The Influence of the Built Environment on Health through Travel Behavior

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Abstract – Average weights, controlled for length, the so-called body mass index (BMI) are increasing and a lot of health issues are related with this weight gain. Governments around the world try to turn this trend around. One of the policies that is expected to influence BMI, is influencing travel behavior by making changes in the built environment. However, a lot is still unknown about the relationship between the built environment, travel behavior and BMI and about the causality of this relationship. For assessing whether implementing adaptions in the built environment is an effective policy, it is needed to further research this relationship. Using longitudinal structural equation modeling the short and long term relationships between the factors are defined and the strength of these relationships is assessed. The study finds that making travel behavior strongly influences BMI, and thus that steering travel behavior is a good approach for counteracting weight gain. For influencing travel behavior the study finds that both by making adaptions to the built environment, and by directly influencing the attitudes towards travel modes travel behavior can be influenced. In order to create effective policies research has to be conducted on the influence of detailed design characteristics of the built environment, on the impact of policies on other health indicators than BMI and on the applicability of the found results for younger and less affluent citizens.

Key words: Built environment, Travel Behavior, Body Mass Index, Structural Equation modeling, Longitudinal, Causality.

1. Introduction

Around the world obesity rates are rising, and with this so are the related chronic diseases (Malik *et al.*, 2012). In 2014, globally, 1.9 billion adults were overweight, and of this group 600 million people were obese (WHO, 2015). This is about 13% of the adult population. Governments are implementing policies in order to counteract this trend. One proposed policy is incentivizing active travel, so travel by foot or bike, over passive travel, by car. It is believed that the built environment (BE) can influence travel behavior. The effectiveness of measures to influence health and travel behavior (TB) through the BE have been researched thoroughly. Ewing et al. (2008) find that urban sprawl is related to minutes walked, and that citizens of counties with less sprawl are likely to weigh less than the citizens of counties with more sprawl. Handy *et al.* (2005) find that the built environment affects the attitude towards travel modes, which in turn influences travel behavior. Additionally, Frank *et al.* (2012) find that land use mix is associated with vehicle miles traveled and distance walked, however the study suggests that the strength of this relationship varies across gender and ethnicity.

Throughout research consensus exists that there is a relationship between the BE, TB and health. However, regarding this relationship some aspects are unknown or not yet researched. Firstly, so far almost all studies have been conducted using cross-sectional data. When conducting a research with cross-sectional data it can only be validated that a relationship exists between two variables, however whether this relationship is causal, and the direction of this causality cannot be assessed, because temporal precedence cannot be proved. Secondly, the relationship itself has not yet been clearly defined. Many analyses do not control for socio-demographic characteristics or do not incorporate intermediary variables such as attitudes towards travel modes. Excluding these characteristics distorts results, finds relationships between variables that are actually explained by another variable, and excluding intermediary variables does not provide insights into the influence of certain factors in the relationship. Thirdly, most research has been conducted in the United States, which can distort the overall outcomes of research. A distortion of the results may occur because of cultural dimensions and because of built environment related factors. Cultural dimensions because policies that affect people positively in one culture may not have the same effect in another. Built environment related factors because the BE in the United States exists of extremes, so extremely dense cities, and extremely thinly populated rural areas. This research aims to contribute to the knowledge on this relationship.

The research question is formulated as follows:

> *To what extent and by what factors does the built environment influence health through travel behavior, considering short and long term effects, and how can these factors contribute to spatial and transport-oriented policies?*

The study looks into which factors of the built environment influence travel behavior and to what extent, which intermediary variables are important and what their role is in the relationship, and to what extent travel behavior influences health. By answering these questions a more complete image of the relationship between the built environment, travel behavior, and health is created. This improved image provides insights into the question whether making to adjustments to the built environment is a promising policy for influencing health through travel behavior.

This is an empirical study using longitudinal data. The study shall be conducted using three types of structural equation models. First, a synchronous model, incorporating the short-term effects. Second, a lagged model, which includes the long-term effects. Third, a combined model in which the found short and long term effects are integrated to provide a complete overview.

The article is structured as follows. First, an overview of prior research on the relationship between the BE, TB and health is provided. Second, the data and method are discussed. Thereafter the results of the study are set forth by presenting the model specifications and discussing the found relationships. The last section concludes upon the findings and provides recommendations for further research.

2. Literature review

Throughout research consensus exists that a relationship exists between the BE, TB and health (Ewing & Cervero, 2010; Lovasi *et al*., 2009; Leck, 2006). This relationship is often structured so that the BE influences health through TB (Lakerveld *et al.*, 2015; Saelens *et al.*, 2003; Smith *et al.*, 2008). In this relationship attitudes towards travel modes are expected to have an intermediary role, so that the BE influences attitudes towards travel modes, which in turn influence TB.

The BE influences TB directly, so that for instance more compact city structures have a positive influence on the share of active travel, and through attitude, so people for example have a more negative attitude towards cars in compact cities with, for instance, few available parking spaces.. Then, because of this change in attitude, they will change their behavior. TB is in turn expected to influence health so that an increased share of active travel increases physical activity which in turn decreases weight. This section looks into the current knowledge on all parts of the relationships separately, to what extent the relationships have already been supported by empirical evidence, and which aspects are still unclear.

2.1 BMI as indicator for health

Health is a very broad term and BE and TB could affect health in many ways. To make this research manageable the scope of health effects that is narrowed to body mass index (BMI), weight controlled for length. Doorley *et al.* (2015) provide an overview of research on the health impacts of active travel, i.e. walking and cycling. They conclude that only easily measurable, quantifiable and significant health impact of active travel is physical activity. Increase of physical activity decreases risk on multiple conditions, such as obesity, Diabetes Type II, Coronary Heart Disease, and hypertension (Must *et al.*, 1999). Although BMI does not capture all health effects at play in this relationship, it is expected to be a good indicator.

2.2 The relationship between BE and TB

The BE influences TB through all kinds of factors. Multiple studies talk of “high-walkability” or “car-friendliness” of neighborhoods, and suggest that improving neighborhood walkability and reducing car-friendliness would increase active travel. However, these studies do not address what these terms exactly represents (Saelens *et al.*, 2003; Smith *et al.*, 2008; Handy & Mokhtarian, 2005). These studies find that an increased walkability and a decreased car friendliness have a positive effect on active travel. However, the BE variable used is not transparent,.

Two indicators for BE that are more upfront are urban sprawl and land use mix. Research has shown that active travel can be incentivized by reducing urban sprawl. Ewing *et al*. (2003) find that citizens of more compact counties and urban areas walk more than citizens of more sprawling areas. Schwanen *et al*. (2004) look into mode choice in the Netherlands and conclude that public transport, walking, and cycling can best be promoted by developing relatively compact city structures (Schwanen *et al.*, 2004). The meta-analysis of the BE-TB literature up until 2009, conducted by Ewing & Cervero (2010), finds that vehicle miles traveled (VMT) is most strongly correlated with accessibility and street network design, while walking is correlated with land use mix, intersection density and destinations within walking distance. PT is most strongly related to street network design and land use mix (Ewing & Cervero, 2010). Following from this it thus can be said that land use mix, street network design, destinations within walking distance, intersection density and accessibility all influence TB. A seven wave longitudinal study conducted in US cities finds that the effects of urban sprawl are dynamic rather than static, so the impacts of urban sprawl on TB increase over time (Kashem *et al.*, 2014). This study is one of the only studies found that conducts longitudinal research in the BE-TB domain.

Other mechanisms are also at play when studying the relationship between the BE and TB. A factor that has been widely discussed to be of influence is trip purpose. Scheepers *et al.* (2014) find that trips with some purposes, such as commuting, shopping, and visiting private contacts, are prevailingly made by car, while trips with other purposes, such as recreational outings, and daily grocery shopping, are more often made by bicycle. Also the weight that people put on land use influences their travel decisions, which again is dependent upon the trip they are making and the purpose of the trip (Zhang, 2004). Frank *et al.* (2012) find that land use mix is associated with VMT and distance walked, however the study suggests that the strength of this relationship varies across gender and ethnicity. Concluding from the above, the strength of the BE-TB relationship is also dependent on factors such as trip purpose, gender, social characteristics and ethnicity.

The underlying direction of causality has not thoroughly been researched yet (Handy *et al.*, 2005). Up until now it has been assumed that the BE influences TB, but it is not proven whether this is true, or that it is actually the other way around. Reversed causality would mean that TB influences the choice of neighborhood, and TB thus actually influences BE, which is referred to as residential self-selection (RSS) (Cao *et al.*, 2009; Bothe *et al.,* 2009).

2.3 Intermediate variables: attitude and car ownership

Attitude is defined as ‘a settled thinking or feeling about something’. A study, based on data from Northern California, finds that attitude is the linking variable between the BE and TB (Handy *et al.*, 2005). Handy *et al.* (2005) find that BE affects the attitude towards travel modes, which in turn influences TB. In this thesis it is expected that attitude fulfills this intermediary role between BE and TB.

Many travel behavior related studies are based upon the Theory of Planned Behavior (TPB) (Ajzen, 1991). The TPB states that attitudes are based upon a series of underlying beliefs (Ajzen & Fishbein, 1977). Next to attitudes, TPB assumes that there are two additional determinants of behavior: perceived social pressure and perceived ability to perform behavior. It is expected that both the direct relation between BE and TB and the indirect relation via attitude will be found. In most studies attitudes precede and causally influence behavior (Schwanen *et al.*, 2012), however the connection is also sometimes established the other way around (Festinger, 1957; Cullen, 1978).

Car ownership also fulfills an intermediary role between the BE and car use (Van Acker & Witlox, 2010). The built environment influences whether people purchase cars, and whether people own cars or not influences the share of trips executed by car. Attitude and car ownership are thus on the same level of the model. Car ownership is a factor that is not explicitly researched, but controlled for in the model.

2.4 The relationship between TB and BMI

The relationship between TB and BMI is thoroughly researched. Frank *et al.* (2004), state that on a daily basis each additional hour spent in a car increases the likelihood of obesity by 6%, each additional kilometer walked per day was associated with a 4.8% reduction in the likelihood of obesity. Lopez-Zetina *et al.* (2006) find a significant relationship between vehicle miles traveled and obesity, in which obesity is measured through BMI. Smith *et al.* (2008) find that doubling the proportion of neighborhood residents walking to work decreases an individual’s risk of obesity by almost 10%. Bassett *et al.* (2008) analyze data from Europe, North America and Australia and find that countries with a bigger share of active travel have lower obesity rates, also when controlling for socio-demographic characteristics. Concluding from these studies, it can be said that a bigger share of active travel, so cycling and walking, compared to inactive travel, driving a car, is associated with a lower body mass index. To explore the direction of causality, Martin *et al.* (2015) investigated the effects of switching from active to inactive travel or the other way around. They found that a change in TB leads to a significant change in BMI, in their research they found that this change occurred within a short time period, of under 2 years.

2.5 Socio-demographic characteristics

When looking into the relationship it is important to control for socio-demographic characteristics. The characteristics that are expected to influence the relationship between BE, TB and BMI are briefly discussed.

Polk (2004) found that males drive significantly more than females. Also, Falconer *et al.* (2015) found that an adaption in mode choice would have a different effect for males than for females when considering BMI. A third study found no connection between gender and mode choice (Anable, 2005). The influence of gender is thus expected to be bigger for males, but some uncertainty still exists about whether this relationship is significant.

Older people more often have difficulty walking and are thus expected to make more use of inactive travel modes compared to younger respondents. Steg (2004) found that in her study younger respondents valued car use more, which implies more car use. Another study finds no connection between age and mode choice (Anable, 2005). Age is a factor that complicates the BE-TB-BMI relationship.

Income is also a factor of which the influence is two-sided. On the one hand people with a lower income value car use more than people with a higher income (Steg, 2005), on the other hand, driving a car is expensive, and thus better affordable for people that have more to spend.

Educational level is often assumed to be a determinant of influence in mode choice (Schwanen *et al.,* 2004). Limnatakool *et al*., (2006) find that higher educated respondents travel more by public transport and less by car than less educated peers on medium to long distance trips for both business and leisure.

Polk (2004) found that having children increases car use. This is probably due to the fact that children have to be dropped off and picked up at all kinds of locations. Other dimensions of household composition, such as living with a partner, are expected to be of less importance.

3. Data and method

The study is an empirical analysis using existing data. When an analysis is based upon existing data this limits possibilities of the study based upon the availability of variables, and the distribution of the variables.

3.1 Study areas

The areas in which data is collected are Amersfoort, Veenendaal, and Zeewolde. These three cities in the Netherlands are chosen because they are very different from each other, and thus the combination of data from all three cities gives a more complete overview on the relationships that are explored. The cities are chosen for their specific attributes, Amersfoort because it is seen as the most ordinary city of the Netherlands, Veenendaal because of its high bicycle friendliness, and Zeewolde because of its remote position in terms of travel. The three cities are all situated quite centrally in the Netherlands.

3.2 Data collection

The data has been collected in 2005 and 2012 data has been collected by means of surveys (Bohte *et al*., 2009; Van de Coevering *et al.*, 2015). The data from surveys was first collected from about 3000 respondents in 2005. The same respondents were contacted in 2012 and a substantial amount responded. When accounting for missing information and data inconsistencies 287 cases remain in the dataset. The analysis is conducted using these 287 cases.

3.3 Selection of variables

The factors discussed in the literature section are the built environment, car ownership, attitude towards modes, travel behavior, and health. Socio-demographic characteristics are controlled for to account for external influences. For these factors variables have to be chosen to include them in the model.

For health the indicator body mass index is chosen. As discussed in the literature section this is the only health indicator within the scope of the research. Although BMI is not an all-comprising indicator for health, it does represent health to a good extent.

The built environment is one of the most encompassing variables. A first set of variables for the built environment is the number of grocery stores, other stores, and personal care facilities within a certain geographical scale. These three factors correlate very strongly, above 0.9. Because of this overlap only the variable that is expected to have the strongest effect on TB is included, the amount of grocery stores. This variable is expected to have the strongest effect because grocery stores are most frequently visited. Next to the availability of facilities, a bigger amount of grocery stores also is a proxy variable for a denser city structure and an increased degree of land use mix. This variable is used in two geographical scales, namely 400 meters and 3 kilometers. These geographical scales are used because 400 meters is a 5-minute walking distance, 3 kilometers is a 15-minute biking distance. The reason that the amount of grocery stores is expected to be of influence in the model is that it provides information about the distance to the city center and other daily activities. Two other variables that look into level of urbanization is the amount of addresses within one square kilometer from the address of the respondent (OAD), and the amount of addresses translated into a score on a 5-point scale (STED). In this 5-point scale 1 is a very urbanized area with over 2500 addresses per square kilometer and 5 is a non-urban area with less than 500 addresses per square kilometer (CBS, 2014). Because the value of STED is based solely on OAD it is chosen to only incorporate OAD of these two variables in the model. OAD is chosen because it is a more detailed variable with a continuous scale. The BE variables included in the model specification are thus amount of grocery stores within 400m, 3000m and OAD.

The variables attitudes towards public transport (PT), car, and bicycle are represented by factors that are created from nine indicators. These factors had already been created in prior research (Van de Coevering *et al.,* 2015). The nine indicators are based upon both affective (e.g. driving a car is pleasurable) and cognitive (e.g. bicycling is environmentally friendly) statements, measured on a 5-point scale ranging from –2 'strongly disagree' to +2 'strongly agree'. To create the factors, the 9 scores are summed. The model controls for the measurement error of these variables, by fixing the variance of the error terms of the variables by the unreliability, 1-Cronbach's alpha, times the variance of the composed scale of the variables. The Cronbach's alphas of the six attitude variables are presented in Table 1.

Table 1 – Cronbach's alphas of the attitude variables

Variable	Cronbach's Alpha
Attitude towards bicycles 2005	0.776
Attitude towards bicycles 2012	0.775
Attitude towards cars 2005	0.753
Attitude towards cars 2012	0.739
Attitude towards PT 2005	0.838
Attitude towards PT 2012	0.863

Travel behavior is incorporated as the share of trips conducted by car compared to other modes. As discussed in the previous sections prior research showed that it is expected that a higher share of active travel lowers BMI, and that more time spent in cars leads to a higher BMI.

Car ownership is included in the model through the variable whether someone has unlimited access to a car. The socio-demographic characteristics that are in the model specifications are age, gender, level of education, and monthly income.

3.4 Structural equation modeling

The analysis is conducted using structural equation modeling (SEM). SEM is used because of its broad applicability, its ability to estimate causation and longitudinal models, and its flexibility regarding model specification.

In this particular study three different SEMs are estimated. First, a synchronous effects SEM, which estimates the effects within one wave of data collection. Second, a longitudinal effects SEM, which estimates the effects that occur between the waves. Last, a combined effects SEM in which both the significant synchronous and longitudinal effects that are found in the first two model specifications are incorporated. The lag between the two waves of data collection is seven years. Following from this, the synchronous model represents the short-term effects, with a shorter effect-time than seven years. The lagged model represents the long-term effects, with an effect-time of seven years or longer. The Combined model represents a complete overview of the short and long-term effects at play in the relationship between the built environment, travel behavior, and BMI.

The model fit is assessed using multiple model fit indicators. Firstly, for good model fit the CMIN/DF, Chi squared per degrees of freedom, should not exceed 3 (Ullman, 2001). Secondly, RMSEA is under 0.05

for good fit, between 0.05 and 0.08 for fair fit, and above 0.1 the model fit is unacceptable (Browne & Cudeck, 1993). All comparative model fit indicators, NFI, RFI, IFI, TLI, and CFI, should all exceed 0.9 (Byrne, 1994)

4. Results

The descriptive statistics of the variables are presented in Table 2. Between 2005 and 2012 mean BMI has increased, mean share of car use has increased, and so have the mean amount of grocery stores within 400m and within 3000m, however mean OAD has increased.

Table 2 – Descriptive statistics

	Mean	Share	St. Dev	Min	Max	Missing values
Gender (male)		*60.6%*				0
Age 2005	48.47		9.488	27	79	0
Age 2012	55.47		9.588	34	86	0
Education 2005	2.63		0.589	1	3	0
Education 2012	2.64		0.586	1	3	0
Monthly income 2005	4.34		1.761	1	7	23
<€500		*7.0%*				
€500-€1000		*7.3%*				
€1000-€1500		*14.3%*				
€1500-€2000		*20.9%*				
€2000-€2500		*18.1%*				
€2500-€3000		*9.8%*				
>€3000		*14.6%*				
Monthly income 2012	4.76		1.741	1	7	34
<€500		*4.2%*				
€500-€1000		*6.6%*				
€1000-€1500		*10.5%*				
€1500-€2000		*15.3%*				
€2000-€2500		*17.4%*				
€2500-€3000		*16.4%*				
>€3000		*17.8%*				
Household 2005 (child)		*53%*				0
Household 2012 (child)		*64.5%*				0
BMI 2005	24.84		3.391	18.47	41.47	0
BMI 2012	25.36		3.850	19.15	47.18	0
Free access car 2005	3.58		0.748	1	4	0
No free access		*5.2%*				
Household		*26.1%*				
Always access		*68.6%*				
Free access car 2012	3.63		0.721	1	4	0
No free access		*5.2%*				
Household		*21.6%*				
Always access		*73.2%*				
Attitude car 2005	3.14		4.880	-14	18	0
Attitude car 2012	3.46		4.621	-14	15	0
Attitude bicycle 2005	8.88		4.995	-12	22	0
Attitude bicycle 2012	9.37		4.686	-13	21	0
Attitude PT 2005	-5.15		6.175	-22	13	0
Attitude PT 2012	-4.00		6.255	-21	14	0

Share car use 2005	4.76		1.902	1	7	0
Share car use 2012	4.78		1.948	1	7	0
Daily grocery stores 400m 2005	1.35		3.411	0	20	0
Daily grocery stores 400m 2012	1.21		2.648	0	15	0
Daily grocery stores 3000m 2005	49.51		2.220	1	137	0
Daily grocery stores 3000m 2012	43.39		1.756	1	156	0
OAD 2005	1511.35		731.542	219	3497	0
OAD 2012	1578.59		734.447	66	5067	0

Regarding the extent to which the results properly represent the population some comments should be made. The data was collected from respondents between 27 and 79 years old at the first point of measurement, with an average respondent age of 49 years. Using this range of ages neglects young adults and children. Another difficulty in the representation of the population is that survey is conducted only amongst homeowners. Homeowners often have a permanent job, so they can issue a mortgage. So people that rent their home, and often have less to spend and are more often unemployed, are excluded from the analysis.

4.1 Synchronous effects model

All relationships that are specified in the synchronous effects SEM are between variables within one wave of data. A multiple group analysis is conducted, in which both waves of data are included as separate groups and the parameters for all variables are equated for the two waves.

In Figure 1 the specification of the synchronous effects SEM is visualized. In the figure the variables are specified in groups that are expected to influence together other variables. The attitude variables are latent constructs, represented as ovals. The direction of causality is the assumed direction, since it cannot be proven by temporal precedence.

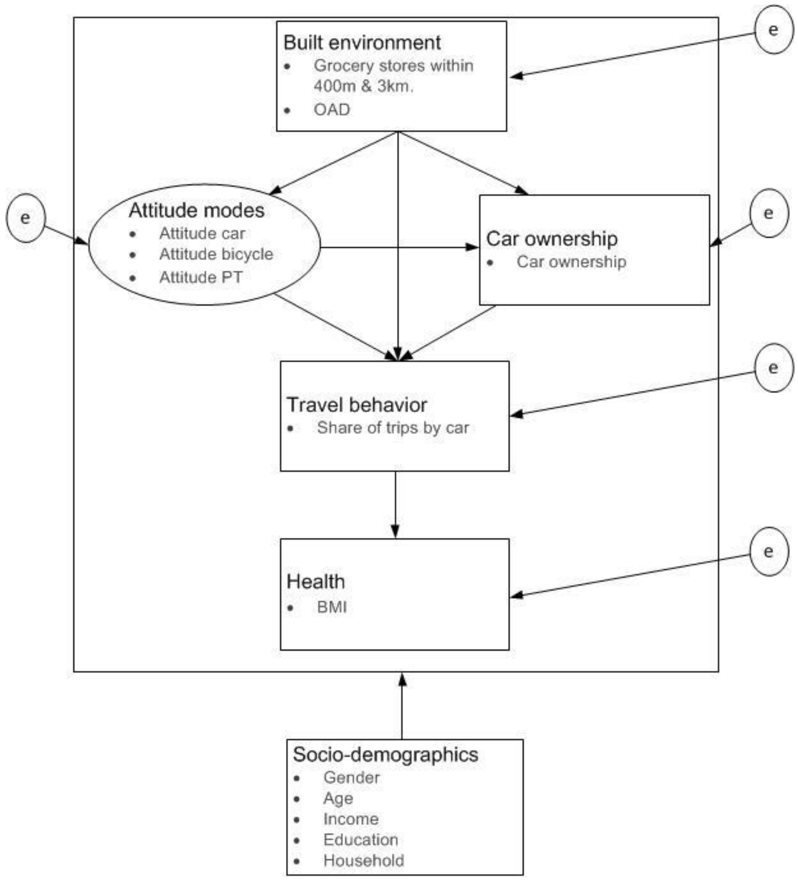

Figure 1 – Model specification synchronous effects SEM

When including both the amount of grocery stores within 3000m and OAD into the model it is found that all relations between OAD and the other variables become insignificant. This is likely to be caused by a high correlation between OAD and the amount of facilities within 3000m, of 0.843 in 2005 and 0.821 in 2012. The high correlation between these variables leads to a risk of multicollinearity. To eliminate this risk it is chosen to include one of the variables in the model, the chosen variable is grocery stores within 3000m. This variable is chosen because the relationships between this variable and other variables in the model remained significant, while the relations between OAD and the other variables became insignificant. The larger scale of this variable, three times the scale of OAD, is an expected reason for the stronger relationship. Another expected reason for the stronger relationship is that this variable encompasses direct implications not only on the level of urbanization but also on the degree of land use mix. Also the amount of grocery stores within 400m showed a less or insignificant role in the model, and has also been excluded considering the risk of multicollinearity.

Attitude towards bicycles has also been removed from the model. This variable did not significantly influence and was not significantly influenced by other variables in the model. This is unexpected since a better opinion of bicycles is expected to increase the share of trips by bicycles, which decreases the share of trips by car. The insignificance of relationships can be caused by the fact that almost all respondents had a very positive attitude towards bicycles, and because bicycles are only a substitute for cars for short distances.

The direct relationship between the built environment and travel behavior has become insignificant in the resulting model. This implies that the built environment on the short term only influences travel behavior through the intermediate variables car ownership and attitude.

The unstandardized strengths of the relationships are presented in Table 3. In the table the strength of the relationship stands for to what extent the column variable influences the row variable, a '-' implies that no relationship, stronger than four decimals, 0.000, was found between the variables.

Table 3 – Unstandardized total effects synchronous effects SEM

	Age	**Education**	**Income**	**Groceries**	**Attitude PT**	**Attitude car**	**Car ownership**	**Share of car use**
Endo-/Exogenous	Endogenous	Endogenous	Endogenous	Exogenous	Exogenous	Exogenous	Exogenous	Exogenous
Groceries	0.678	-	1.270	-	-	-	-	-
Attitude PT	0.116	-	0.050	0.040	-	-	-	-
Attitude car	-0.024	-1.525	0.823	-0.036	-	-	-	-
Car ownership	-0.006	-0.091	0.097	0.004	-0.040	0.060	-	-
Share of car use	-0.015	-0.464	0.274	-0.023	-0.295	0.305	0.759	-
BMI	0.060	-0.727	0.087	-0.007	-0.094	0.097	0.242	0.319

The relationship between TB and BMI is stronger than the relationship between the BE and TB. Concretely, if the average amount of grocery stores would double, from 50 to 100, car use would on an individual level decrease by 1.15 on a 7-point scale, and BMI would decrease by 0.35 point. When looking only at the TB-BMI side of the relationship, if people would go from almost making every trip by car and to 'making no trips by car', a 6 point decrease on the 7-point scale, their BMI would decrease by 1.914 point, a considerable amount.

Of the socio-demographic characteristics incorporated in the specification of the synchronous model, only age, income and education are still included in the final model specification. Correlations exist between these characteristics; the correlations are so that when people are older or more educated, they earn more. The strength of these correlations are 0.073 respectively 0.257.

Many modifications have been made to the model specification in order to reach the resulting model. The resulting model fit is acceptable. All thresholds for good fit are met; only the RFI is 0.833, which is slightly below the threshold of 0.9.

4.2 Lagged effects model

The lagged effects model specifies the relations that occur between the waves of data. These are both effects from variable one in wave one to variable one in wave two, and from variable one in wave one to variable two in wave two. Figure 2 presents the model specification of the lagged model.

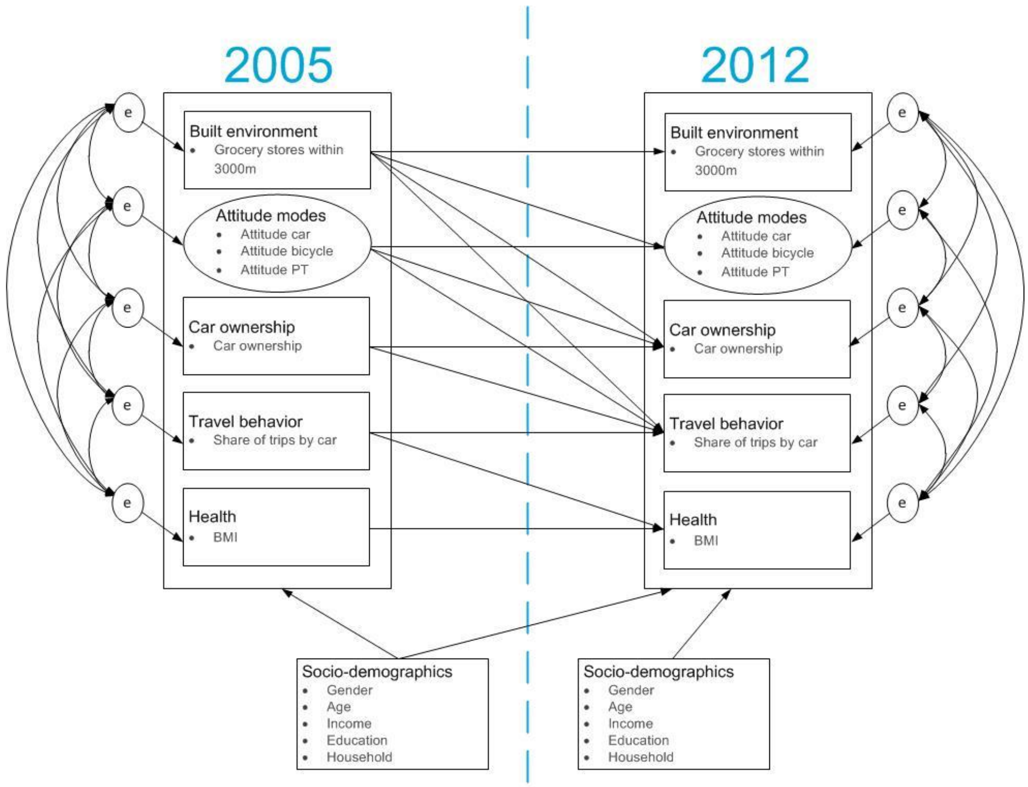

Figure 2 – Model specification lagged effects SEM

OAD and grocery stores within 400m have not been included in the model specification because of the risk that multicollinearity between OAD, amount of grocery stores within 400m and amount of grocery stores within 3000m might distort the results.

The found unstandardized strengths of the relationships between the variables are presented in Table 4. In this table attitude is abbreviated to 'Att', car ownership to 'Car Own', grocery stores within 3000m to 'Groceries', and share of trips conducted by car to 'Share car'. Whether a variable is endogenous or exogenous is indicated by the abbreviations 'endo' respectively 'exo'.

When only incorporating the lagged effects, no relationship is measured between the BE and BMI since the relationship is not direct, however via car ownership and/or share of car use the BE does affect BMI. As in the synchronous model, it becomes clear that the relationship between the BE and TB is less strong than the relationship between TB and BMI. When doubling the average amount of daily grocery stores within 3000m people will decrease their car use by 0.75 on a 7-point scale. When decreasing the share of car use by 6 points on a 7-point scale, BMI would, on an individual level, decrease by 0.702 point.

The significant correlations and their values are presented in Table 5. The correlations between the variables are almost all as expected. However, a more positive attitude towards PT is unexpected to correlated positively with BMI.

Table 5 – Correlations lagged effects SEM

Correlation	Value
Daily groceries 05 – Income 05	0.219
Income 05 – Age	0.298
Daily groceries 05 – Age	0.354
Income 05 – Education 05	0.246

Attitude PT 05- Attitude bicycle 05	0.434
Attitude car 05 – Attitude PT 05	-0.549
Attitude car 05 – Attitude bicycle 05	-0.165
Attitude car 05 – Daily groceries 05	-0.241
BMI 05 – Attitude PT 05	-0.255
BMI 05 – Attitude bicycle 05	-0.261
Share car use 05 – Attitude bicycle 05	-0.372
Share car use 05 – Attitude PT 05	-0.326
Share car use 05 – Attitude car 05	0.321
Share car use 05 – Daily groceries 05	-0.201
Share car use 05 – Car ownership 05	0.413
BMI 05 – Share car use 05	0.125
BMI 12 – Attitude PT 12	0.191
Car ownership 12 – Daily groceries 12	-0.183

The model fit indicators indicate fair to good fit. RMSEA is 0.079 and thus just within the fair fit threshold. The NFI and RFI are 0.889 and respectively 0.852 which are just below the 0.9 minimums. All other indicators imply good fit.

Table 4 – Unstandardized total effects lagged effects SEM

	Age	Income 05	Income 12	Education 05	Education 12	Groceries 05	Att bicycle 05	Att PT 05	Att car 05	Car own 05	Share car 05	BMI 05
Endo-/Exogenous	Exo	Exo	Endo	Exo	Endo	Exo	Endo	Exo	Endo	Endo	Exo	Endo
Income 12	-0.015	0.770	-	0	-	-	-	-	-	-	-	-
Education 12	-	-	-	0.997	-	-	-	-	-	-	-	-
Groceries 12	-	-	-	-	-	0.770	-	-	-	-	-	-
Att bicycle 05	-	-0.506	-	-0.413	-	-	-	-	-	-	-	-
Att bicycle 12	-0.005	-0.115	0.337	-0.718	-0.413	-	0.741	-	-	-	-	-
Att PT 12	-	-	-	-	-	0.029	-	0.765	-	-	-	-
Att car 05	-	0.191	-	-0.993	-	-	-	-	-	-	-	-
Att car 12	-0.003	0.330	0.191	-1.944	-0.993	-	-	-	0.960	-	-	-
Car own 05	-	0.043	-	-	-	-	-	-	-	-	-	-
Car own 12	-0.001	0.075	0.043	-	-	-0.001	-	-	-	0.954	-	-
Share car 05	-	-	-	0.191	-	-	-	-	-	-	-	-
Share car 12	-	0.227	-	0.263	0.191	-0.015	-	-0.098	-	1.177	0.378	-
BMI 05	0.108	-	-	-	-	-	-	-	-	-	-	-
BMI 12	0.099	-	-	0.022	-	-	-	-	-	-	0.117	0.916

4.3 Combined effects model

In the combined model specification all significant relations that were found in the lagged and synchronous model are estimated in order to create a more complete overview of effects. The model specification is presented in Figure 3.

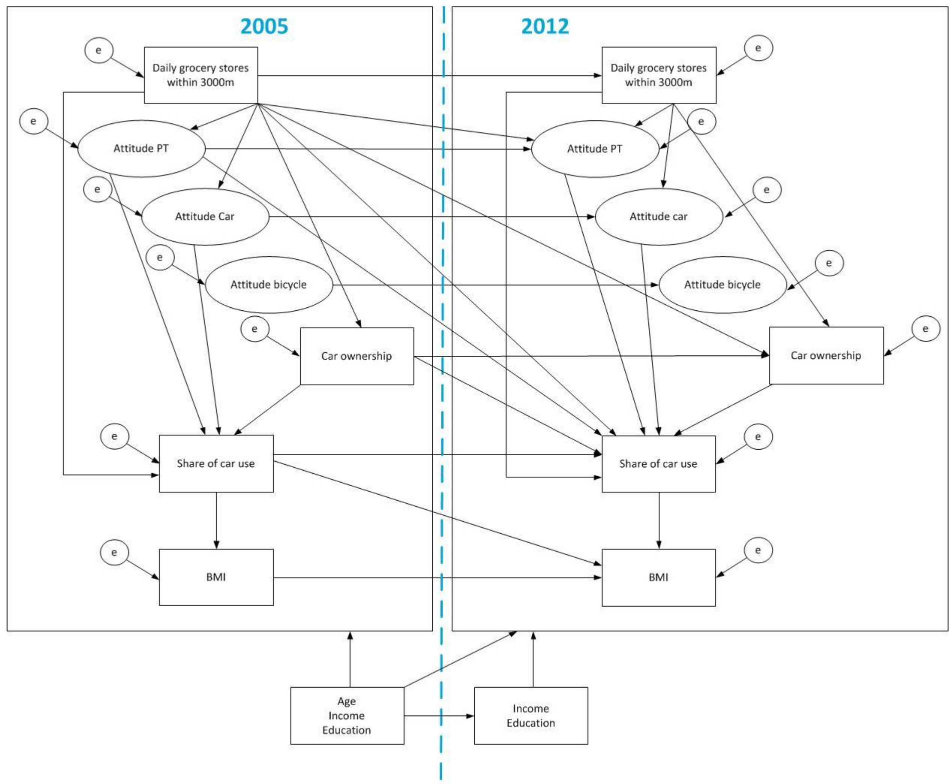

Figure 3 – Model specification combined effects SEM

Some of the relationships between variables occur both lagged and synchronous, however there is overlap in the variance that both relations account for. When including both the lagged and the synchronous effects in the model in general the synchronous effects remain significant. The lagged effects that do remain significant are between the BE and the attitude towards PT, the BE and car ownership, the BE and the share of car use, and attitude towards PT and car ownership.

The biggest differences between the lagged and the combined effects model is that no lagged effects are found between car ownership and share of car use, and between share of car use and BMI. A difference between the synchronous effects and the combined effects SEM is that two extra relationships are found to be significant, the relationship between PT and car ownership, and between the BE and attitude towards bicycles. Also some of the relationships become insignificant, for example the relationship between the attitudes towards modes and share of car use.

Table 6 shows the unstandardized and Table 7 the standardized effects. The combined effects model confirms that the relationship between the BE and TB is less strong than the relationship between TB and BMI. Doubling the amount of average grocery stores within 3000m would increase the share of car use synchronously by 0.15 and lagged by 1.00, and this would lead to a decrease of BMI of 0.05 synchronously and a lagged decrease of 0.02. Decreasing the share of car use by 6 points on a 7-point scale would affect BMI so that an individual synchronous decrease of 1.08 and a lagged decrease of 1.38 is found. These decreases in BMI are considerable, especially when keeping in mind that BMI is affected by a lot of factors and that socio-demographic characteristics are controlled for.

An overview of the influence of the BE on BMI is drawn up in Figure 4. The L's and S's that are presented on the arrows stand for 'Lagged', respectively 'Synchronous' and the number is the unstandardized strength of the relationship. As can be extracted from Figure 4 a lot of dynamics are at play when interpreting the BE-TB-BMI relationship. The BE influences BMI via various paths, which complicates interpreting and fully understanding the relationship.

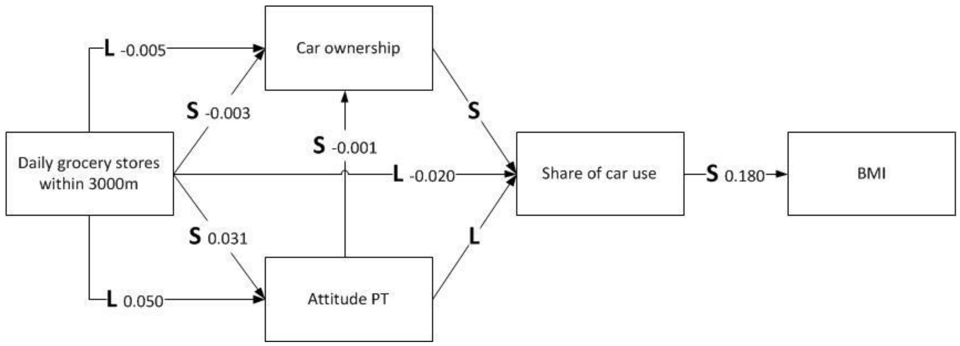

Figure 4 – Overview of relevant relationships between the BE and BMI in the combined model

In Table 8 the correlations that are found to be significant in the total effects SEM are presented together with their values. The directions of the found correlations are as expected.

Table 8 – Correlations in the combined effects SEM

Correlation	Value
Daily groceries 05 – Income 05	0.196
Income 05 – Age 05	0.248
Daily groceries 05 – Age 05	0.380
Income 05 – Education 05	0.245
Attitude bicycle 05 – Attitude PT 05	0.263
Attitude car 05 – Attitude PT 05	-0.558
Attitude bicycle 05 – Share car use 05	-0.341
Share car use 05 – Attitude PT 05	-0.313
Attitude car 05 – Share car use 05	0.342
Share car use 05 – Daily groceries 05	-0.334
Attitude car 12 - Share of car use 12	0.370
Attitude car 05 – Daily groceries 05	-0.180

The model fit is fair to good. The model fit indicators indicate that the fit is good for all of the indicators except for the RMSEA. The value for RMSEA is 0.056, which indicates fair fit.

Table 6 – Unstandardized total effects combined effects SEM

	Age	Income 05	Income 12	Education 05	Education 12	Groceries 05	Groceries 12	Att bicycle 05	Att PT 05	Att PT 12	Att car 05	Car own 05	Car own 12	Share car 05	Share car 12	BMI 05
Endo-/Exogenous	Exo	Exo	Endo	Exo	Endo	Exo	Endo	Endo	Endo	Endo	Endo	Endo	Endo	Endo	Endo	Endo
Income 12	-0.018	0.797	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Education 12	-	-	-	0.997	-	-	-	-	-	-	-	-	-	-	-	-
Groceries 12	-	-	-	-	-	0.786	-	-	-	-	-	-	-	-	-	-
Att bicycle 05	-	-0.347	-	-	-	0.010	-	-	-	-	-	-	-	-	-	-
Att bicycle 12	-0.006	-0.042	-0.347	-	-	0.016	0.010	0.879	-	-	-	-	-	-	-	-
Att PT 05	-	-	-	-	-	0.031	-	-	-	-	-	-	-	-	-	-
Att PT 12	-	-	-	-	-	0.050	0.031	-	0.823	-	-	-	-	-	-	-
Att car 05	-	0.712	-	-1.047	-	-0.021	-	-	-	-	-	-	-	-	-	-
Att car 12	-0.013	0.857	0.712	-1.999	-1.047	-0.036	-0.021	-	-	-	0.912	-	-	-	-	-
Car own 05	-	0.040	-	-	-	-0.003	-	-	-0.010	-	-	-	-	-	-	-
Car own 12	-0.001	0.067	0.040	-	-	-0.005	-0.003	-	-0.016	-0.010	-	0.892	-	-	-	-
Share car 05	-	0.040	-	-	-	-0.003	-	-	-0.010	-	-	0.996	-	-	-	-
Share car 12	-0.001	0.253	0.040	-	-	-0.020	-0.003	-	-0.075	-0.010	-	1.260	0.996	0.373	-	-
BMI 05	0.105	0.007	-	0.031	-	-0.001	-	-	-0.002	-	-	0.179	-	0.180	-	-
BMI 12	0.095	0.052	0.007	0.413	0.031	-0.004	-0.001	-	-0.015	-0.002	-	0.389	0.179	0.230	0.180	0.908

Table 7 – Standardized total effects SEM

	Age	Income 05	Income 12	Education 05	Education 12	Groceries 05	Groceries 12	Att bicycle 05	Att PT 05	Att PT 12	Att car 05	Car own 05	Car own 12	Share car 05	Share car 12	BMI 05
Endo-/Exogenous	Exo	Exo	Endo	Exo	Endo	Exo	Endo	Endo	Endo	Endo	Endo	Endo	Endo	Endo	Endo	Endo
Income 12	-0.101	0.795	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Education 12	0.020	-	-	0.999	-	-	-	-	-	-	-	-	-	-	-	-
Groceries 12	-	-	-	-	-	0.956	-	-	-	-	-	-	-	-	-	-
Att bicycle 05	-	-0.166	-	-	-	0.102	-	-	-	-	-	-	-	-	-	-
Att bicycle 12	-0.020	-0.025	0.196	-	-	0.212	0.104	1.094	-	-	-	-	-	-	-	-
Att PT 05	-	-	-	-	-	0.228	-	-	-	-	-	-	-	-	-	-
Att PT 12	-	-	-	-	-	0.248	0.178	-	-0.075	-	-	-	-	-	-	-
Att car 05	-	0.318	-	-0.157	-	0.212	-	-	-	-	-	-	-	-	-	-
Att car 12	-0.031	0.364	0.303	-0.285	-0.149	-0.342	-0.166	-	-	-	0.867	-	-	-	-	-
Car own 05	-	0.104	-	-	-	-0.172	-	-	-0.075	-	-	-	-	-	-	-
Car own 12	-0.010	0.166	0.098	-	-	-0.286	-0.134	-	-0.121	-0.084	-	0.842	-	-	-	-
Share car 05	-	0.036	-	-	-	-0.059	-	-	-0.026	-	-	0.342	-	-	-	-
Share car 12	-0.003	0.215	0.034	-	-	-0.381	-0.046	-	-0.191	-0.025	-	0.409	0.343	0.353	-	-
BMI 05	0.394	0.005	-	0.007	-	-0.008	-	-	-0.003	-	-	0.045	-	0.132	-	-
BMI 12	0.312	0.030	0.004	0.080	0.006	-0.053	-0.006	-	-0.026	-0.003	-	0.086	0.042	0.148	0.122	0.792

5. Conclusion and further research

Around the world obesity rates are increasing, and so are health problems related to obesity. To counteract this trend governments implement all kinds of policies. One of the ways to decrease obesity rates is by increasing physical activity. A proposed policies is to incentivize active travel, so by foot or bicycle, by making adaptions in the built environment. However, considering the relationship between the built environment (BE), travel behavior (TB), and body mass index (BMI), some aspects are still unknown or not yet researched.

The study looked into which factors of the built environment influence travel behavior and to what extent, which intermediary variables are important and what their role is in the relationship, and to what extent travel behavior influences health. By answering these questions a more complete image of the relationship between the built environment, travel behavior, and health is reached. This improved image provides insights into the question whether making to adjustments to the built environment is a promising policy for influencing health through travel behavior.

In prior research the relationship between BE, TB, and BMI is mainly structured so that the BE influences health through TB. Two other factors are believed to have an intermediary role in this relationship. First, the attitudes toward travel modes are believed to be influenced by the BE and to drive behavior, thus to influence TB. Second, car ownership is also expected to be influenced by the BE and to influence the mode choice for certain trips, so to affect TB. However, also some socio-demographic characteristics are expected to influence the BE-TB-BMI relationship. Age, income, education, gender and household composition are expected to have some kind of effect on the variables and the results of the analysis are thus controlled for these influences.

Three type of SEMs are created. A synchronous effects model that estimates the effects that occur within a wave. This model estimates the short term effects. The second type of SEM is a lagged effects model. This model estimates the effects that occur between the two waves of data collection, and thus represents the long term effects. Finally, the significant relations from the synchronous and lagged effects SEM are combined into a combined effects model. This model provides a complete overview of all the effects, both short and long term, that occur in the relationship between the built environment, travel behavior and BMI.

The BE is, in the study, represented by the amount of grocery stores within a 3 kilometer range. This variable is a proxy variable for the availability of facilities, the level of urbanization and the degree of land use mix. The share of car use is the share of trips conducted by car, on a 7-point scale.

The analysis pointed out that the relationship between the built environment, travel behavior and BMI is very complex. The share of car use has a positive influence on BMI, this means that when people conduct relatively more trips by car, their BMI is higher, and when they conduct more trips by other travel modes their BMI is lower. This is a strong relationship, when people reduce the share of trips they conduct by car by six points on a seven point scale, their BMI decreases 1.08 point. The direct impact of the amount of grocery stores within 3000m on the share of car use is negative and quite strong. So, if the average amount of grocery stores in the sample would double from 50 to 100, the average share of trips conducted by car would decrease by one point on a seven point scale. Next to this direct effect, the amount of grocery stores available within three kilometer also indirectly affects travel behavior, through car ownership and the attitude towards public transport. Also, the analysis pointed out that 3 kilometer is the built environmental scale at which travel behavior takes place, because when including the same variable with a scale of 400 meters, and OAD with a scale of 1000 meters, only few or none significant relationships with the other variables were found. Concluding from this, the study confirms the hypothesis that BMI is affected by the built environment through travel behavior, although the direct impact of car use is much stronger than the indirect effect of the BE. Prior research confirms the relationship between the built environment and BMI through travel behavior. In short, studies thus far found a strong relationship between vehicle miles traveled and BMI and between active travel and BMI, and research also found a significant but less strong relationship between built environment characteristics, such as land use mix, and BMI. However, to the author's knowledge the ratio between the direct relationship, between TB and BMI, and indirect relationship, between the BE and BMI, has not yet been directly addressed.

The two analyses thus found that both adaptions to the built environment and direct adaptions to attitudes towards travel modes would be effective policies for influencing travel behavior. However, to further operationalize and strengthen these results some additional research is suggested.

1. The built environment variable with the biggest impact on travel behavior and through this on BMI is the amount of grocery stores within a three kilometer range. As mentioned before this variable implies a degree of land use mix and the level of city density. City centers are often denser and have a higher degree of land use mix, than the city outskirts, and in city centers some concrete BE design characteristics are often implemented. Examples of such BE design characteristics are one way streets, limited amount of parking spaces, and many traffic lights. So a higher city density and degree of land use mix also implies these kinds of concrete BE design characteristics. To enable municipalities to develop effective land use designs for influencing travel behavior the influence of these more concrete design variables should be researched.
2. It is expected that other health indicators than BMI are impacted by the built environment. Only the effect of the built environment and travel behavior on BMI are within the scope of this research. However, other health related aspects can be expected to be affected by the BE and TB, for instance lung related benefits that can be associated with less emissions or an emotional health benefit gained by more green spaces.
3. The data did not include children, young adults, and non-home owners. So whether the relationships are as found in the analysis for younger and less affluent citizens could not be assessed. This should be looked into

Travel behavior strongly influences BMI. So incentivizing active travel is an effective policy for influencing weight and through this health. However, the question of how to effectively influence travel behavior remains. Increasing the degree of land use mix and the city density is a promising option for influencing travel behavior. Denser city structures and a diverse availability of facilities steers towards more active travel modes. For existing cities this implies that creating shopping areas in the less central city districts would incentivize active travel. For new cities and new city districts it implies that the cities should be densely structured and that a variety of facilities and stores should be available within a 3-kilometer range to incentivize active travel.

When considering this conclusion, two upcoming trends are negative for BMI. Firstly, as e-commerce is upcoming, and people start buying more and more products over the Internet, it is often speculated that stores will move away from the city districts and neighborhoods. Secondly, for a long time it was governmental policy in the Netherlands to not allow shopping areas outside of urban areas. However, this policy is fading, which can lead to big shopping malls outside of the cities, and less stores within the city boundaries. If these two trends will continue as expected, people will travel more by car and BMIs will increase. In the light of BMI, it is thus advisable to counteract these trends.

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