mode of presenting virtual reality environments to measure walkability and walking emotions evoked by the environment. We collected data by using the different modes to represent alternative neighborhood environments in a conjoint experiment. Three random effect regression models were estimated to analyze the effects of the different modes on individuals' reported experiences of walkability. Our results support findings from earlier research that land use mix, road size, open space, and green space have an influence on individuals' experience of walkability. The results also showed that land use mix, connectivity, and green (trees along the road) have effects on overall satisfaction with the walking environments. Individuals' positive emotions are influenced by connectivity and road size when they are walking through the virtual environment. In addition, our results did not show a significant main effect of the representation mode on overall satisfaction and walkability of the neighborhood environments. We found that the immersive VR mode has a weak positive effect on positive emotions, which suggests that individuals experience positive emotions more strongly in immersive VR.

As for the evaluation of attributes, our results suggest that respondents do not value all attributes the same in different dynamic VR representation modes. The main difference is that respondents assign higher value to open space in the lab experiment. Because open space probably is the most salient attribute in a 3D space, respondents are more likely to observe the changes of the open space and have opportunities to interact with the open space in the immersive VR environments. This indicates that the influence of such salient 3D attributes is underestimated in a video of virtual environment due to the fact that immersion in the environment is more limited in that mode. Therefore, it is useful and meaningful to consider open space and other similar attributes (e.g., green park) with the immersive VR representation mode in a conjoint experiment. In addition, there is a tendency that individuals assign higher value to green of the neighborhood in the on-line video mode. A possible explanation is that the video provides a wider viewpoint to respondents in the fixed observing route, allowing them to monitor the changes in the amount of green more easily than in the immersive VR mode (the view of respondents is under the trees). We also found some differences that are not related to mode but to the countries involved in our experiment. Dutch individuals assign a lower value to green for overall satisfaction and a lower value to block connectivity for positive emotions compared to the Chinese participants. This provides evidence that people from diverse cultural backgrounds evaluate attributes differently. The absence of mode effects related to the evaluation of the other attributes indicate that the on-line video mode (which allows larger samples and is less costly) provides robust measurement results in the sense that estimation results will not change when a (more costly) full-fletched VR mode is used for the experiment.

Although our study provides insight in the effects of different dynamic VR representation modes on respondents' experiences of walkability, it still has some limitations. The data used here was collected with three different experimental groups (online survey in the Netherlands, lab experiment in the Netherlands, and online survey in China). Although for all groups we selected individuals with a similar background (age, education level), there may still be some sample bias. That is to say, the on-line group and lab group consisted of individuals of different origins (Dutch versus Chinese). Although we controlled for this by including a second on-line group with the same nationality (Chinese), the basis for the comparison was not straight-forward. Furthermore, the sample in the present study consisted of young and highly educated respondents. Therefore, it would be interesting to repeat this experiment with different socio-demographic groups because empirical studies suggest that different groups of people have different perspectives to evaluate the built environment (Zhu et al., 2020).

Despite these limitations, our study has offered insights on the effect of VR representation mode and showed that there are some differences in experience of walkability and individuals' walking emotions that can affect the measurement results. This study suggests that videos of virtual environments as a more convenient alternative for immersive VR may lead to measurement biases for salient 3D attributes (e.g., open space) but appears to lead to the same results for other types of attributes.

Chapter 7 Conclusion

CHAPTER 7
CONCLUSION

7.1 Summary and findings

The aim of this dissertation was to explain the influence of walkability on walking behavior and walking experience in neighborhoods, and to provide deeper insights in walkability and walkable neighborhoods design. To that end, this dissertation was structured in three research parts.

The first part used data from the Dutch National Travel Survey and the Dutch Bureau of Statistics to empirically analyze walkability in the Netherlands, and to identify the relationships between walkability (objective), out-of-home activities (activity choice), short-distance trips (destination choice), and walking trips (mode choice). The second part was based on data collected through an online survey including a national sample of 295 persons to analyze the role of residential location choice and walking attitude in the formation of the relationship between walkability (subjective) and walking behavior. The third part was based on preference data collected though a conjoint experiment with virtual technology to investigate in-depth the relationship between walkability (subjective) and walking experience. The data were collected in two rounds. The first round was based on an online, video-based conjoint experiment that was part of the same survey and sample of 295 respondents. Next, in the second-round a lab experiment was conducted to collect complementary data using the immersive VR.

The findings indicate that existing walkability (objective) indices only partly capture observed variation in walkability across neighborhoods in the Netherlands. The results further indicate that mismatches emerge on the level of both the selection and weighting of variables to objectively measure walkability. For the relationship between walkability (objective) and various aspects of walking behavior, the results show that direct relationships exist between walkability, on the one hand, and trip generation, destination choice, and transport mode choice, on the other hand, after controlling for the mutual relationships between the activity and trip variables. Comparing different age groups (children, adults, and elderly), differences found mostly concerned the relationship between walkability (objective) and trip generation. It suggests that relationships between walking behavior and walkability are not the same for all age groups.

Furthermore, the results of this dissertation confirmed the significant role of walking reasons for location in walkability, and the importance of walking attitude as a factor that influences walking behavior. Although walking reasons for location is important, it does not completely explain the variance in walkability of the neighborhood where one lives. Furthermore, it was found that walking attitude is a much stronger predictor of walking behavior than walkability. Therefore, there is a relationship between walkability of the neighborhood where one lives and walking behavior also after controlling for walking reasons for location, but the strength of the relationship is much smaller than that of the relationship between walking attitude and walking behavior.

Regarding the relationship between (perceived) walkability and walking experience, the results confirmed earlier findings from empirical studies that land use mix, connectivity, road size, open space, and green have an influence on individuals' perception of walkability. The findings also revealed substantial differences between persons. Where one group is specifically sensitive to the size of sidewalks and the existence of open spaces, another approximately equally sized group considers residential land-use and existence of open spaces to be important. The groups differ in socio-demographic characteristics. This means that individuals with different socio-demographic characteristics evaluate walkability attributes differently. Furthermore, this dissertation found that perceived walkability is mainly associated with feelings of comfort and feelings of security. At the same time, we found significant relationships with socio-demographic characteristics and group membership at this level. Whereas full-time workers who work near home are more likely to associate walkability with a happy feeling, high-income workers who work distant from home are more likely to associate it with a secure sense. By and large this means that people from different socio-demographic backgrounds have varying feelings about walkability.

In addition, the findings of this dissertation only partly supported the hypothesis that different dynamic VR representation modes result in different experiences related to neighborhood walkability when it comes to the comparison between on-line video-based and the more immersive VR mode in the lab. Only a weak association was found between mode and emotions, which implies that the immersive VR mode is more likely to evoke positive emotions. As for the evaluation of attributes, our results suggest that respondents do not value all attributes the same in different dynamic VR representation modes. The main difference is that respondents assign higher value to open space in the lab experiment. It is likely that differences in the amount of open space in the immersive VR environments are more salient. Furthermore, in the online video mode, respondents assign a higher value to green in the neighborhood. An explanation may be that the video gives respondents a broader perspective of the surroundings on the walking route, allowing them to watch changes in the green more readily than in the immersive VR mode (the view of respondents is under the tree). This study also discovered some differences that are not linked to mode, but rather to the countries of individuals who participated in our experiment.

When we compare the findings from the different parts of the thesis a remarkable difference emerges regarding the type of neighborhood characteristics that influence walking behavior and subjective experiences of walkability respectively. Whereas daily facilities (such as supermarkets, daily good stores, and cafeterias) appear to have the largest effect on walking behavior (first part of the thesis), public open space has the strongest influence on individual's walking experiences (third part of the thesis). This suggests that individuals' walking trips are to an important extent governed by functional facilities, whereas their walking experiences are more strongly determined by design characteristics.

7.2 Implications for theory and practice

The empirical analysis of walkability indicates which factors are key for creating walkable neighborhoods. The findings indicate that both the selection and weighting of neighborhood variables in existing indices should be improved. At least this holds for the Netherlands where the study was conducted and we should be aware of the fact that regional differences in the lay-out and infrastructure of urban environments may play a role. Although this is generally recognized, a more systematic investigation of the matter and articulation of an approach is still lacking. When regional differences are strong and influential, the idea of a generally applicable measure of walkability should be abandoned and replaced by an approach in which local estimation and validation of a model is an integrated component of the implementation of a walkability analysis. Furthermore, differences between different age groups in how walkability influences activity-travel choice (activity choice, destination choice, and mode choice) need to be taken into account. The relationship between walkability and out-of-home activities and the relationship between out-of-home activities and share of short distance trips are absent for children and elderly. These findings mean that refinement of walkability indices is needed to allow their use for a broader group of people. In particular these groups respond differently to neighborhood design characteristics that stimulate outdoor activities, such as accessibility of facilities, green spaces and spacious playgrounds. This raises the question whether a single measure of walkability should be replaced by several measures tailored to different age groups, in general practice to improve the analysis.

With regard to residential self-selection, the findings of this dissertation suggest that enhancing walkability mainly will have an impact on walking behavior through individuals' location choice and, moreover, that the effects are confined to walking for transport as opposed to walking for leisure. This is indicative of people's perception of walkability, which appears to be most strongly impacted by safety considerations. Therefore, it would be useful to consider road safety (e.g., traffic speed limits) as the most important factor in creating walkable neighborhood designs.

Furthermore, this dissertation added to the increasing experience of using VR in combination with using a conjoint experiment for the analysis of spatial perceptions and behavior. The findings of the conjoint experiment indicate that individuals with different socio-demographic characteristics experience walkability attributes differently in terms of both emotions and the perception of walkability. It is recommended to have various walkable designs for neighborhoods with different socio-demographic compositions. In addition, the use of the video mode instead of the more immersive VR mode in conjoint experiments can lead to biases in the estimates of effects especially for salient 3D attributes (e.g., open space) but offers a robust alternative regarding other types of attributes.

In summary, the findings of this research suggest that urban planners should especially consider people-oriented walkability principles, notably safety, comfort and convenience, for improving the pedestrian experience. In particular, a walkable neighborhood has to include accessible amenities within walking distance, diverse outdoor areas for different groups of people (e.g., green spaces and spacious playgrounds), a safe road, and pedestrian pavement of a wider size. Furthermore, a walkable neighborhood design should also be adapted to local circumstances, given the fact that areas differ on socio-demographic variables that have an impact on perceptions of walkability.

7.3 Limitations and future research

The objective of this dissertation was to contribute to an improved understanding of associations between walkability, walking behavior, and walking experience. The models estimated in this dissertation showed that neighborhood walkability has impacts on various aspects of walking behavior and walking experience and that these impacts differ depending on socio-demographic characteristics and especially age groups. Although this thesis yields valuable findings, there are also several limitations and possible ways for future research.

Firstly, the empirical analysis of walkability was based on data from the Netherlands, but as several scholars have argued, it is necessary to take into account the diversity in typologies of urban settings (Frank, 2010; Habibian & Hosseinzadeh, 2018). Therefore, future works should consider more systematically the question whether a completely different approach to measure walkability would be needed when regional variations are so significant. Furthermore, the empirical analysis of walkability did only partially consider possible differences in responses to neighborhood characteristics related to different types of walking trips. Especially, walking for transport and walking for leisure may differ in that respect (Cao et al., 2009). In addition, independent variables considered in the empirical analysis of walkability did not include neighborhood variables that are less commonly used in primary (neighborhood) databases, but that may influence walkability as well, such as lighting, pedestrian safety, and aesthetic variables (Glazier et al., 2012).

Secondly, since the study used cross-sectional data to estimate the effects of walkability on walking behavior, we did not analyze walking behavior over a longer period of time. Therefore, the results do not allow inferences of causality regarding the relationships found. For future research the collection and analysis of longitudinal data is thus recommended to analyze the relationship between walkability and walking behavior through time so that the direction of causality can be identified (e.g., whether a change in neighborhood environments lead to a change in perception and behavior of people).

Lastly, the conjoint experimental designs used in this thesis are based on the typical Dutch neighborhood environments, and our respondents were also mainly recruited from the Netherlands. A complementary study in China that was carried out to compare the video and immersive VR mode. The results revealed several differences between Dutch and Chinese respondents on how walkability characteristics are perceived and experienced. Therefore, also the findings on this level of this study are more useful and meaningful for the built environment in the Dutch context. More systematic research however is needed on the influence of regional differences and especially socio-cultural factors. It should be noted, however, that the findings are inconclusive, as the data used for comparison of different representation VR modes was collected using three different groups instead of a fully randomized design of the experiment. More research is needed to compare the impact of different VR modes without this data limitation.

Although more research is needed, this dissertation has increased our understanding of the effects of walkability on walking behavior and walking experience in neighborhoods. The findings and contributions about the use of virtual reality and revealed preferences approaches to measuring walkability will help planners and designers to better implement walkable healthy neighborhoods design.

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AUTHOR INDEX

SUBJECTIVE INDEX

Questionnaire of the perceived neighborhood environment

We would like to find out more about the way that you think about your neighborhood environment. We also would like to understand what you think about our virtual reality environment. We would be most grateful for your participation in this brief survey. Please answer as honestly and completely as possible and provide only one answer for each item. There are no right or wrong answers and your information will be kept confidential. Answering the survey will take you about 30 minutes, and the results will only be used on scientific research.

If you have any concerns or questions, please contact:

Bojing Liao   Ph.D. Candidate
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Department of Built Environment
Eindhoven University of Technology

Informed Consent Form

Study Information

This survey includes two parts to investigate how you are feeling about the neighborhood environment where you live (Part I) and our virtual reality neighborhood environment (Part II). The first part has 5 sections, namely: your socio-demographic characteristics, your satisfaction with your neighborhood, your social contact, travel behavior, and place attachment in your neighborhood. The second part asks about your perception of our virtual reality neighborhood environment.

Consent Items

Participation in this research is **voluntary**, please real below items carefully:

- I have **read** and **understood** the study information. **I have been able to ask questions** about the study;
- **I consent voluntarily to be a participant** in this study and **understand that I can refuse** to answer questions and **I can withdraw** from the study at **any time**, **without having to give a reason**;
- I **understand** that the information I provided will be used for **research publication** and that **information will be anonymized**;
- I agree that **my information** can **be quoted** in research output;
- I understand that any personal information that can identify me- such as my address and age- will be **kept confidential** and **not shared with anyone**;
- I give permission for **the anonymized information** I provide to be deposited in a data archive so that it may be used for future research.

☐ I agree with all of the statements above.

Part I: Your neighborhood

Section 1: Socio-demographic characteristics

Please choose **one** answer per question.

1.1 What is your birth year (e.g., 1990)?

_____

1.2 What is your gender?
☐ Male ☐ Female

1.3 What is your education level?
☐Elementary school ☐ VMBO/HAVO/VWO ☐ MBO ☐ HBO ☐ Master ☐ Other, namely____

1.4 How many hours do you work per week?
☐ Full time work (38 hours or more)
☐ Part-time work (21-37 hours)
☐ Part-time work (1-21 hours)
☐ No paid work

1.5 How long does it currently take you to travel to work on an average day?
☐ Less than 15 minutes ☐ Between 15 and 30 minutes ☐ Between 30 and 45 minutes
☐ Between 45 and 60 minutes ☐ Over an hour ☐ Not Applicable, I don't work

1.6 What is your personal gross income level per year?
☐ Less than 10,000 euros ☐ 10,000 to 20,000 euros ☐ 20,000 to 30,000 euros
☐ 30,000 to 40,000 euros ☐ 40,000 to 50,000 euros ☐ 50,000 to 100,000 euros
☐ 100,000 euros or more ☐ I don't know or I don't want to answer

1.7 What is your ethnic background:
☐ Dutch ☐ Western migration ☐ Non-western migration

1.8 What is your household composition?
☐ Single
☐ Couple without children
☐ Couple with child(ren)
☐Single parent with child(ren)
☐ Other

1.9. What is the age of the youngest child in your household?

____

☐ Not applicable; I don't have a child

1.10. What type of dwelling do you live?
☐ Detached house
☐ Semi-detached or terraced house
☐ Apartment or flat in a building
☐ Other, namely_______

1.11. Do you own or rent the dwelling where you live?
☐ Own
☐ Rent
☐ Other

1.12 In general, how would you rate your physical health in the past year?
☐ Very good ☐ Good ☐ Moderate ☐ Bad ☐ Very bad

1.13. How many years did you live in your current neighborhood?
________years

1.14. To what extent have below items affected your choice where you live (1 = not at all influencing location choice, 5 = very much influencing location choice) ?
a. There are shops on walking distance;
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
b. There are schools on walking distance;
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
c. The residential environment is pedestrian friendly;
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

1.15. What is the postcode of your home address (e.g., 5042 EJ)? ___________

Section 2: Characteristics of your neighborhood

(a) Walkability

Below are statements about your neighborhood with which you may or may not agree. Please indicate to what extent you agree with each item. By your neighborhood, we mean the area within approximately one kilometer of your home or that you could walk to in 10 minutes.

Please choose **one** answer per statement.

Note: Walkability indicates how friendly an area is to walk.

2a.1.How satisfied are you with the walkability in your neighborhood (1 = not at all satisfied, 10 = fully satisfied)?
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10

2a.2.I like walking;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

2a.3.If possible I rather walk than drive;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

2a.4.I can do most of my shopping in local stores;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

2a.5.It is easy to walk to a transit stop (bus, train) from my home;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

2a.6.Stores (daily goods) are within walking distance from my home;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

2a.7.The sidewalks in my neighborhood are well maintained;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

2a.8.It is safe to walk in or near my neighborhood;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

2a.9.There are many interesting things to look at while walking in my neighborhood;
□ Strongly disagree □ Disagree □ Neutral □ Agree □ Strongly agree

2a.10.The speed of traffic in the neighborhood I live is usually slow;
□ Strongly disagree □ Disagree □ Neutral □ Agree □ Strongly agree

2a.11.My neighborhood is well lit at night;
□ Strongly disagree □ Disagree □ Neutral □ Agree □ Strongly agree

2a.12.I see and speak to other people when I am walking in my neighborhood;
□ Strongly disagree □ Disagree □ Neutral □ Agree □ Strongly agree

2a.13.There are attractive buildings/homes in my neighborhood;
□ Strongly disagree □ Disagree □ Neutral □ Agree □ Strongly agree

2a.14.The streets in the neighborhood are understandable and recognizable.
□ Strongly disagree □ Disagree □ Neutral □ Agree □ Strongly agree

(b) Neighborhood satisfaction

Below are questions about your satisfaction with your neighborhood.

Please choose **one** answer per statement.

2b.1.How satisfied are you with your neighborhood as a place to live taken all together (1 = Very dissatisfied, 10 = Very satisfied)?
□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ 8 □ 9 □ 10

2b.2.How satisfied are you with the public transportation in your neighborhood?
□ Very dissatisfied □ Dissatisfied □ Neutral □ Satisfied □ Very satisfied

2b.3.How satisfied are you with the number of people you know in your neighborhood?
□ Very dissatisfied □ Dissatisfied □ Neutral □ Satisfied □ Very satisfied

2b.4.How satisfied are you with the access to schools in your neighborhood?
□ Very dissatisfied □ Dissatisfied □ Neutral □ Satisfied □ Very satisfied

2b.5.How satisfied are you with the access to a coumminty center in your neighborhood?
□ Very dissatisfied □ Dissatisfied □ Neutral □ Satisfied □ Very satisfied

2b.6.How satisfied are you to access to green parks or playgrounds in your neighborhood?
□ Very dissatisfied □ Dissatisfied □ Neutral □ Satisfied □ Very satisfied

2b.7.How satisfied are you to access recreational facilities in your neighborhood?
□ Very dissatisfied □ Dissatisfied □ Neutral □ Satisfied □ Very satisfied

2b.8.How satisfied are you with the safety from threat of crime in your neighborhood?
□ Very dissatisfied □ Dissatisfied □ Neutral □ Satisfied □ Very satisfied

2b.9.How satisfied are you with the traffic volume in your neighborhood?
□ Very dissatisfied □ Dissatisfied □ Neutral □ Satisfied □ Very satisfied

2b.10.How satisfied are you with the speed of traffic in your neighborhood?
□ Very dissatisfied □ Dissatisfied □ Neutral □ Satisfied □ Very satisfied

2b.11.How satisfied are you with the noise from traffic in your neighborhood?
□ Very dissatisfied □ Dissatisfied □ Neutral □ Satisfied □ Very satisfied

2b.12.How satisfied are you with the quality of daily goods stores in your neighborhood?
☐ Very dissatisfied ☐ Dissatisfied ☐ Neutral ☐ Satisfied ☐ Very satisfied

Section 3: Social contacts in your neighborhood

The questions below are about social contacts in your neighborhood.

Please choose **one** answer per statement.

Note: A social interaction is stated as a direct (face to face) interaction one has with another individual, ranging from a simple friendly talk about the weather to a in depth conversation about personal problems.

3.1 How satisfied are you with the amount of social contacts in your neighborhood (1 = Very dissatisfied, 10 = Very satisfied)?
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10

3.2 How satisfied are you with the quality of social contacts in your neighborhood (1 = Very dissatisfied, 10 = Very satisfied)?
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10

3.3 How often do you have a chat with someone from your neighborhood?
☐ Almost every day ☐ 2 to 5 times a week
☐ Once a week ☐ 2 to 3 times a month
☐ Once a month ☐ Less than once a month ☐ Never

3.4 If you are away from home, is there someone in your neighborhood who looks after your house?
☐ Almost never ☐ Not usually ☐ Sometimes ☐ Usually ☐ Almost always

3.5 If something important happens in the neighborhood or with a neighbor, is there someone in your neighborhood who will make you aware of it?
☐ Almost never ☐ Not usually ☐ Sometimes ☐ Usually ☐ Almost always

3.6 Do you feel involved with the people who live in your neighborhood?
☐ With hardly anyone ☐ Not with most people ☐ With some people
☐ With most people ☐ With almost everyone

3.7 If there is a sad moment or a sad event in your life, are there any local residents who help and support you?
☐ Almost never ☐ Not usually ☐ Sometimes ☐ Usually ☐ Almost always

3.8 Are there any neighborhood parties, barbecues or other activities in the neighborhood, for which the whole neighborhood is invited? [IF YES] How often do you attend these activities?
☐ Almost never ☐ Not usually ☐ Sometimes ☐ Usually ☐ Almost always

3.9 Have you collaborated with other local residents to organize something in the neighborhood, in the past year? [IF YES] How often have you met the other residents, in the past year?
☐ Not collaborated
☐ Collaborated once every half year
☐ Collaborated once every three months
☐ Collaborated once every two months
☐ Collaborated once every month or more frequently

Section 4: Means of Transport and trips

The questions below are about means of transport and trips in your neighborhood.

Please choose **one** answer per statement.

4.1 How often do you take public transportation (bus/tram/metro) for travel?
☐ Almost everyday ☐ 2 to 5 times per week ☐ Once per week
☐ 2 or 3 times per month ☐ Once per month ☐ Less than 1 time per month
☐ Never

4.2 How often do you take a bike for traveling?
☐ Almost everyday ☐ 2 to 5 times per week ☐ Once per week
☐ 2 or 3 times per month ☐ Once per month ☐ Less than 1 time per month
☐ Never

4.3 How often do you walk for transport?
☐ Almost everyday ☐ 2 to 5 times per week ☐ Once per week
☐ 2 or 3 times per month ☐ Once per month ☐ Less than 1 time per month
☐ Never

4.4 How often do you walk for recreation, health or fitness?
☐ Almost everyday ☐ 2 to 5 times per week ☐ Once per week
☐ 2 or 3 times per month ☐ Once per month ☐ Less than 1 time per month
☐ Never

4.5 How many cars do you or your household own?
☐ No car ☐ One car ☐ Two cars ☐ More than two cars

4.6 How often do you take the car for travel as a passenger?
☐ Almost everyday ☐ 2 to 5 times per week ☐ Once per week
☐ 2 or 3 times per month ☐ Once per month ☐ Less than 1 time per month
☐ Never

4.7 How often do you take the car for travel as a driver?
☐ Almost everyday ☐ 2 to 5 times per week ☐ Once per week
☐ 2 or 3 times per month ☐ Once per month ☐ Less than 1 time per month
☐ Never

4.8 Because of a health or physical problem do you have any difficulty walking?
☐ Yes, severe difficulties
☐ Yes, mild difficulties
☐ No

Section 5: Place attachment in your neighborhood

The questions below are about place attachment in your neighborhood.

Please choose **one** answer per statement.

5.1 I feel that neighborhood is a part of me;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

5.2 This neighborhood is the best place for what I like to do;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

5.3 No other neighborhood can compare to this neighborhood;

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

5.4 This neighborhood is very special to me;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

5.5 I identify strongly with this neighborhood;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

5.6 I get more satisfaction out of being in this neighborhood than in another neighborhood;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

5.7 I am very attached to this neighborhood;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

5.8 Doing what I do in this neighborhood is more important to me than doing it in any other place;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

5.9 Being in this neighborhood says a lot about who I am;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

5.10 I wouldn't substitute any other area for doing the type of things I do in this neighborhood;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

5.11 This neighborhood means a lot to me;
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

5.12 The things I do in this neighborhood I would enjoy doing just as much at a similar neighborhood.
☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Part II: Neighborhood scenarios in virtual reality (VR)

We will now present neighborhood scenarios in virtual reality which are typical Dutch neighborhoods. Following each scenario we will ask you to indicate the overall quality of the VR scenario, the walking friendly of the the VR scenario, and how are you feeling about the VR scenarios when you watch the VR scenario.

Please choose **one** answer per statement.

Scenarios

Satisfaction with walking in theVR scenario

How would you rate the overall quality of this VR environment (1 = Very bad, 10 = Very good)?

□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ 8 □ 9 □ 10

How would you rate the walking friendly of this VR environment (1 = Very bad, 10 = Very good)?

□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ 8 □ 9 □ 10

When walking through this VR environment,

1. I felt happy (Completely disagree = 1, Completely agree = 7)

□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7

2. I felt comfortable (Completely disagree = 1, Completely agree = 7)

□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7

3. I felt annoyed (Completely disagree = 1, Completely agree = 7)

□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7

4. I felt secure (Completely disagree = 1, Completely agree = 7)

□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7

CURRICULUM VITAE

Bojing Liao was born on 10-12-1990 in Loudi, China.
After finishing Bachelor's degree in 2013 at China, he studied Art Design of Master's study at Huazhong University of Science and Technology in Wuhan, China. In 2017, he graduated within the Urban Environment Design Group on Environmental design. From 2017-2021, he started a PhD project at Eindhoven University of Technology at the Netherlands of which the results are presented in this dissertation.

PUBLICATION LIST

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Liao, B.*, van den Berg, P. E. W., van Wesemael, P. J. V. & Arentze, T. A. (2020). How does walkability change behavior? A comparison between different age groups in the Netherlands, ***International Journal of Environmental Research and Public Health***. DOI: 10.3390/ijerph17020540

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Local People Matter: Towards participatory governance of cultural heritage in China
Ji Li

Over the last decades, an increasing number of researchers have examined the influence of walkability on walking behavior and walking experience of individuals. Despite the extensive research work investigating the relationships between walkability, walking behavior, and walking experience, there are still fundamental knowledge gaps in this research field. First, the empirical validation of objective walkability measures has received only limited attention, and the exact nature of the relationship between walkability and walking behavior is not clear. Second, although the effects of residential self-selection on walkability has received some attention in empirical studies, the independent roles of residential self-selection and walking attitude in the relationship between walkability and walking behavior are not clear. Third and finally, combining conjoint experiments with virtual reality techniques at neighborhood and street level is increasingly seen as a promising research method to measure preferences and experiences related to walkability but has received only limited attention. Moreover, the question whether different virtual reality representation modes result in different experiences and preferences of individuals is still unanswered. Therefore, to fill these gaps, the aim of this dissertation is to explain the influence of walkability on walking behavior and walking experience in neighborhoods, and to provide deeper insights on walkability and walkable neighborhoods design, and methods of representation for walkability research.

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